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Germ of Life

Interreg Euro-MED Project GERM OF LIFE

“Digital Drought Risk Management enabling the drought mitigation and adaptation strategies for the restoration of the ecosystem equilibrium in Mediterranean European Countries”.

Test Project (Thematic Project)
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Deliverable description (from AF)
The D.1.1.1. ‘Drought indices review’ is a document containing the description of the selected indices suitable for the development of the project at the Pilot Test Areas (PTAs).

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1 Executive Summary

This document contains the description of the selected indices suitable for the development of the project at the Pilot Test Areas and reports on the main activities done in the first part of the Activity 1.1 'Review of existing drought indices and formulation of new indicators/proxies that are potentially useful from drought detection and impact quantification' and carried out on in the frame of WP 1 and for the Period 1 from M1 to M6.

1.1 Role of deliverable

The deliverable D.1.1.1. 'Drought indices review' reports on the first part of the Activity 1.1 'Review of existing drought indices and formulation of new indicators/proxies that are potentially useful from drought detection and impact quantification' which was carried out in the frame of WP 1 and for the Period 1 from M1 to M6. It contains the description of the selected drought indices suitable for the development of the project at the Pilot Test Areas (PTAs).

1.2 Relationship to other GERM OF LIFE deliverables

The deliverable D.1.1.1. describes the selected drought indices suitable for the project implementation at the PTAs at M6, while a description of tailored algorithms will be internally deliverables as D.1.1.2 at the end of the Activity 1.1. at M12.
The deliverable D.1.1.1. contains preliminary information useful for the definition of the workflow for the joint design and prototyping of the collaborative Vulnerability Assessment Tool (VAT) at the PTAs as planned for the Activity 1.3 and which will be internally deliverables as D.1.3.1 at M12.

1.3 Structure of the document

This deliverable is organised in the following four sections:

2.1 Drought types and their impact
2.2 Satellite-based indicators for drought monitoring
2.3 Agricultural drought monitoring
2.4 Datasets for meteorological and soil water availability monitoring
2.5 Development of drought indicator at PTAs

2 Review of drought indicator

2.1 Drought types and their impact

Drought is the least understood natural phenomenon induced by consequent hydrological imbalance and precipitation deficiency. Droughts drastically impact people's health, agriculture, economy and water resources. In the last decades, the frequencies of occurrence and intensities of droughts increased and the ever-growing requirement for water resources and the compound uncertainty of hydroclimatic factors aggravate the potential impacts of droughts on agro-ecosystems. More frequent heat waves and climate extremes would further exacerbate the droughts and their influences in many regions worldwide[1].

Water availability limits ecosystem growth and productivity across much of the Earth's surface. In arid, semi-arid and Mediterranean ecosystems, limiting water availability is a recurrent phenomenon and governs plant growth and phenology[2]. Agriculture is one of the sectors to be directly hit by the increased frequency of droughts. Changes must be made to adapt to such events, which may well become more extreme in both intensity and duration under climate change. As one of society's most pressing concerns, this challenge to the food supply has excited keen interest in the solutions research can provide.

Recent research has increased understanding of droughts and – based on the acknowledgement that drought is more than a lack of rainfall – led to many different definitions of droughts.

Four different kind of droughts[3] are commonly used:

- **Meteorological drought**: when there is a lack of precipitation (rain or snow);
- **Agricultural drought**: when soil moisture cannot support plants;
- **Hydrological drought**: when river flows and groundwater levels are unusually low.

Droughts are one of the most complex of all natural hazards to analyse and understand because they have a wide-range of cascading impacts (Fig. 1) that may be caused or exacerbated by different drought aspects or other external factors (i.e. precipitation

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[1] Fu, Z. et al., 2020. Sensitivity of gross primary productivity to climatic drivers during the summer drought of 2018 in Europe. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 375(1810): 20190747.

[2] Reichstein, M. et al., 2005. On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm. *Global Change Biology*, 11(9): 1424-1439.

[3] Kiem, A. S., Johnson, F., Westra, S., van Dijk, A., Evans, J. P., O'Donnell, A., ... & Mehrotra, R. (2016). Natural hazards in Australia: droughts. *Climatic Change*, *139*, 37-54.

deficits (or absence of extreme rainfall events); actual and potential evapotranspiration and driving variables; soil moisture deficits and groundwater). Meteorological drought due to a prolonged lack of rain is the trigger of the other types of drought: the absence of precipitation combined with rising temperatures and the consequent increase in evapotranspiration determines both hydrological drought characterised by watershed depletion and agricultural drought featured by an impoverishment of soil moisture and leading to reduction in total agricultural productivity. Furthermore, agricultural and hydrological drought lead to unpredictable socioeconomic losses and ecosystem degradation, defined as socio-economic drought.

