# D8 - ALGORITHM THEORETICAL BASIS DOCUMENT

## SOUTH AFRICA DROUGHT MONITORING (ANIN)


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# 1. INTRODUCTION

## 1.1. PURPOSE

**Develop innovative** (e.g., methods, indicators, services with respect to the review of the state of the art, Deliverable-3) **EO-based solutions** in relation to:

- the **drought monitoring** and **forecasting** and
- **responding to** both the South African **partner** organisations' **needs** (identified in Deliverable-2) and the **underlying policy frameworks** (Deliverable-4).

Integrate, apply and further advance, as necessary, **state of the art models and non-EO data** developed by third parties and providing full knowledge of their accuracy (e.g. in-situ gauges) related to drought monitoring

## 1.2. SCOPE

This document is structured according to the following sections:

- Section 1, this section, for the introduction to the subject, including, purpose and scope of the document as well as definitions and acronyms used in the text.
- In Section 2 reference and applicable documents are reflected
- Section 3 introduces the subject of study and briefly introduces the drought types
- In Section 4 the Drought monitoring indicators implemented by ANIN are defined
- Section 5 reflects the indicators developed in the context of seasonal drought forecasting.
- Data catalog for ANIN is described in Section 6

## 1.3. DEFINITIONS AND ACRONYMS

### 1.3.1. DEFINITIONS

Concepts and terms used in this document and needing a definition are included in the following table:

**Table 1-1 Definitions**

| Concept / Term | Definition |
|---|---|
| | |

### 1.3.2. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

**Table 1-2 Acronyms**

| Acronym | Definition |
|---|---|
| ANIN | South African Drought Monitoring |
| AOI | Area Of Interest |
| ASAP | Anomaly hot Spots of Agricultural Production |
| ATBD | Algorithm Theoretical Basis Document |
| CCI | Climate Change Initiative |
| CDI | Combined Drought Indicator |
| EOP | Earth Observation Programmes |
| EOS | End Of the growing Season |
| ESA | European Space Agency |
| FAO | The Food and Agriculture Organization |

| Acronym | Definition |
|---|---|
| FAPAR | Fraction of Absorbed Photosynthetically Active Radiation |
| GDO | Global Drought Observatory |
| GLASS | The Global Land Surface Satellite |
| IDI | Integrated Drought Index |
| JRC | Joint Research Centre |
| MODIS | Moderate-Resolution Imaging Spectroradiometer |
| NDVI | Normalised Difference Vegetation Index |
| OLCI | SENTINEL-3 Ocean and Land Colour Instrument |
| PET | Potential Evapotranspiration |
| SGI | Standardised Groundwater Index |
| SMA | Soil Moisture Anomaly |
| SOS | Start Of the growing Season |
| SOW | Statement Of Work |
| SPEI | Standardised Precipitation Evapotranspiration Index |
| SPI | Standardised Precipitation Index |
| SSI | Standardised Streamflow Index |
| STD | Standard Deviation |
| VCI | Vegetation Condition Index |

# 2. REFERENCES

## 2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.x]:

**Table 2-1 Applicable Documents**

| Ref. | Title | Code | Version | Date |
|---|---|---|---|---|
| [AD.1] | Statement of Work. EO AFRICA - NATIONAL INCUBATORS EXPRO+ | ESA-EOP-SD-SOW-0249 | 1.0 | 26/10/2021 |
| [AD.2] | Proposal EO AFRICA NATIONAL INCUBATORS (ANIN) | GMV10277/22 V1/22, | 1.0 | 18/02/2022 |

## 2.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.x]:

**Table 2-2 Reference Documents**

| Ref. | Title | Code | Version | Date |
|---|---|---|---|---|
| [RD.1] | Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A. (2010) Business Model Generation, John Wiley & Sons. | | | 2010 |
| [RD.2] | Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A. (2014) Value Proposition Design: How to Create Products and Services Customers Want, John Wiley & Sons. | | | 2014 |
| [RD.3] | Mukhawana, M.B.; Kanyerere, T.; Kahler, D. Review of In-Situ and Remote Sensing-Based Indices and Their Applicability for Integrated Drought Monitoring in South Africa. *Water* 2023, *15*, 240. https://doi.org/10.3390/w15020240 | | | 2023 |

# 3. INDICES SUMMARY

Drought is a recurrent feature of all climates that results from a shortfall in precipitation over an extended period, its inadequate timing compared to the needs of the vegetation cover, or a negative water balance due to an increased potential evapotranspiration caused by high temperatures. These conditions may be exacerbated by strong winds, atmospheric blocking patterns and antecedent conditions in soil moisture, reservoirs and aquifers, for example. If this situation leads to an unusual and temporary deficit in water availability, it is termed a drought.

Droughts are slow-onset events that can last from weeks to years. They are often defined as meteorological, soil moisture (i.e. agricultural and ecological) or hydrological droughts. In reality, these are progressive manifestations of the same drought propagating through the hydrological cycle. Recently, the concept of flash droughts has emerged, describing quick-onset, severe events of water stress due to high temperatures and a high evaporative demand.

Due to the different types of droughts, its monitoring is based on the analysis of a series of drought indicators and indices (WMO and GWP, 2016), representing different components of the hydrological cycle (e.g., precipitation, soil moisture, reservoir levels, river flow, groundwater levels) or impacts (e.g., vegetation water stress). Usually, indicators represent statistical anomalies of the current situation with respect to the long-term climatology at a given location and time interval. As such they are a measure of the probabilistic severity of a given event (EC-JRC Barbosa, et al. 2021).

There are three main methods for monitoring drought and guiding early warning and assessment:

1. Using a single indicator or index
2. Using multiple indicators or indices
3. Using composite or hybrid indicators

Just as there is no 'one-size-fits-all' definition of drought, there is no single index or indicator that can account for and be applied to all types of droughts, climate regimes and sectors affected by droughts.

A brief summary of the indices and indicators agreed with the South African partners, fitting the requirements for drought early warning, monitoring and forecasting is South Africa, and therefore implemented by ANIN, is included in the figure below.

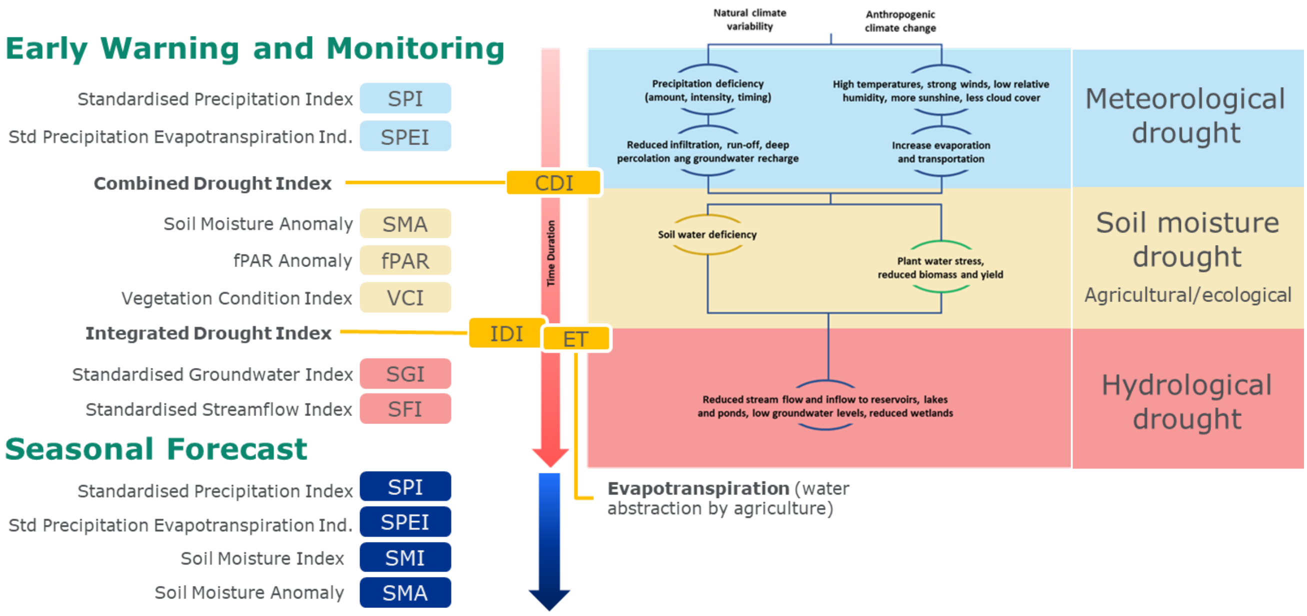



**Figure 3-1: Drought indices and indicators**

# 4. DROUGHT MONITORING

## 4.1. METEOROLOGICAL DROUGHT

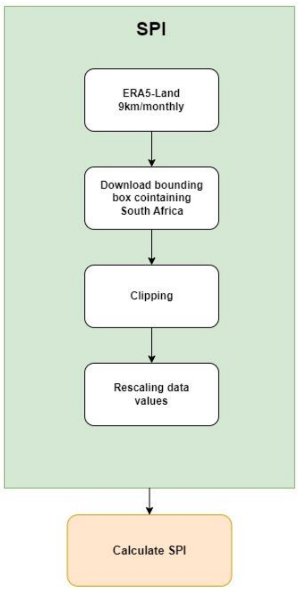
### 4.1.1. STANDARDISED PRECIPITATION INDEX (SPI)

**Index description**

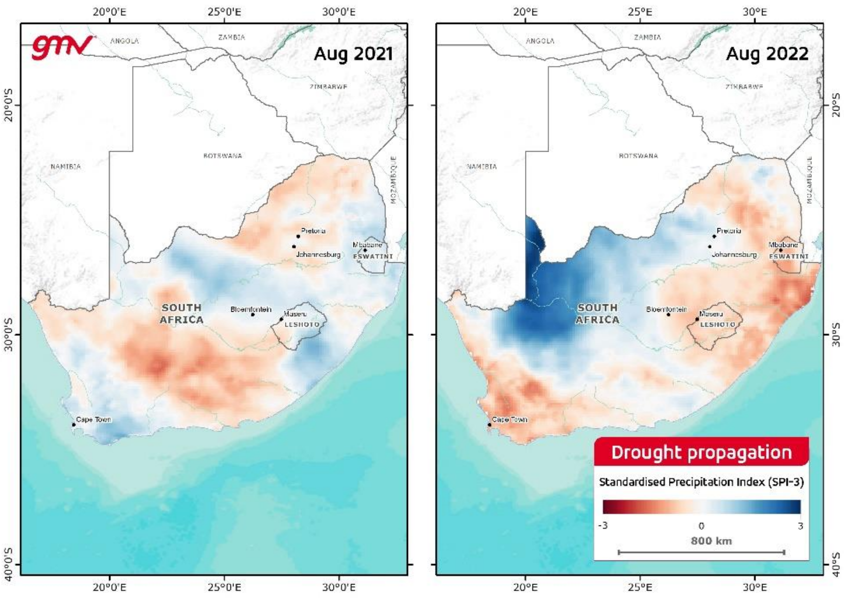
The Standardised Precipitation Index is a statistical indicator widely used to represent processes of meteorological drought. The SPI is calculated comparing accumulation of precipitation on a location over a period, to the same period of time through the historical data at that location. It allows the user to compare the meteorological status of the given location across the time and across regions with different climates.