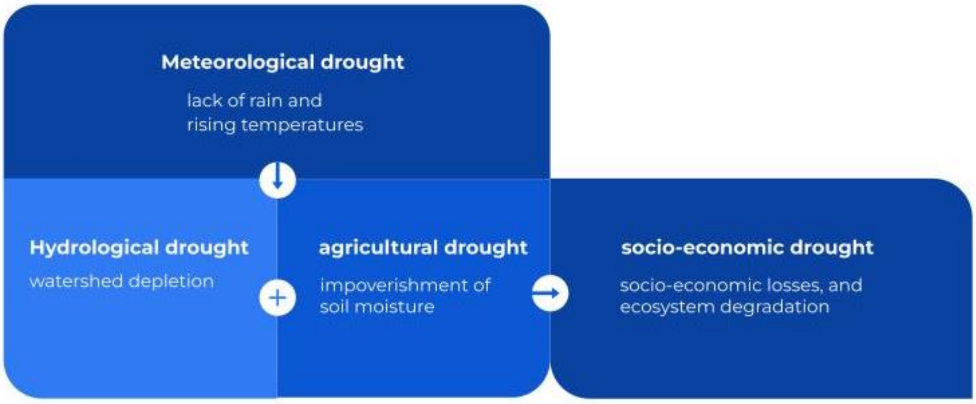

Figure 1. Drought types and their correlation.

In the Germ of Life project we investigate 'droughts' that can account for the impact of drought on vegetation growth and productivity in relation to meteorological conditions and soil water availability. This corresponds most closely to the definition of '**agro-meteorological droughts**' considering both the impact of rain deficiency and the low soil water availability on vegetation status and productivity.

2.2 Satellite-based indicators for drought monitoring

Proximal and remote sensing are powerful tools for describing the vegetation status under drought conditions. Both in situ and satellite observations have been used together with other variables that are more directly linked to ecosystem phenology and physiology. Remote-based models for describing vegetation growth and development usually combine observations of vegetation greenness, shortwave incoming radiation, temperature, and atmospheric demand for water (vapour-pressure deficit). Recently, it has been reported by Stocker et al.[4] that soil moisture can also be a proxy of aridity because its deficits have a direct impact on ecosystem productivity.

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[4] Stocker, B.D., Zscheischler, J., Keenan, T.F., Prentice, I.C., Peñuelas, J. and Seneviratne, S.I. (2018), Quantifying soil moisture impacts on light use efficiency across biomes. *New Phytol*, 218: 1430-1449. https://doi.org/10.1111/nph.15123

In situ optical observations offer fundamental complementary information that can be combined with satellite information to better understand the drought effects on ecosystem productivity at global scale[5].

Recent advances in proximal sensing technologies (e.g., finer spectral resolution, higher temporal resolution) have substantially increased their applications in ecosystem ecology[6,7]. The main advantages of in situ optical measurements over satellite remote sensing are finer spectral resolution (few nanometers) and the higher temporal resolution (hourly or less).

Research has shown that drought stress can provoke changes in plant physiology without affecting vegetation greenness. For that reason, most of the mentioned VIs do not describe well the productivity during drier years or during drought periods[8]. Greenness VIs – with not being sensitive to the quick changes of plant photosynthesis – are not suitable for detecting seasonal changes in plant physiology that are induced by common environmental stresses especially when greenness and photosynthesis become uncoupled (i.e. low water availability and heat)[9,11]. It has been reported also that greenness VIs are able to detect strong changes in canopy structure resulting from tree mortality or defoliation[10,11], but not small changes in foliar leaf area and biomass, as reported for a beech forest in Vicca et al.[12].

In the Germ of Life project we focus on a subset of vegetation indices used in scientific literature for quantifying vegetation status, growth and productivity. These indices together with environmental variables are used in a machine learning algorithm to

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[5] Asner, G.P., Knapp, D.E., Anderson, C.B., Martin, R.E. and Vaughn, N., 2016. Large-scale climatic and geophysical controls on the leaf economics spectrum. *Proceedings of the National Academy of Sciences*, 113(28): E4043-E4051.

[6] Balzarolo, M. et al., 2011. Ground-based optical measurements at European flux sites: a review of methods, instruments and current controversies. *Sensors*, 11(8): 7954-7981.