SPI is calculated monthly over periods of n months, indicating the rainfall accumulation over the period of 1, 3, 6, 9, 12, 24, or 48 months. Depending on the scale SPI can be related to soil moisture (short scales) or to ground water and reservoir storage (long scales).

**Methodology/Algorithm**




| Product name | STANDARDISED PRECIPITATION INDEX (SPI) |
|---|---|
| Product description | This product provides time-series information on meteorological droughts.<br>Based on precipitation monthly data, this product offer values for SPI given in units of standard deviation from the long-term mean of the standardized distribution. |
| Main applications | • Identifying and classifying meteorological droughts<br>• Drought alert an monitoring<br>• Agricultural drought assessment<br>• Water management<br>• Climatic risk assessment |
| Update frequency | Monthly with a delay of about three months relatively to actual date |
| Format | Raster format: NetCDF |
| Input data | Precipitation: ERA5-Land |
| Archive Length | January 1950 to present – Calculated from January 1980 to present |

| | |
|---|---|
| **Spatial resolution** | 0.1 degree |
| **Spatial coverage** | Computed at national scale |
| **Requires Field Data** | No |
| **Product Overview** |   |

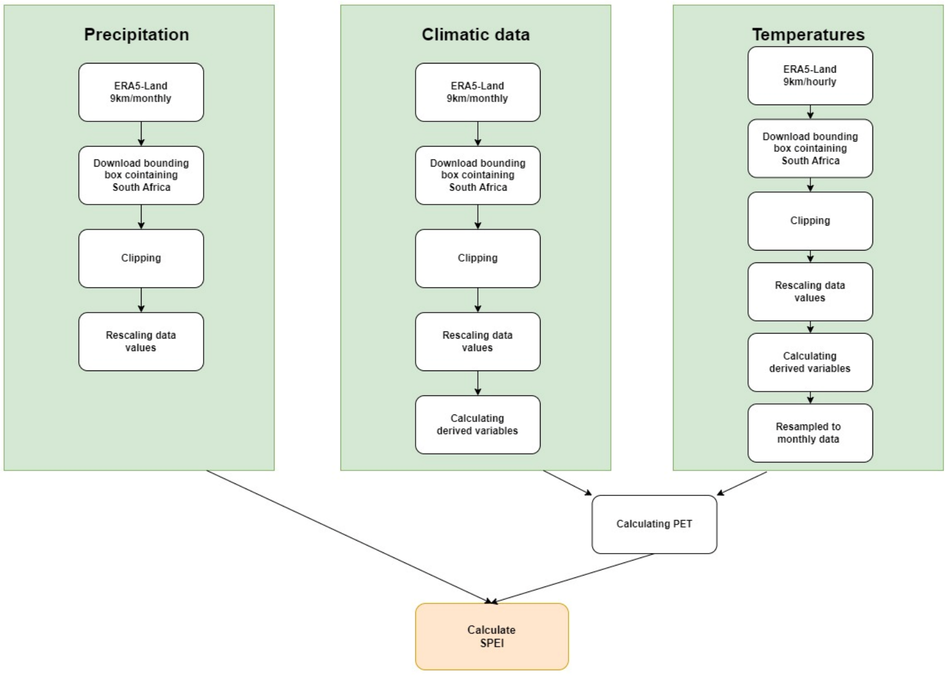
## 4.1.2. STANDARDISED PRECIPITATION-EVAPOTRANSPIRATION INDEX (SPEI)

**Index description**

The Standardised Precipitation-Evapotranspiration Index is a statistical indicator that shows the severity of the meteorological droughts according to precipitation and the water demand. Its multi-scalar character allows us to use it to detect, monitor and analyze droughts. The SPEI is calculated for a location over a period, to the same period through the historical data at that location. It allows the user to compare the meteorological status of the given location across the time and across regions with different climates.

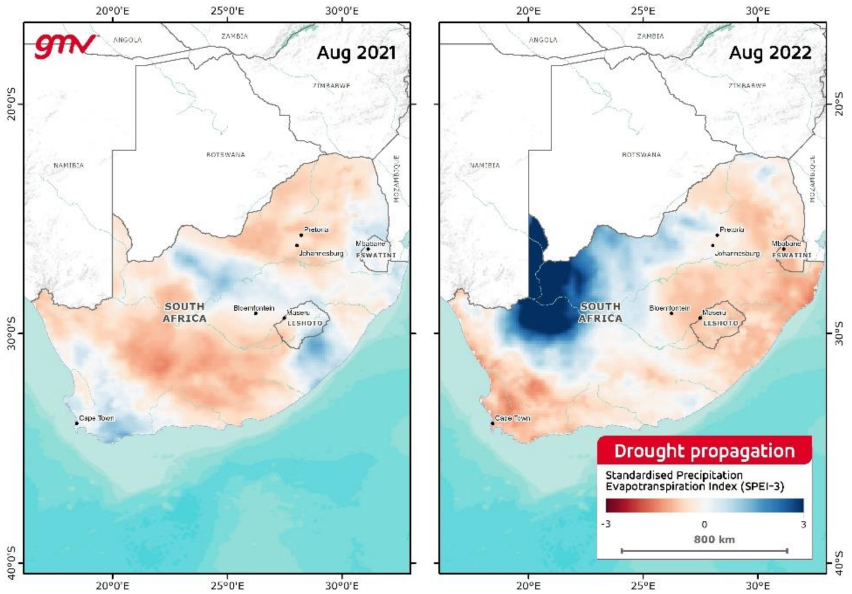
SPEI can be calculated on a range of timescales form 1 month to 48 months. Depending on the scale, this index can be related to soil moisture (short scales) or to ground water and reservoir storage (long scales).

**Methodology/Algorithm**




| **Product name** | **STANDARDISED PRECIPITATION-EVAPOTRANSPIRATION INDEX (SPEI)** |
|---|---|
| **Product description** | This product provides time-series information on meteorological droughts integrating precipitation and potential evapotranspiration (PET) information capturing the main impact of increased temperatures on water demand. For this purpose, PET was calculated according to FAO-56 Penman-Monteith equation.<br>SPEI is calculated similarly to SPI, but based on precipitation monthly data, temperature hourly data and other climate monthly variables. This product offer values for SPEI given in units of standard deviation from the long-term mean of the standardized distribution. |
| **Main applications** | • Identifying and classifying meteorological droughts<br>• Drought alert an monitoring<br>• Agricultural drought assessment<br>• Water management<br>• Climatic risk assessment |

| | |
|---|---|
| **Update frequency** | Monthly with a delay of about three months relatively to actual date |
| **Format** | Raster format: NetCDF |
| **Input data** | Precipitation: ERA5-Land monthly data<br>2m temperature: ERA5-Land hourly data<br>2m dewpoint temperature: ERA5-Land monthly data<br>Surface solar radiation downwards: ERA5-Land monthly data<br>10m u-component of wind: ERA5-Land monthly data<br>10m v-component of wind: ERA5-Land monthly data<br>Surface pressure: ERA5-Land monthly data |
| **Archive Length** | January 1950 to present – Calculated from January 1980 to present |
| **Spatial resolution** | 0.1 degree |
| **Spatial coverage** | Computed at national scale |
| **Requires Field Data** | No |
| **Product Overview** |  |

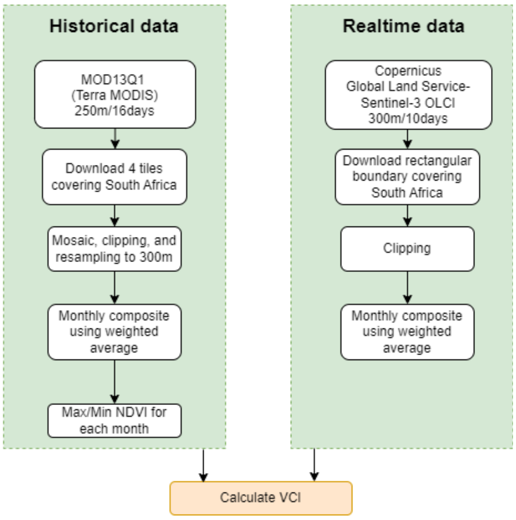
## 4.2. SOIL MOISTURE DROUGHT (AGRICULTURAL/ECOLOGICAL)

### 4.2.1. VEGETATION CONDITION INDEX (VCI)

**Index description**

The Vegetation Condition Index (VCI)[1] compares the current NDVI to the range of values observed in the same period in previous years. The VCI is expressed in % and gives an idea where the observed value is situated between the extreme values (minimum and maximum) in the previous years. Lower and higher values indicate bad and good vegetation state conditions, respectively.

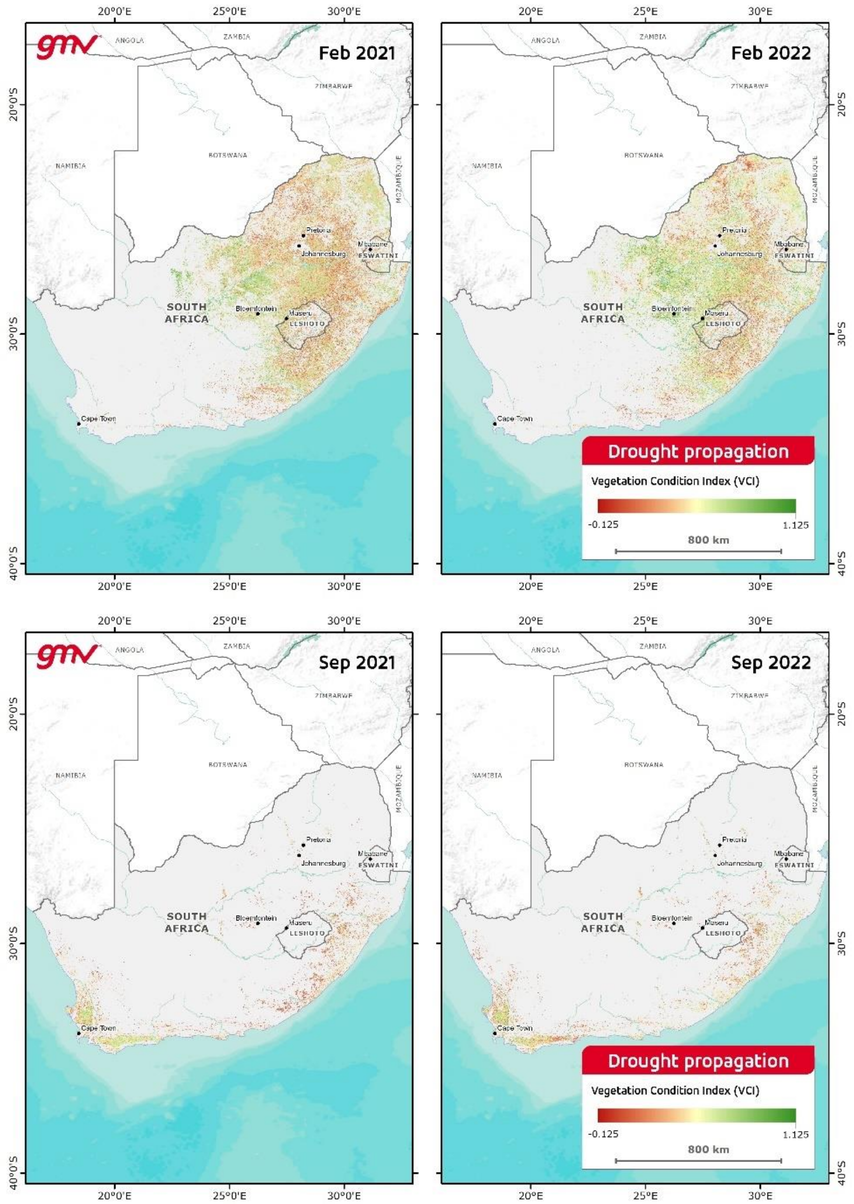
**Methodology/Algorithm**




$$VCI_{yp} = \frac{NDVI_{yp} - MinNDVI_{yp}}{MaxNDVI_{yp} - MinNDVI_{yp}}$$

| **Product name** | **VEGETATION CONDITION INDEX (VCI)** |
|---|---|
| **Product description** | VCI focuses on the impact of drought on vegetation and can provide information on the onset, duration and severity of drought by observing vegetation changes and comparing them with historical values.<br>VCI evaluates the current NDVI in relation to the range of values seen during the same time period in preceding years. The VCI provides a sense of where the observed value falls in relation to the extreme values (minimum and maximum) from prior years. Lower and greater values, respectively, represent poor and good vegetative state conditions. |
| **Main applications** | VCI is a valuable tool for monitoring and assessing vegetation health and productivity, providing critical information for decision-making in various sectors including:<br>• Agricultural monitoring<br>• Forestry management<br>• Environmental monitoring<br>• Water resource management<br>• Flood Monitoring<br>• Drought Monitoring |
| **Update frequency** | Monthly with a delay of five days |

[1] https://land.copernicus.eu/global/products/vci

| | |
|---|---|
| **Format** | Raster format: tiff |
| **Input data** | Satellite-based NDVI data: MODIS (MOD13Q1), Copernicus Global Land Service |
| **Archive Length** | July 2020 to Present |
| **Spatial resolution** | 300m |
| **Spatial coverage** | South Africa, Lesotho, and Eswatini |
| **Requires Field Data** | No |
| **Product Overview** |  |

## 4.2.2. COMBINED DROUGHT INDICATOR (CDI)

**Index description**

The Combined Drought Indicator (CDI) is utilized to identify and monitor regions that are either experiencing or prone to agricultural drought.

Using the combination of spatial patterns of precipitation, soil moisture, and greenness vegetation anomalies, the CDI identifies areas at risk of agricultural drought, regions in which the vegetation has already been impacted by drought, and areas that are in the process of returning to normal conditions.

CDI classification method establishes three basic classes of drought (Watch, Warning, and Alert) as well as two classes of recovery (partial recovery and full recovery).

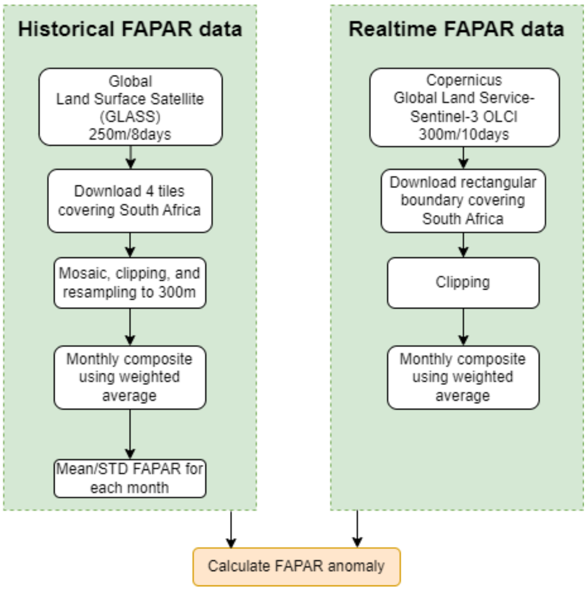
CDI uses three inputs which are SPI for precipitation, Soil Moisture Anomaly (SMA) for soil moisture, and FAPAR anomaly for vegetation condition.

Methodology/Algorithm

CDI is calculated based on thresholds of SPI, SMA, and FAPAR anomaly. Therefore, the methodology used to generate these three indices is discussed first then the methodology for CDI is mentioned later.

The methodology of SPI is described briefly in section 3.2. For SMA, a ready product from JRC (https://edo.jrc.ec.europa.eu/gdo/php/index.php?id=2112) is used directly, only we clipped it to the AOI.

**The methodology of FAPAR anomaly is discussed in detail as follow:**




The FAPAR anomaly formula is $FAPAR\ Anomaly_{yp} = \frac{FAPAR_{yp} - Mean\ FAPAR_{yp}}{Standard\ deviation\ FAPAR_{yp}}$, where $FAPAR_{yp}$ is the FAPAR of the month, $Mean\ FAPAR_{yp}$ is the long-term average FAPAR for the same month, and $Standard\ deviation\ FAPAR_{yp}$ is the long-term standard deviation of FAPAR for the same month.

Therefore, historical data is required to calculate the mean and standard deviation, also, real time data is required. In this product, the historical and real time data are from different sources. Historical FAPAR data from The Global Land Surface Satellite (GLASS) at 250m and 8days resolutions covering period from 2000 to 2021 (http://www.glass.umd.edu/FAPAR/MODIS/250m/), whereas real time FAPAR data is from Copernicus Global Land Service, sensor/platform: Sentinel-3 OLCI at 300m and 10days resolutions covering period from July 2020 to present.

**FAPAR data Pre-processing**

**Historical data/ GLASS (250m-8days):**

- Mosaic and clipping: GLASS data comes as tiles similar to MODIS, there are 4 tiles which overlapping South Africa. These 4 tiles were mosaiced first, then clipped.

- Resampling to monthly: the 8days data is aggregated to monthly using weighted average based on the number of days overlapping the month. These overlapping days change from a month to another.
- Resampling to 300m resolution: Nearest neighbour was used for resampling.
- Mean and STD calculations: we generated a stack of tiff files for each month separately, then we calculated mean and STD for corresponding pixels.

**Real time data/ Copernicus Land Service (300m-10days):**

- Clipping: the data comes as bounding box around South Africa, so we clipped it to match only South Africa
- Resampling to monthly: The start dates for each 10 days ($1^{st}$, $11^{th}$, $21^{st}$) are fixed for all months, however number of days start on $21^{st}$ differ with the length of the month, so we used also weighted average to calculate the monthly data rather than the mean.

**Crop mask:**

crop masks are based on two land use/land cover sources which are CCI LAND COVER - S2 PROTOTYPE LAND COVER 20M MAP OF AFRICA 2016 and GlobCover 2009 land cover map. Pixels which related to crop class of both datasets were used for crop mask. So, we have binary raster file crop/no crop. Finally, the binary mask has been integrated with the information retrieved by the ASAP phenology maps reporting, for each crop cell, the Start Of the growing Season (SOS) and the End Of the growing Season (EOS). The SOS and EOS maps have been derived as long-term average of 10-day MODIS NDVI data. The result is a collection of 12 binary maps for each month.

**FAPAR anomaly:**

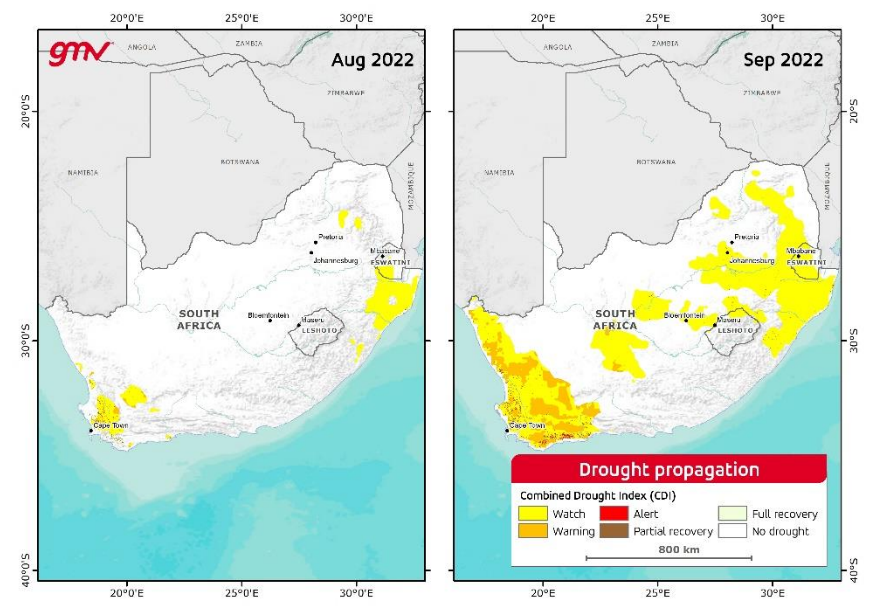
- We used the mean and STD that calculated from historical data with the real time data as inputs to the formula of FAPAR anomaly, the output is monthly FAPAR anomaly.
- Only pixels of FAPAR anomaly that match the monthly crop masks based on the growing season were used.