[7] Porcar-Castell, A. et al., 2015. EUROSPEC: at the interface between remote-sensing and ecosystem CO_2 flux measurements in Europe. *Biogeosciences*, 12(20): 6103-6124.

[8] Zhang, L. et al., 2012. The 2010 spring drought reduced primary productivity in southwestern China. *Environmental Research Letters*, 7(4).

[9] Hmimina, G., Merlier, E., Dufrêne, E. and Soudani, K., 2015. Deconvolution of pigment and physiologically related photochemical reflectance index variability at the canopy scale over an entire growing season. *Plant, Cell & Environment*, 38(8): 1578-1590.

[10] Dardel, C. et al., 2014. Re-greening Sahel: 30 years of remote sensing data and field observations (Mali, Niger). *Remote Sensing of Environment*, 140: 350-364.

[11] Sangüesa-Barreda, G., Camarero, J.J., García-Martín, A., Hernández, R. and de la Riva, J., 2014. Remote-sensing and tree-ring based characterization of forest defoliation and growth loss due to the Mediterranean pine processionary moth. *Forest Ecology and Management*, 320: 171-181.

[12] Vicca, S. et al., 2016. Remotely-sensed detection of effects of extreme droughts on gross primary production. *Sci Rep*, 6: 28269.

model the effect of drought on ecosystems. The table 1 lists the main indexes we selected as potential indicators of drought stress on vegetation. The selection of those indicators have been done considering the availability of Sentinel-2 bands for calculating them. When Sentinel-2 bands were available the corresponding indicator was indicated as a suitable indicator and classified as 'Y' in table 1.

Table 1. Description of remotely-based vegetation indicators of vegetation status. The letter 'Y' in the sixth column indicates that the index can be derived from Sentinel-2 data and it is used in the Germ of Life project for training the machine learning algorithm.

Index acronym	Index name	Sentinel bands	Formula	Geometric resolution (m)	Suitable (Yes or No)	Referenc e
NDVI	Normalised Difference Vegetation Index	B8, B4	$\frac{B8 - B4}{B8 + B4}$	10	Y	Rouse et al., 1974[13]
ChlRedEdg e	Chlorophyll Red Edge Index	B7, B5	$\frac{B7}{B5} - 1$	20	Y	Gitelson et al., 2006[14]
GNDVI	Green Normalized Difference Vegetation Index	B3, B8	$\frac{B3 - B8}{B3 + B8}$	10	Y	Gitelson n et al., 1996[15]
DVI	Difference Vegetation Index	B5, B9	$\frac{B9}{B5}$	60 (B9) 20 (B5)	N	Roujean and Breo, 1995[16]

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[13] Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. *NASA Spec. Publ*, *351*(1), 309.

[14] Gitelson, A. A., Viña, A., Verma, S. B., Rundquist, D. C., Arkebauer, T. J., Keydan, G., ... & Suyker, A. E. (2006). Relationship between gross primary production and chlorophyll content in crops: Implications for the synoptic monitoring of vegetation productivity. *Journal of Geophysical Research: Atmospheres*, *111*(D8).

[15] Gitelson, A. A., Kaufman, Y. J., & Merzlyak, M. N. (1996). Use of a green channel in remote sensing of global vegetation from EOS-MODIS. *Remote sensing of Environment*, *58*(3), 289-298.

[16] Roujean, J. L., & Breon, F. M. (1995). Estimating PAR absorbed by vegetation from bidirectional reflectance measurements. *Remote sensing of Environment*, *51*(3), 375-384.

Index acronym	Index name	Sentinel bands	Formula	Geometric resolution (m)	Suitable (Yes or No)	Referenc e
DSWI-4	Disease Water Stress Index-4	B3, B4	$\frac{B3}{B4}$	10	Y	Apan et al., 2004[17]
DSWI/DSWI -5	disease water stress index-5	B3,B4,B8, B11	$\frac{B8\ + B3}{B11 + B4}$	10 (B3) 10 (B4) 10 (B8) 20 (B11)	N	Apan et al., 2004
DSWI-2	disease water stress index-2	B3, B11	$\frac{B11}{B3}$	10 (B3) 20 (B11)	N	Apan et al., 2004
DSWI-3	disease water stress index-3	B4, B11	$\frac{B11}{B4}$	10 (B4) 20 (B11)	N	Apan et al., 2004
MSI	Moisture Stress Index	B11, B8	$\frac{B11}{B8}$	10 (B8) 20 (B11)	N	Hunt and Rock, 1989[18]
SIWSI	Shortwave Infrared Water Stress Index	B8a, B11	$\frac{B8a\ - B11}{B8a + B11}$	20	Y	Fensholt and Sandholt, 2003[19]
LWCI	Leaf Water Content Index	B9, B11	$\frac{-log(1-(B9-B}{-log(1-(B9_{FT}-B}$	60 (B9) 20 (B11)	N	Hunt et al., 1987[20]

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[17] Apan, A., Held, A., Phinn, S., & Markley, J. (2004). Detecting sugarcane 'orange rust' disease using EO-1 Hyperion hyperspectral imagery. *International journal of remote sensing*, *25*(2), 489-498.