**CDI generation:**

- SPI and SMA were resampled to 300m resolution as FAPAR anomaly using the bilinear method.
- Monthly stacks of SPI, SMA, and FAPAR anomaly is generated.
- CDI is calculated based on the following thresholds:

| Level | CLASSIFICATION CONDITION |
|---|---|
| **Watch** | SPI-3 < -1 |
| **Warning** | SMA < -1 and SPI-3 < -1 |
| **Alert** | FAPAR anomaly < -1 and SPI-3 < -1 |
| **Partial recovery** | FAPAR anomaly < -1 and SPI-3(m-1) < -1 and SPI-3 > -1 |
| **Full recovery** | FAPAR anomaly > -1 and SPI-3(m-1) < -1 and SPI-3 > -1 |

| Product name | COMBINED DROUGHT INDICATOR (CDI) |
|---|---|
| Product description | The Combined Drought Indicator (CDI) is utilized to identify and monitor regions that are either experiencing or prone to agricultural drought.<br>Using the combination of spatial patterns of precipitation, soil moisture, and greenness vegetation anomalies, the CDI identifies areas at risk of agricultural drought, regions in which the vegetation has already been impacted by drought, and areas that are in the process of returning to normal conditions.<br>CDI classification method establishes three basic classes of drought (Watch, Warning, and Alert) as well as two classes of recovery (partial recovery and full recovery).<br><br>**Level** / **Interpretation**:<br>**Watch** – The amount of precipitation is lower than normal<br>**Warning** – Soil moisture deficit coexists with the precipitation deficit<br>**Alert** – Indicator of stress in the vegetation<br>**Partial recovery** – The meteorological conditions have returned to normal following a period of drought, but vegetative growth has not<br>**Full recovery** – The meteorological conditions and vegetation growth have returned to normal following a period of drought<br><br>This product also benefits from utilising time-varying crop masks, which limits the use of the ALERT effect class (stress for vegetation) in agricultural areas outside of the growing season. |
| Main applications | • Agricultural Drought Monitoring<br>• Early Warning Systems<br>• Drought Assessment and Reporting<br>• Agricultural Planning<br>• Environmental Impact Assessment |
| Update frequency | Monthly with a delay of about three months due to the latency of SPI |
| Format | Tiff |
| Input data | • Standardized Precipitation Index (SPI): calculated using ERA5 land data.<br>• Soil Moisture Anomaly (SMA): from JRC (Joint Research Centre) Europa which downloaded directly from Global Drought Observatory (GDO) data download.<br>• FAPAR anomaly: calculated using historical FAPAR data from The Global Land Surface Satellite (GLASS) Product and real time data Copernicus Global Land Service, sensor/platform: Sentinel-3 OLCI. |
| Archive Length | November 2020 to present |
| Spatial resolution | 300m |
| Spatial coverage | South Africa, Lesotho, and Eswatini |
| Requires Field Data | No |

| **Product Overview** |  |
|---|---|



## 4.3. HYDROLOGICAL DROUGHT

### 4.3.1. STANDARDISED STREAMFLOW INDEX (SSFI)

**Index description**

The Standardized Streamflow Index (SSFI) is a widely used hydrological index that provides a standardized measure of streamflow anomalies. It is designed to assess and compare streamflow conditions across different regions and time periods. The values indicate the departure of streamflow from the long-term mean in terms of standard deviations; Positive SSFI values represent above-average streamflow conditions, while negative values indicate below-average streamflow conditions. The value of the index also provides information about the severity of streamflow anomalies. For example, larger negative values indicate more severe drought conditions, while larger positive values indicate wetter-than-average condition.

**Methodology/Algorithm**

Given that the SSFI is based on the SPI, the calculation steps are similar. Nevertheless, given that the SSFI is based on in-situ measurements it requires a thorough preprocessing to perform quality check on the data.

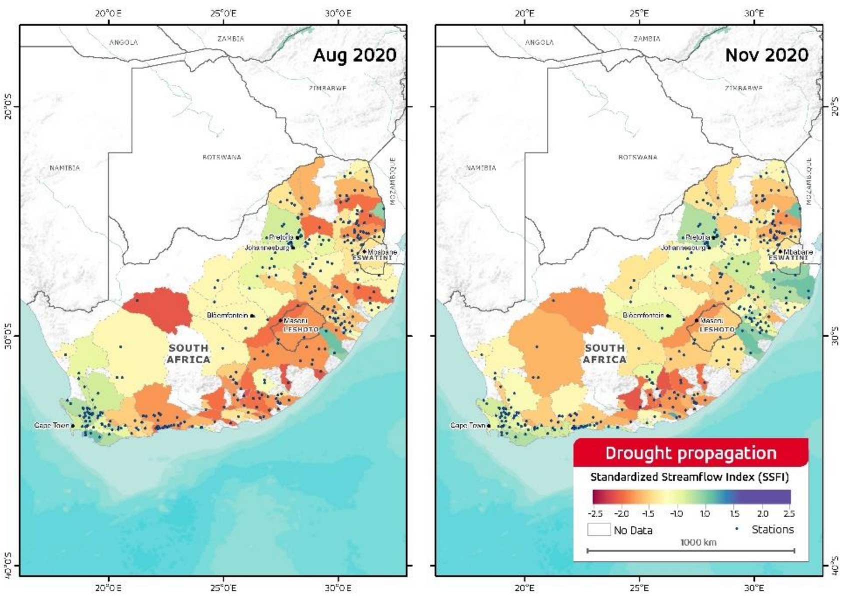
In this case, the time series were accompanied by a quality flag which categorized each measurement into "usable", "unsure" and "unusable". These quality flags included missing data, so it was possible to evaluate the presence of significant gaps on the time series with the general quality check. In this way, just the stations which have at least 75% of data regarded as usable have been used for the computation of the SSFI. This led to a final selection of 335 streamflow stations across South Africa.

Streamflow data may follow a number of statistical distributions depending on local physical factors which vary from catchment to catchment, making it difficult to use a single statistical distribution across the country. Instead of fitting different statistical distributions and assessing their goodness-of-fit for each station, non-parametric distributions are often used as they are more flexible, and some can be applied without previous evaluation of their goodness-of-fit. In this case, the plotting plots method has been applied to transform and normalize the streamflow data. Then, the SSFI index can be computed following the expression below:

$$\mathrm{SSF}I_{\mathrm{i,j}} = \frac{Q_{\mathrm{i,j}} - \bar{Q}}{\sigma_Q}$$

Where $\mathrm{SSFI}_{i,j}$ is the SSFI at this period, whereas $\bar{Q}$ and $\sigma_Q$ are the average streamflow and standard deviation respectively.

| Product name | STANDARDISED STREAMFLOW INDEX (SSI) |
|---|---|
| **Product description** | The Standardized Streamflow Index (SSFI) is a drought monitoring index used to assess the state of river discharge relative to long-term averages. This index quantifies the departure of streamflow from their long-term average by providing a standardized value that indicates the severity and duration of streamflow anomalies. |
| **Main applications** | • Hydrological drought monitoring<br>• Water resources management<br>• Early warning system & Water supply forecasting<br>• Environmental Impact assessment<br>• Decision support for water users, police makers and water resources planning. |
| **Update frequency** | - |
| **Format** | Tiff |
| **Input data** | Streamflow data |
| **Archive Length** | Nov 1979 to May 2023 |
| **Spatial resolution** | Secondary catchments |
| **Spatial coverage** | South Africa |
| **Requires Field Data** | Yes |
| **Product Overview** |  |

## 4.3.2. STANDARDISED GROUNDWATER INDEX (SGI)

**Index description**

The Standardized Groundwater Index (SGI) is a drought monitoring index used to assess the state of groundwater levels relative to long-term averages. More specifically, the SGI is a continuous index of groundwater drought based on the Standardized Precipitation Index (SPI) methodology. This index quantifies the departure of groundwater levels from their long-term average at a given location by providing a standardized value that indicates the severity and duration of groundwater anomalies. When applied at different time scales (e.g., monthly, seasonal, or annual) it can capture different aspects of groundwater variability enabling the comparison of current groundwater conditions to long-term averages and providing insights into the persistence and magnitude of groundwater anomalies.

**Methodology/Algorithm**

Like in the case of the SSFI, given that the SGI is based on in-situ measurements it requires a thorough preprocessing to perform quality check on the data and ensure that there are no substantial gaps in the time series.

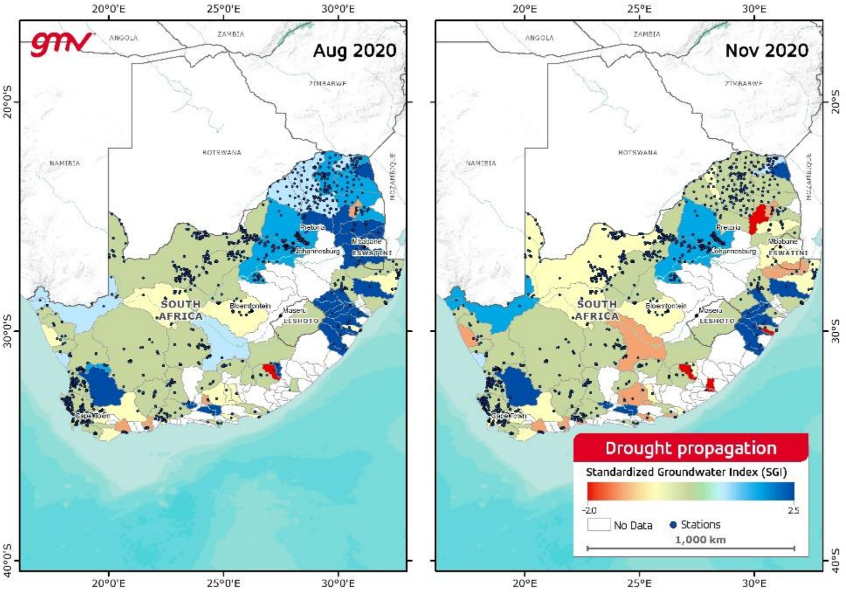
In this case, given that the aim is to have an operational drought monitoring system, just the active measuring points with data until 2022 were selected. Then, the stations with high percentage of missing data (80% or higher) were discarded. Similarly, the stations with 12 or more consecutive years with high percentage of missing data (80% or higher) were also discarded. This process led to a final selection of 1062 stations across South Africa.

In contrast with precipitation data, groundwater level data may not always follow a specific parametric distribution. Groundwater levels can exhibit complex and varied patterns that may not conform to well-known distributions. Therefore, in order to normalize the data prior to the implementation of the index, a non-parametric approach is often used to avoid making assumptions about the underlying distribution of the data and allows for a more flexible analysis. In the case of the SGI calculation, normal scores are used as a non-parametric distribution transformation to normalize the groundwater level data. Then, the SGI index can be computed following the expression below:

$$\mathrm{SGI}_{\mathrm{i,j}} = \frac{\Delta GWS_{\mathrm{i,j}} - \Delta\overline{GWS}}{\sigma_{\Delta GWS}}$$

Where $\mathrm{SGI}_{i,j}$ is the SGI at this period, $\Delta GWS_{\mathrm{i,j}}$ denotes the groundwater storage changes in the same period, whereas $\Delta\overline{GWS}$ and $\sigma_{\Delta GWS}$ are the averaged changes in groundwater storage and standard deviation respectively.

| **Product name** | **STANDARDISED STREAMFLOW INDEX (SGI)** |
|---|---|
| **Product description** | The Standardized Groundwater Index (SGI) is a drought monitoring index used to assess the state of groundwater levels relative to long-term averages This index quantifies the departure of groundwater levels from their long-term average by providing a standardized value that indicates the severity and duration of groundwater anomalies. When applied at different time scales (e.g., monthly, seasonal, or annual) it can capture different aspects of groundwater variability. |
| **Main applications** | • Hydro(geo)logical drought monitoring<br>• Groundwater management<br>• Early warning system & Water supply forecasting<br>• Drought impact assessment<br>• Decision support for water users, police makers and water resources planning. |
| **Update frequency** | - |
| **Format** | Tiff |
| **Input data** | Groundwater levels |
| **Archive Length** | October 1990 to July 2022 |
| **Spatial resolution** | Secondary catchments |
| **Spatial coverage** | South Africa |

<table>
<tr><td>Requires Field Data</td><td>Yes</td></tr>
<tr><td>Product Overview</td><td>
</td></tr>
</table>

## 4.4. INTEGRATED DROUGHT INDEX (IDI)

**Index description**

The Integrated Drought Index (IDI) is a tool used to assess and monitor drought conditions by combining multiple drought indicators into a single index. In fact, the IDI can capture both short-term and long-term droughts and the integrated responses of meteorological, hydrological, and agricultural droughts in river basins located in different climatic and geographical regions. It provides a comprehensive picture of drought severity, incorporating various meteorological, hydrological, and agricultural factors. More specifically, it integrates the Standardized Precipitation Index (SPI), Standardized Soil Moisture Index (SMI), Standardized Streamflow Index (SSFI), Standardized Groundwater Index (SGI), using a copula-based approach. Indeed, the IDI is designed to capture the integrated response of droughts and account for the variability in different climatic and geographical regions. It provides a holistic view of drought conditions by considering various aspects of the water cycle and groundwater storage.

The IDI, as described in Shah and Mishra (2020), was originally developed to be implemented at national scale using gridded datasets for the computation of the different drought indicators. In this way, streamflow data was obtained from the land surface models that were the part of Global Land Data Assimilation System (GLDAS), whereas the SGI, was calculated based on Terrestrial Water Storage anomalies from the GRACE satellite. Although, in principle, this methodology should be transferable to in-situ measurements, there are some points that require careful consideration:

1. There is not a sufficient density of measurements as to generate a gridded streamflow/groundwater dataset. Therefore, the index could just be calculated using an average of the respective indices at catchment level.
2. The observed streamflow/groundwater measurements may have a limited historical record. Using a different number of stations across the time series, a bias may be introduced. If only stations covering the entire time series were used, the number of measurement points would be significantly reduced and consequently the number of catchments for which the IDI can be calculated.
3. Although streamflow and groundwater in-situ measurements have undergone a data quality-check, there might still be erroneous/missing values that can affect the robustness of the resulting IDI.

Therefore, it is considered that implementing the IDI with in-situ measurements in the context of South Africa would entail considerable uncertainties that would undermine the robustness and reliability of the index. Alternatively, the GLDAS dataset outputs -streamflow and groundwater- could be used to derive the IDI for the 2004-2023 period. Additionally, this approach could be simply adapted to be operational.

# 5. DROUGHT SEASONAL FORECAST

Seasonal forecasts serve as a powerful tool in meteorology, providing a look into future climate conditions for periods extending up to six months in advance. Unlike short-term weather predictions, these forecasts focus on long-term patterns and trends, rather than day-to-day fluctuations. Leveraging advanced modelling techniques and computational power, they simulate a range of possible weather scenarios and provide probabilities for various outcomes. This could include whether a season will be wetter, drier, warmer, or colder than average.

Crucially, these forecasts consider slower-evolving components of the Earth system such as El Niño or La Niña phenomena and the North Atlantic Oscillation, which can be more predictably modelled over extended periods. The data generated by these forecasts not only aid in understanding the broader climatic trends, but also help in planning various activities that are sensitive to climatic variations, from agricultural planning to disaster risk management.

The seasonal forecast from the Copernicus Climate Change Service (C3S)[2] operates in a distinctive methodological framework, employing ensemble simulations to model a suite of possible meteorological outcomes. Thus, it provides probabilistic forecasts, quantifying the likelihood of deviation from climatological norms in terms of precipitation and temperature for the upcoming season. Forecasts independently generated by eight global centres are consolidated into a comprehensive multi-system seasonal forecast. This ensemble-based methodology serves to mitigate the impacts of systematic biases inherent to each individual model.

This seasonal forecast framework provides the input data sets to calculate for the upcoming six months drought indices like SPI, SPEI, SMI, SMA. C3S updates monthly the seasonal forecast product, allowing to calculate and update on a monthly basis the six-month forecasts of drought indices.

## 5.1. STANDARDIZED PRECIPITATION INDEX (SPI)

**Index description**

The Standardized Precipitation Index (SPI) (see Section 4.1.1) is a universally accepted measure used to describe meteorological drought across varying timescales. In the short term, the SPI has a direct correlation with soil moisture, whereas it associates with groundwater and reservoir storage over extended periods. A distinctive feature of the SPI is its ability to compare precipitation across different climatic regions.

The SPI translates observed precipitation into a standard deviation from a selected probability distribution function that fits the raw precipitation data. The raw data are usually adjusted to either a gamma or Pearson Type III distribution, followed by a transformation to a normal distribution. The resulting SPI values can then be interpreted as the number of standard deviations the observed precipitation deviates from the long-term average.

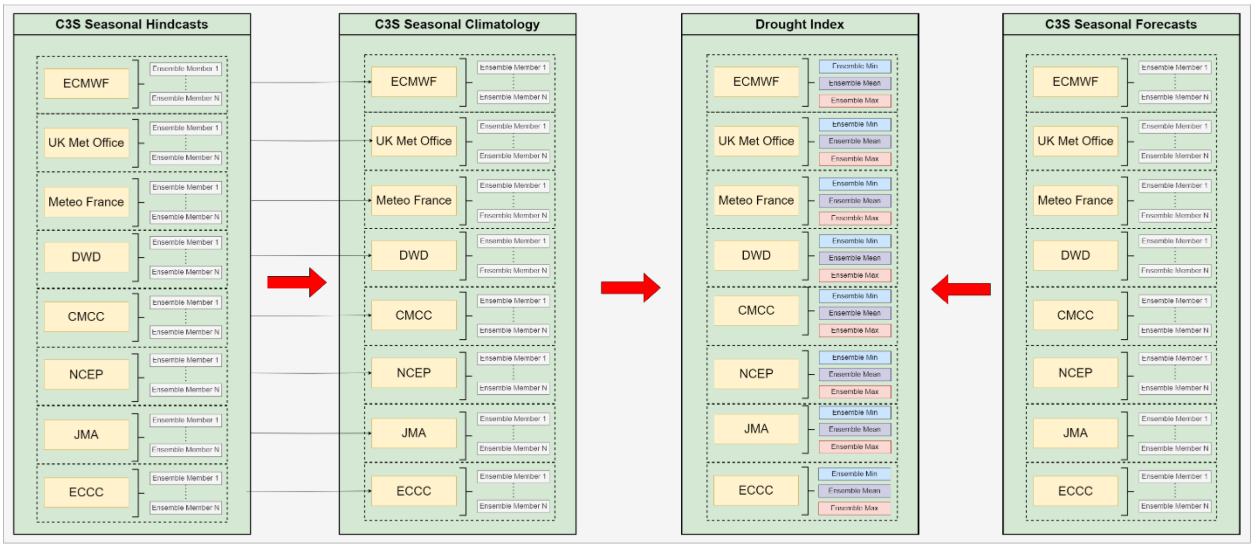
The SPI can be computed over various timescales, utilizing monthly input data. Among practitioners, the SPI is recognized as the definitive index for globally quantifying and reporting meteorological droughts.

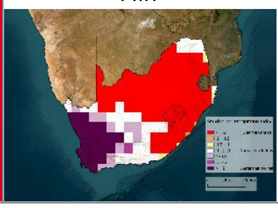
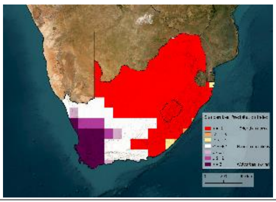
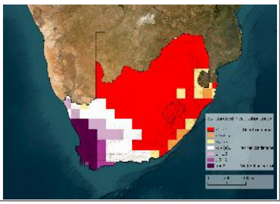
**Methodology/Algorithm**

SPI index is calculated with data from C3S[3], from the provided data sets produced by eight global data centers. Each data center offers hindcast data with reduced ensemble members from which the precipitation climatology for each data center is calculated. Monthly seasonal forecasts for six months ahead are produced by the eight providers with a monthly update frequency. The precipitation forecast data from each provider are collected, fitted to the gamma distribution and along with the climatology for each data center's model, the SPI index is calculated. The minimum, maximum and mean SPI index from all centers and per data centers are produced.