[18] Hunt Jr, E. R., & Rock, B. N. (1989). Detection of changes in leaf water content using near-and middle-infrared reflectances. *Remote sensing of environment*, *30*(1), 43-54.

[19] Fensholt, R., & Sandholt, I. (2003). Derivation of a shortwave infrared water stress index from MODIS near-and shortwave infrared data in a semiarid environment. *Remote Sensing of Environment*, *87*(1), 111-121.

[20] Hunt Jr, E. R., Rock, B. N., & Nobel, P. S. (1987). Measurement of leaf relative water content by infrared reflectance. *Remote sensing of environment*, *22*(3), 429-435.

Index acronym	Index name	Sentinel bands	Formula	Geometric resolution (m)	Suitable (Yes or No)	Reference
NDWI/LSWI	Normalized Multiband Drought Index/Land surface water Index	B8, B11	$\frac{B8 - B11}{B8 + B11}$	10 (B8) 20 (B11)	N	Gao, 1996[21]
SAVI	Soil Adjusted Vegetation Index	B4, B8	$\frac{B8 - B4}{B8 + B4 + L} \cdot (1 + L)$	10	Y	Huete, 1988[22]
NMDI	Normalized Multiband Drought Index	B8a, B11, B12	$\frac{B8a - (B11 - B12)}{B8a + (B11 - B12)}$	20	Y	Wang and Qu, 2007[23]

2.3 Agricultural drought monitoring

The table 2 lists the main indexes used in scientific literature for quantifying the vegetation water content starting from in situ detected data such as meteorological and soil profile data.

Table 2. Agricultural drought monitoring indicators.

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[21] Gao, B. C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote sensing of environment*, *58*(3), 257-266.

[22] Huete, A.R., 1988: A Soil-adjusted Vegetation Index (SAVI). Remote Sensing of Environment, 25(3):295–309

[23] Wang, L., & Qu, J. J. (2007). NMDI: A normalized multi-band drought index for monitoring soil and vegetation moisture with satellite remote sensing. *Geophysical Research Letters*, *34*(20).

Index acronym	**Index name**	**Required inputs**	**Reference**
CMI	Crop Moisture Index	Weekly precipitation, weekly mean temperature, previous week's CMI value.	Palmer, 1968[24]
CSDI	Crop specific drought index	Daily maximum temperature, daily minimum temperature, precipitation, dew point temperature, wind speed, global solar radiation, characteristics of the soil profile, yield and phenology data	Meyer et al., 1993[25]
CWSI	Crop Water Stress Index	Actual evapotranspiration, potential evapotranspiration	Idso et al., 1981[26]
SMDI	Soil Moisture Deficit Index	Weekly soil moisture product calculated at four different soil depths	Narasimhan and Srinivasan, 2005[27]
DTx	Agriculture Drought Index	CRITeRIA water balance model	Matera et al., 2007[28]

2.4 Datasets for meteorological and soil water availability monitoring

In addition to the Sentinel-2 data other remote-based proxies and agricultural

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[24] Palmer, W. C. (1968). Keeping track of crop moisture conditions, nationwide: the new crop moisture index.

[25] Meyer, S. J., Hubbard, K. G., & Wilhite, D. A. (1993). A crop-specific drought index for corn: I. Model development and validation. *Agronomy Journal*, *85*(2), 388-395.

[26] Idso, S. B., Jackson, R. D., Pinter Jr, P. J., Reginato, R. J., & Hatfield, J. L. (1981). Normalizing the stress-degree-day parameter for environmental variability. *Agricultural meteorology*, *24*, 45-55.

[27] Narasimhan, B., & Srinivasan, R. (2005). Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring. *Agricultural and forest meteorology*, *133*(1-4), 69-88.

[28] Matera, A., Fontana, G., Marletto, V., Zinoni, F., Botarelli, L., & Tomei, F. (2007). Use of a new agricultural drought index within a regional drought observatory. *Methods and tools for drought analysis and management*, 103-124.

indicators useful to detect drought stress on vegetation in the table 3 are listed the main global meteorological dataset and soil profile data that are commonly used in the calculation of definition of meteorological conditions and soil water availability.