[2] https://climate.copernicus.eu/seasonal-forecasts

[3] https://cds.climate.copernicus.eu/cdsapp#!/dataset/seasonal-monthly-single-levels?tab=overview




| Product name | STANDARDIZED PRECIPITATION INDEX (SPI) |
|---|---|
| Product description | This product provides time-series (monthly) information on meteorological droughts. Based on precipitation monthly data, this product offer values for SPI given in units of standard deviation from the long-term mean of the standardized distribution. |
| Main applications | • Identifying and classifying meteorological droughts<br>• Drought alerts and monitoring<br>• Agricultural drought assessment<br>• Water management<br>• Climatic risk assessment |
| Update frequency | Monthly |
| Format | Raster format: NetCDF |
| Input data | Monthly precipitation data from C3S seasonal forecasts and hindcasts. |
| Archive Length | January 1981 – to present |
| Spatial resolution | 1° x 1° |
| Spatial coverage | Computed at national scale. |
| Requires Field Data | No |
| Product Overview | **June 2023**<br>Min  Mean  Max  |

## 5.2. STANDARDISED PRECIPITATION-EVAPOTRANSPIRATION INDEX (SPEI)

### Index description

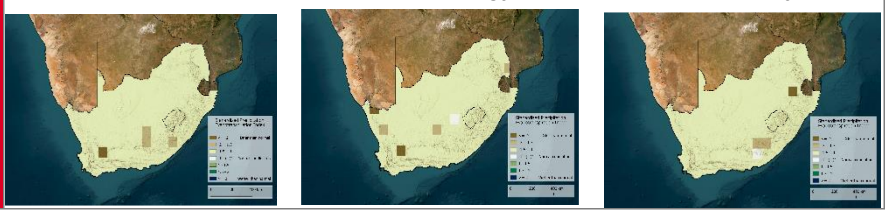
The Standardized Precipitation Evapotranspiration Index (SPEI) extends the capabilities of the well-established Standardized Precipitation Index (SPI) by incorporating both precipitation and potential evapotranspiration (PET) into drought assessment. This inclusion allows the SPEI to capture the significant effect of elevated temperatures on water demand, a feature not present in the SPI.

Like its predecessor, the SPEI can be calculated for diverse timescales, ranging from 1 to 48 months. For longer timescales (greater than approximately 18 months), correlations have been found between the SPEI and the self-calibrating Palmer Drought Severity Index (sc-PDSI).

To calculate the PET, the Penman-Monteith method is applied. The Penman-Monteith method is a mathematical model used to estimate potential evapotranspiration (PET), which is the amount of water that would evaporate and transpire under optimal conditions (i.e., if water were not limited). This method is widely regarded as the most accurate approach to calculate PET and has been endorsed by the Food and Agriculture Organization (FAO) of the United Nations as the standard method for estimating evapotranspiration. Developed by Howard Penman and John Monteith, this approach combines two individual models. It incorporates both energy balance considerations (Penman's approach) and the mass transfer theory (Monteith's approach) to determine evapotranspiration rates. In essence, the Penman-Monteith method considers the effects of radiation, temperature, humidity, and wind speed on evapotranspiration. Specifically, it calculates PET based on these parameters, as well as surface resistance and aerodynamic resistance, which account for the capacity of the plant canopy and the air above it to resist moisture transfer.

**Methodology/Algorithm**

SPEI index is calculated with data from C3S[4], from the provided data sets produced by eight global data centers. Each data center offers hindcast data with reduced ensemble members from which the PET climatology for each data center is calculated. Monthly seasonal forecasts for six months ahead are produced by the eight providers with a monthly update frequency. The PET forecast data from each provider are collected, fitted to the gamma distribution and along with the climatology for each data center's model, the SPEI index is calculated. The minimum, maximum and mean SPI index from all centers and per data centers are produced.

| **Product name** | **STANDARDIZED PRECIPITATION-EVAPOTRANSPIRATION INDEX (SPEI)** |
|---|---|
| **Product description** | This product provides time-series (monthly) information on meteorological droughts. Based on precipitation monthly data, this product offer values for SPI given in units of standard deviation from the long-term mean of the standardized distribution. |
| **Main applications** | • Water demand caused by elevated temperatures.<br>• Combines multi-timescales aspects of the Standardized Precipitation Index (SPI) with information about evapotranspiration, making it more useful for climate change studies |
| **Update frequency** | Monthly |
| **Format** | Raster format: NetCDF |
| **Input data** | Monthly PET data from C3S seasonal forecasts and hindcasts. |
| **Archive Length** | January 1981 – to present |
| **Spatial resolution** | 1° x 1° |
| **Spatial coverage** | Computed at national scale. |
| **Requires Field Data** | No |
| **Product Overview** | **June 2023**<br>Min Mean Max<br> |

[4] https://cds.climate.copernicus.eu/cdsapp#!/dataset/seasonal-monthly-single-levels?tab=overview

## 5.3. SOIL MOISTURE INDEX (SMI)

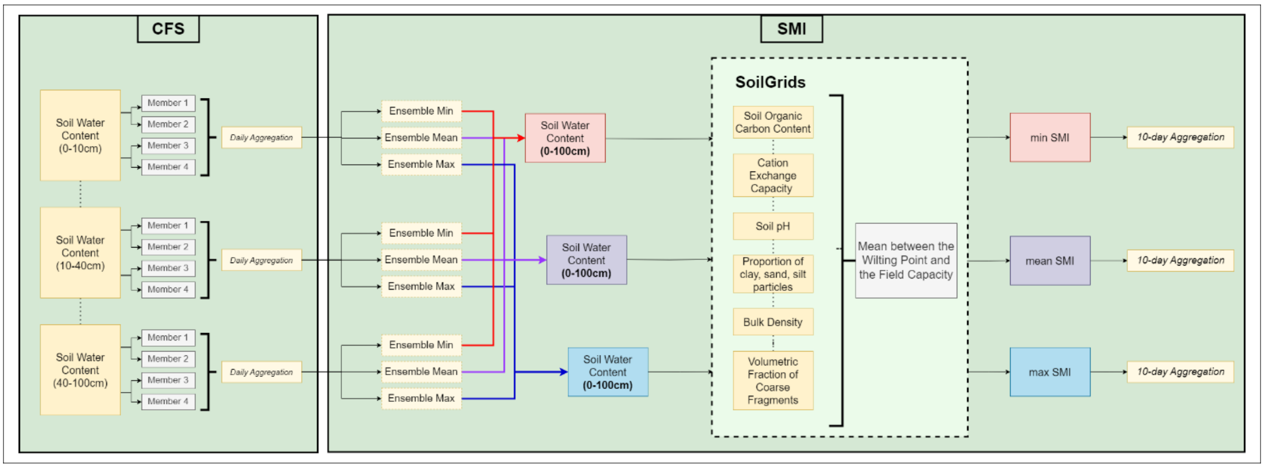
**Index description**

The Soil Moisture Index (SMI) is frequently used in the field of hydrology, agriculture, and meteorology to evaluate the water content in the soil. This index is derived from soil water content parameters and can assist in monitoring the available water capacity in soil for plant growth, determining drought conditions, and predicting floods. The SMI is dimensionless and varies between 0 (extreme dryness) and 1 (above field capacity moisture). Positive values of the index typically indicate above-average soil moisture conditions, suggesting sufficient water available for plants, while negative values generally suggest below-average conditions, hinting at potential drought conditions.

SMI forecasts showcase the spatial and temporal variations in soil water. These data flag the start and duration of water stress and can be used for predicting the onset of potential drought conditions.

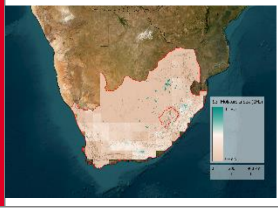
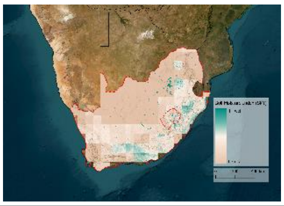
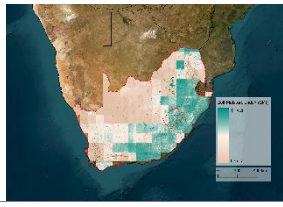
**Methodology/Algorithm**

For the SMI index, data from CFS[5] (Climate Forecast System) by NCEP (National Centers for Environmental Prediction) were selected, since they provided the necessary variables (soil water content parameters) for the index calculation. Monthly seasonal forecasts for six months ahead are produced with a monthly update frequency. The SMI forecast data from each of the 4 ensemble members are collected, and following the workflow depicted in the figure below, the SMI index is calculated. The minimum, maximum and mean SMI index are produced for 10-day periods of the next 6 months, following the JRC's (Joint Research Center) guidelines.




| **Product name** | **SOIL MOISTURE INDEX (SMI)** |
|---|---|
| **Product description** | This product (ranging between 0 and 1) is based on soil water content parameters and is calculated by normalizing the soil moisture between the wilting point and the field capacity (van Genuchten approach, 1987). This index is equal to 0 when the soil is extremely dry (has reached the wilting point) and equal to 1 when the soil is extremely wet (moisture has surpassed the field capacity). |
| **Main applications** | • Drought Monitoring and Prediction<br>• Flood Forecasting<br>• Irrigation planning<br>• Land Management<br>• Large scale farming, urban planning, environmental studies |
| **Update frequency** | Monthly |
| **Format** | Raster format: NetCDF |
| **Input data** | CFS forecasts – SoilGrids parameters |
| **Archive Length** | January 1981 – to present |
| **Spatial resolution** | 1° x 1° |

[5] https://cfs.ncep.noaa.gov/

| | |
|---|---|
| **Spatial coverage** | Computed at national scale. |
| **Requires Field Data** | No |
| **Product Overview** | **26/11/2023 – 06/12/2023**<br>Min  Mean  Max  |

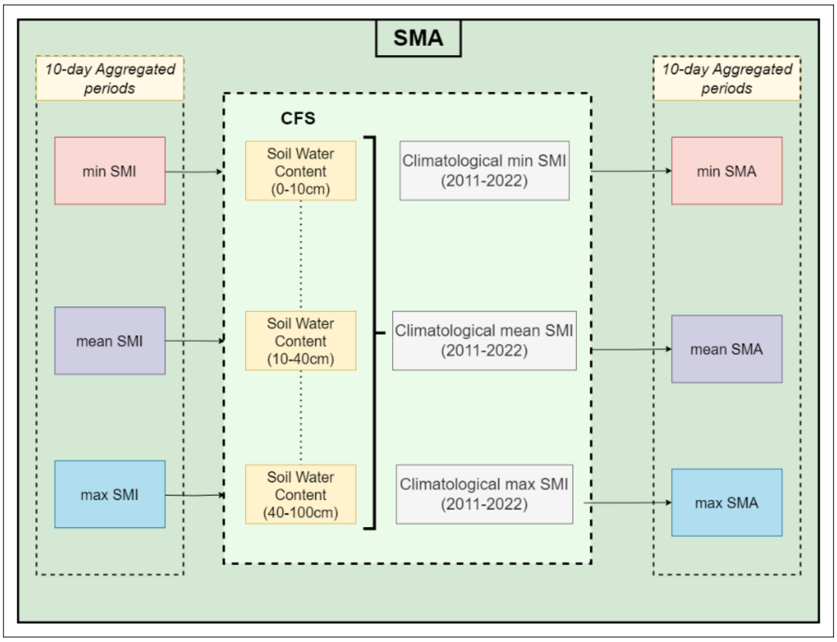
## 5.4. SOIL MOISTURE ANOMALY (SMA)

The Soil Moisture Anomaly (SMA) is an index describing the deviation of soil moisture levels from their long-term averages. Positive values of the index indicate that the soil is wetter than normal, while negative ones usually suggest drought conditions. SMA is a powerful tool for understanding current and future climate conditions. It can be used to quantify periods of drought or unusually wet conditions, providing vital information for agriculture, water resource management, and climate science. Essentially, SMA tracks and assesses the onset and span of agricultural droughts - a state caused by inadequate soil moisture affecting crop yield and agricultural production. It is calculated in 10-day periods and it has proven to be quite effective for drought detection.

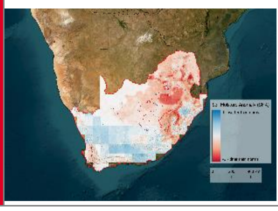
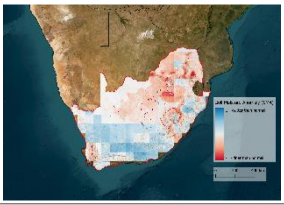
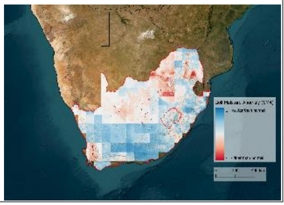
Soil moisture, along with rainfall and evapotranspiration, is crucial for plant growth and the hydrological cycle. SMA forecasts are produced using soil moisture estimates and their variations compared to a reference period. SMA helps monitor agricultural drought, one of three primary drought types, each linked to different aspects of the hydrological cycle. SMA indicates agricultural drought prevalence by showing the deviation from standard water availability.

**Methodology/Algorithm**

The calculation of the SMA index is based on the SMI seasonal forecasts and the SMI climatological values based on the archived CFS forecasts[6] with a reference period of 11 years (2011-2022). Monthly seasonal forecasts for the next six months are produced with a monthly update frequency following the workflow depicted in the figure below. The minimum, maximum and mean SMA index are produced for 10-day periods of the next 6 months, following the JRC's guidelines.




[6] https://www.ncei.noaa.gov/data/climate-forecast-system

| Product name | SOIL MOISTURE ANOMALY (SMA) |
|---|---|
| Product description | This product is computed in 10-day periods as anomalies of the Soil Moisture Index (SMI) with a reference period of 1990-2020. |
| Main applications | • Drought monitoring and prediction<br>• Flood prediction<br>• Crop yield forecasting<br>• Management of Water Resources<br>• Agricultural Planning |
| Update frequency | Monthly |
| Format | Raster format: NetCDF |
| Input data | SMI (historical data -CFS- and forecasts -CFS-) |
| Archive Length | January 1981 – to present |
| Spatial resolution | 1° x 1° |
| Spatial coverage | Computed at national scale. |
| Requires Field Data | No |
| Product Overview | **26/11/2023 – 06/12/2023**<br>Min: <br>Mean: <br>Max:  |

# 6. DATA CATALOG

## 6.1. INTRODUCTION

A data catalog is a centralized repository or database that stores metadata and information about the data assets within an organization or a project. It serves as a comprehensive index or catalog of all the data available making it easier for users to discover, understand, and access data.

### 6.1.1. SCOPE

A data catalog is essential for modern data-driven organizations to effectively manage, govern, share, and leverage their data assets. Within the context of ANIN project the Data Catalog serves to assist the produced data discoverability and understanding by collecting, organizing, and managing their metadata. Independently of the which is the data producer, data catalog provides proper organizing allowing management and governance of the datasets.

Considering the available Data Catalog technologies that would be suitable for ANIN implementation, STAC (SpatioTemporal Asset Catalog) can play this role effectively, compared to other technologies like Geonetwork or Postgress. It is the structural characteristics of a STAC catalog that make it appropriate component for the ANIN architecture. Specifically, the ability of managing Time Series of geospatial data is crucial, since this type of data is widely used for drought monitoring and forecasting. STAC catalog is able to include information about both the geographic extent and the time period, allowing users to search for data in high spatiotemporal detail. Furthermore, it is important that STAC technology supports API connectivity. Especially, the API connectivity with the OpenEO platform used in ANIN environment, allows a smooth data transfer within the workflow.

### 6.1.2. STAC SPECIFICATION

A STAC (SpatioTemporal Asset Catalog) is a standardized format for cataloging and describing geospatial data assets. It is designed to make it easier to discover, access, and share geospatial data, particularly data related to Earth observation, remote sensing, and satellite imagery. STAC provides a consistent way to organize and describe geospatial data so that users can quickly understand what data is available, where it is located, and how to access it.

Key features of a STAC catalog include:

1. **SpatioTemporal Information:** STAC catalogs include information about the geographic extent and time period covered by the data, allowing users to search for data that matches specific spatial and temporal criteria.
2. **Asset-Level Metadata:** Data assets are described at the asset level, meaning that individual files or data sets are listed with detailed metadata. This includes information about data format, projection, resolution, and other relevant details.
3. **Links to Data**: STAC catalogs provide links to the actual data files, making it easy for users to access and download the data they need.
4. **Extensible Metadata**: STAC is designed to be extensible, so organizations can include additional metadata specific to their data sets or needs.

STAC catalogs are particularly useful in the context of Earth observation and satellite imagery because they allow researchers, developers, and data users to easily search for and access data from various sources, which is critical for tasks such as environmental monitoring, agriculture, disaster response, and more.

They are typically used alongside other geospatial tools and standards like GDAL (Geospatial Data Abstraction Library), OGC (Open Geospatial Consortium) standards, and various data formats like GeoTIFF. The STAC community continues to develop and refine the standard, with the goal of improving the discoverability and accessibility of geospatial data.

**STAC Components**

There are three component specifications that together make up the core SpatioTemporal Asset Catalog specification. These components are:

**Item**: A STAC (SpatioTemporal Asset Catalog) item is a fundamental concept within the STAC specification. It represents a single data asset or dataset in a STAC catalog and serves as a container for metadata and information about a specific geospatial data resource. STAC items are used to describe individual assets, such as satellite images, aerial photographs, or any other geospatial data files.

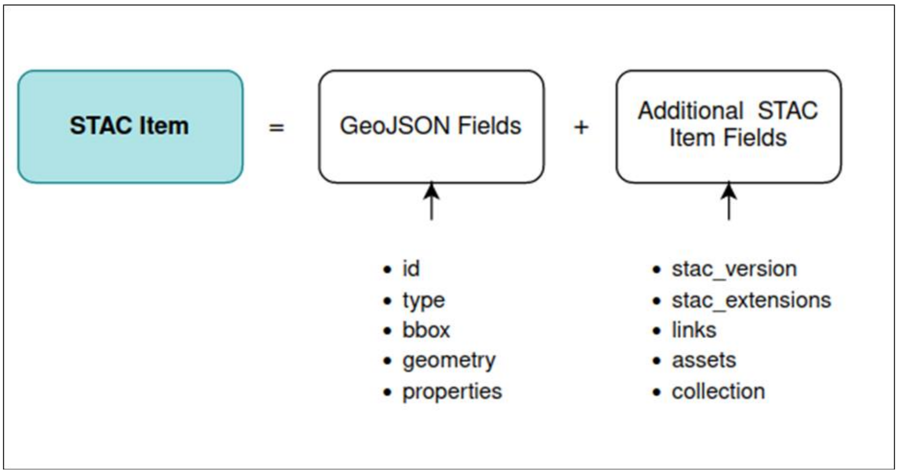



**Figure 6-1: STAC item structure**

**Catalog**: A STAC (SpatioTemporal Asset Catalog) catalog is a standardized format for organizing and describing geospatial data assets. It serves as a structured and consistent way to manage and publish geospatial data, particularly data related to Earth observation, remote sensing, and satellite imagery. STAC catalogs provide a means to make geospatial data more discoverable, accessible, and interoperable across different platforms and applications.

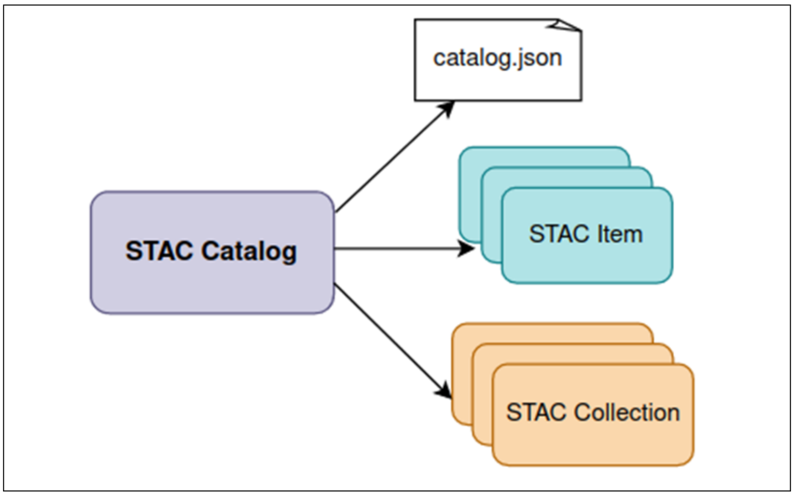



**Figure 6-2: STAC catalog structure**

**Collection**: A STAC (SpatioTemporal Asset Catalog) collection is a concept within the STAC specification that serves as a way to organize and group related geospatial data assets within a STAC catalog. Collections provide a higher-level organizational structure for data assets, making it easier to manage, categorize, and discover data resources that share common characteristics or themes.