Table 3. Description of meteorological and soil moisture global datasets useful for drought monitoring.

Proxy	**Sensor**	**Temporal coverage**	**Spatial information**	**Timeliness**	**Programme**
Meteorological drought indicators (e.g. SPI, indicators proposed by WMO)	ERA-5	2000 - present	Global, 0.1 x 0.1 degrees	Daily	ECMWF
Soil Moisture	Sentinel-1 C-SAR	Jan 2015 - present	Global, 1km	Daily	EU Copernicus

2.5 Development of drought indicator at PTAs

In the Germ of Life the development of the drought indicator suitable to monitor drought effect on vegetation growth was based on preliminary analysis done for each PTAs:

- Analysis of PTAs characteristics to determine the most suitable indicators
  - Bilateral meetings with PTA leaders
  - Definition of specific interest of each PTA
- Review of datasets, available monitoring systems and infrastructure to be re-used for PTAs
  - Bilateral meetings with PTA leaders
  - Check existing data if available

- Analysis of satellite-derived Sentinel-2 vegetation indices
- \- Site homogeneity
- \- Site management and land use
- \- Existing infrastructures

- \- Specific issues on spatial representation of the site

After collecting all information and performing the preliminary analysis above mentioned, the final selection of the suitable PTAs is done following the workflow reported in Figure 2 and results of the preliminary analysis are reported in Table 3.

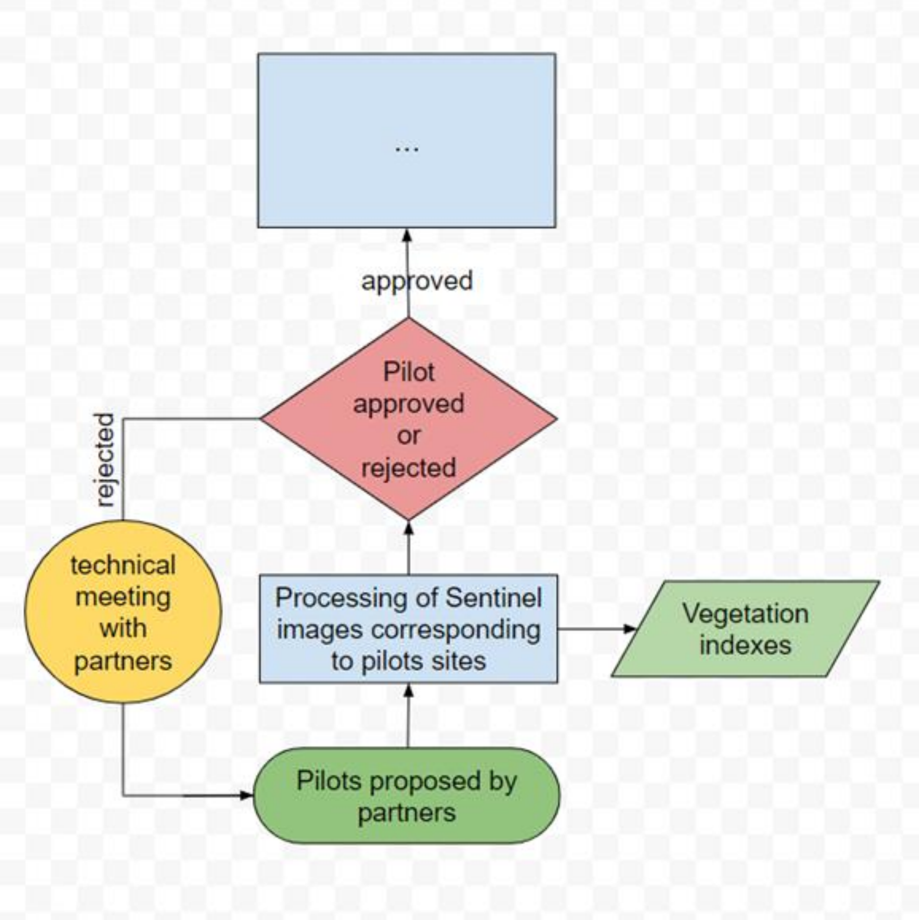

Figure 2 - Description of the workflow used for the selection of the PTAs.

The development of the drought indicator implies intensive use of different satellite data and the first tests conducted in the vicinity of selected PTA stations envisaged the acquisition of satellite Sentinel-2 data throughout the complete growing seasons and covering the surroundings of the PTA.