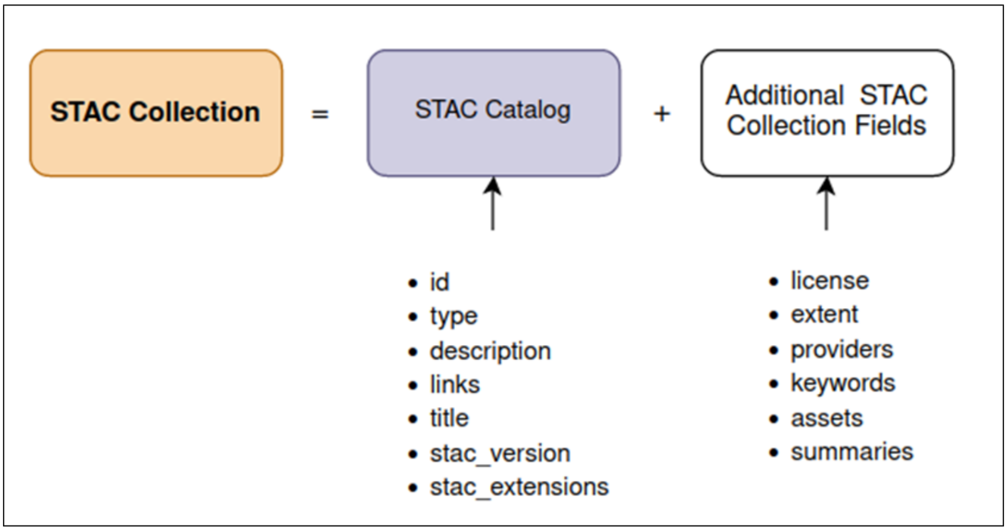



**Figure 6-3: STAC collection structure**

Each of the components can be used alone, but they work best in concert with one another.

## 6.2. STAC DATA CATALOG FOR ANIN

STAC (SpatioTemporal Asset Catalog) specification targets on supporting ANIN's data cataloging. As key components of STAC include Items, Catalogs and Collections, two approaches are followed during the conceptualization of ANIN's STAC Indices Data Catalog:

- ***STAC Approach 1: Items – Catalog***. It is based on the idea of generating Items - Spatiotemporal Assets for each index scene and group them under a Catalog specification.

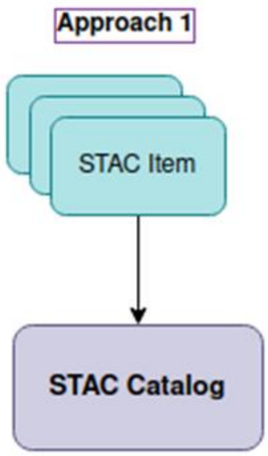



**Figure 6-4: STAC approach 1: Items - Catalog**

- ***STAC Approach 2: Items – Collection – Catalog***. It follows the idea of generating Items - Spatiotemporal Assets for each index scene which will then be grouped under a Collection specification. The Collection will then be enclosed in a Catalog specification.

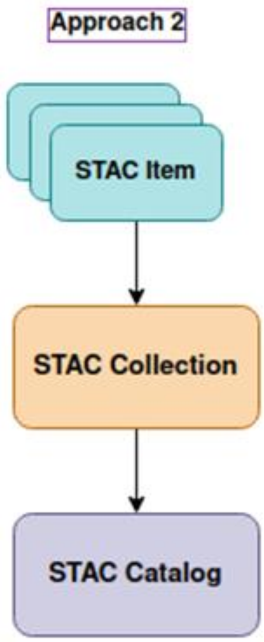



**Figure 6-5: STAC approach 2: Items- Collection - Catalog**

**Python scripts for the creation of ANIN STAC Data Catalogue**

For each of the approaches, one Python script was developed making use of the PySTAC library (v.1.7.3). These scripts were built for the cataloging of input layers that follow a given naming convention. According to this, the name of index appears first while the date follows. This naming convention appears at the following format:

***IndexName_Date.tif***

in which the date field should be given in the format ddmmyyyy. In Table 6-1 the naming convention for each product produced within ANIN is presented.

**Table 6-1 Naming convention**

| Concept / Term | Definition |
|---|---|
| SPI | Spi_ddmmyyyy.tif |
| SPEI | Spei_ddmmyyyy.tif |
| Crop mask | CropMask_ddmmyyyy.tif |
| VCI | Vci_ddmmyyyy.tif |
| FAPAR Anomaly | FaparAnomaly_ddmmyyyy.tif |
| CDI | Cdi_ddmmyyyy.tif |
| SSFI | Ssfi_ddmmyyyy.tif |
| SGI | Sgi_ddmmyyyy.tif |
| IDI | Idi_ddmmyyyy.tif |

Important information such as:

- Id
- Geometry
- Bbox
- date,
- projection
- relation and
- href

are written on each item's json file and the license and spatiotemporal extent are written on the collection.json file.

**Data Catalog implementation**

Each Python script used for the implementation, follows specific steps before reaching the desirable result. These steps are described in Table 6-2 (Approach 1) and Table 6-3 (Approach 2).

**Table 6-2 Data catalog implementation Approach 1**

| | Approach 1 - Implementation steps |
|---|---|
| 1 | # Set the directory containing the index files and the output directory for the STAC catalog |
| 2 | # Create STAC Catalog object |
| 3 | # Get a list of TIFF files |
| 4 | # Read the naming convention and the properties (geometry,bbox,date) of each TIFF file |
| 5 | # Create the items |
| 6 | # Add the items to a catalog |
| 7 | # Save the catalog |
| | **Requirements & Execution** |
| | pystac==1.7.3, shapely==2.0.1, rasterio==1.3.7, pandas==2.0.2, argparse==1.4.0 |
| | # Install requirements in a Python Virtual environment |
| | # The user will get prompted to provide the following inputs:<br>• folder: Path to the folder containing the Index files<br>• output-folder: Path to the output folder for STAC catalog e.g./home/user/STAC |
| | #Execute the code:<br>python stac-approach-1.py --folder /path/to/the/folder/containing/the/Index/files --output-folder /path/to/the/output/folder/for/stac_catalog_1 |

**Table 6-3 Data catalog implementation Approach 2**

| | Approach 1 - Implementation steps |
|---|---|
| 1 | # Set the directory containing the index files and the output directory for the STAC catalog |
| 2 | # Get a list of TIFF files |
| 3 | # Collect the Items' geometry and bbox |
| 4 | # Create a list to store collection items |
| 5 | # Create collection items for each TIFF file |
| 6 | # Read the naming convention and the properties (geometry,bbox,date) of each TIFF file |
| 7 | # Add projection information for each TIFF file |
| 8 | # Create the collection |
| 9 | # Add collection items to the collection |
| 10 | # Add the collection to a catalog |
| | **Requirements & Execution** |
| | pystac==1.7.3, shapely==2.0.1, rasterio==1.3.7, pandas==2.0.2, argparse==1.4.0 |
| | # Install requirements in a Python Virtual environment |
| | # The user will get prompted to provide the following inputs:<br>• tif-dir: Path to the folder containing the Index files<br>• tmp-dir: Path to the output folder for STAC catalog e.g. /home/user/STAC |
| | #Execute the code:<br>python stac-approach-2.py --tmp-dir /path/to/the/output/folder/for/STAC/catalog --tif-dir /path/to/the/folder/containing/the/Index/files |

The code produces a folder structure for the output STAC catalog which contains the catalog.json file and the folder for the corresponding index collection as well. The latter encloses the collection.json file as well as a folder with a json file for each input index scene.

```
{
  "type": "Feature",
  "stac_version": "1.0.0",
  "id": "Spei_20210901",
  "properties": {
    "proj:epsg": "4326",
    "proj:wkt2": "GEOGCS[\"WGS 84\",DATUM[\"WGS_1984\",SPHEROID[\"WGS 84\",6378137,298.257223563,AUTHORITY[\"EPSG\",\"7030\"]],AUTHORITY[\"EPSG\",\"6326\"]],PRIMEM[\"Greenwich\",0,AUTHORITY[\"EPSG\",\"8901\"]],UNIT[\"degree\",0.0174532925199433,AUTHORITY[\"EPSG\",\"9122\"]],AXIS[\"Latitude\",NORTH],AXIS[\"Longitude\",EAST],AUTHORITY[\"EPSG\",\"4326\"]]",
    "datetime": "2021-09-01T00:00:00Z"
  },
  "geometry": {
    "type": "Polygon",
    "coordinates": [
      [
        [
          19.998196784,
          46.048965869
        ],
        [
          19.998196784,
          46.084591869
        ],
        [
          20.049614784,
          46.084591869
        ],
        [
          20.049614784,
          46.048965869
        ],
        [
          19.998196784,
          46.048965869
        ]
      ]
    ]
  },
  "links": [
    {
      "rel": "root",
      "href": "../../catalog.json",
      "type": "application/json"
    },
    {
      "rel": "collection",
      "href": "../collection.json",
      "type": "application/json"
    },
    {
      "rel": "parent",
      "href": "../collection.json",
      "type": "application/json"
    }
  ],
  "assets": {
    "image": {
      "href": "/home/user/Spei/Spei_20210901.tif",
```


**Figure 6-6: Catalog item in .json file format**

"type": "Catalog",

"id": "A catalog of Spei collection",

"stac_version": "1.0.0",

"description": "This catalog contains a collection of Spei scenes",

"links": [

{

"rel": "root",

"href": "./catalog.json",

"type": "application/json"

},

{

"rel": "child",

"href": "./Spei-collection/collection.json",

"type": "application/json"

}

]

}

**Figure 6-7: Catalog specification in .json file format**

```
{
  "type": "Collection",
  "id": "Spei-collection",
  "stac_version": "1.0.0",
  "description": "A collection of Spei scenes",
  "links": [
    {
      "rel": "root",
      "href": "../catalog.json",
      "type": "application/json"
    },
    {
      "rel": "item",
      "href": "./Spei_20211013/Spei_20211013.json",
      "type": "application/json"
    },
    {
      "rel": "parent",
      "href": "../catalog.json",
      "type": "application/json"
    }
  ],
  "extent": {
    "spatial": {
      "bbox": [
        [
          19.998196784,
          46.048965869,
          20.049614784,
          46.084591869
        ]
      ]
    },
    "temporal": {
      "interval": [
        [
          "2021-10-13T00:00:00Z",
          "2021-10-13T00:00:00Z"
        ]
      ]
    }
  },
  "license": "CC-BY-SA-4.0"
}
```

**Figure 6-8: Catalog Collection in .json file format**

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