Integrated Drought Management Programme

Activity 5.4. Drought Risk Management Scheme: a decision support system

Milestone no. 1.1.

1.1. Identification of the national measures for drought susceptibility (drought hazard) assessment

ame of the milestone

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Name of the milestone:	Identification of the national measures for drought susceptibility (drought hazard) assessment
WP:	
Activity:	5.4. Drought Risk Management Scheme: a decision support system
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1. Introduction

According to the European Union Water Framework Directive drought is a natural phenomenon. It is a temporary, negative and severe deviation along a significant time period and over a large region from average precipitation values (a rainfall deficit), which might lead to meteorological, agricultural, hydrological and socioeconomic drought, depending on its severity and duration.

Drought is a widespread and frequent disaster across semiarid areas however this kind of climate anomaly becomes very characteristic in many countries within humid climate zone. Droughts can be divided into meteorological, hydrological, agricultural, socioeconomic etc., and this phenomenon is different from the dry spell that is simply period without precipitation. Drought should be considered relative to some long-term average conditions of the balance between precipitation and evapotranspiration in a particular area (Monacelli, 2009).

Definitions of meteorological drought must be considered as specific to a region since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. Hydrological drought is associated with the effects of periods of precipitation deficiency on surface or subsurface water supply. Also the hydrological drought is often concerned within a watershed or river basin scale. Agricultural drought links various characteristics of meteorological and/ or hydrological drought to agricultural impacts: i.e. precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, and reduced groundwater or reservoir levels. The socioeconomic drought is the phenomenon that starts to affect people, supply and demand of an economic good etc.

Definition of drought as of other hydrometeorological phenomena also includes such measures like spatial scale, severity, duration (length), seasonality etc. Some of these measures are interrelated. For instance, persistent and large scale droughts usually are more severe than smaller scale and short living one. In terms of drought vulnerability the most important things in drought monitoring are: approximate time of the onset of the drought, predictability of its severity and duration as well as identification of the approximate end time of the drought.

Climate change predictions for Europe indicate considerable changes in the water balance throughout Europe, with an increased likelihood for summer droughts especially in the Mediterranean area, and Central and South Eastern Europe countries. However, also other regions in Europe are likely to experience changes in the annual distribution of precipitation as well as in their energy and water balances, resulting in an increased likelihood for periods with reduced water availability as well as in a generally higher variability and in increased probabilities of extreme climatic events.

The report contains an inventory of drought measures (indicators) that are applied to evaluate susceptibility to drought in countries involved in the Project Activity 5.4. A set of measures covers meteorological, agricultural and hydrological drought assessment. The inventory covers the measures for drought assessment that are deployed in the national drought monitoring and early warning systems as well identification of the end-users at national level and their needs for the information on drought.

2. Climatic conditions in the context of drought

Lithuania

Lithuania lies under humid temperate climate conditions and cannot experience such water shortages as it is in Southern Europe. Dry periods and periods of low streamflow could be interpreted as droughts because of the impact on wildlife and the socio-economic sectors. The river basin faces a decrease in yield extent, a reduction in overall agricultural productivity, an increase in wildfires, intensification of tree defoliation, a fall in water level of under the environmental discharge level, etc in 1992, 1999, 2002 and 2006 (Buitkuvienė 1999; Pauliukevičius 2004; Šapolaitė and Skulskis 2008; Ozolincius et al 2009).

Droughts in the southeastern Baltic region are available from the end of April until mid of October. The most harmful droughts are those that start at the beginning of vegetation season and those that follow by intensive heat waves at summer time. In general droughts in Lithuania are highly irregular for various scales: decadal, interannual and intraseasonal. So they differ from their counterparts in Mediterranean and Central European regions.

Due to lack of observational data before Second World War all detailed drought descriptions include information only from the sixties of 20th century. Most intensive droughts were observed in 1963, 1964, 1967, 1969, 1970, 1971, 1975, 1976, 1979, 1982, 1983, 1992, 1994, 2002, 2006 and 2008. So droughts were relatively frequent in sixties, seventies and eighties of 20th century and more occasional in the last two decades. Most persistent (drought length exceeds 5 weeks) and extensive (drought occupies no less than 50 % of territory) droughts observed in 1964, 1969, 1971, 1975, 1983, 1992, 2002 and 2006. Some of them recurred from the previous dry years when the groundwater levels depleted and did not recover during following cold season – 1964, 1971, 1983, 1991 etc. Also, many of the listed droughts were associated with so called continental type of climate – dry and warm summer following by cold winter season (1963, 1969, 1970, 1971, 1979), while other associated with the mild winters (1975, 1976, 1983, 1992, 2002), and the rest – with “normal” or changeable regime winters. The scenario of “continental climate” droughts is as follows: deep soil frost during winter does not allow the water infiltration into deeper layers; almost all melting snow is transformed into spring surface run-off volume and only the negligible part of this volume is transformed into groundwater; dry spell in the late spring followed by such scenario forces the drought onset. The only limiting factor for the drought formation is the low temperatures in the deep soil layers. Contrary, the scenario of droughts associated with the mild winters is different; efficient soil moisture and higher than normal soil temperatures initiate early vegetation season and enhanced evapotranspiration during spring; than precipitation deficiency for the longer period favors the agricultural drought formation.

Main precursors of the droughts are: slowly moving polar anticyclones, quasi-stationary high pressure areas over Central Europe and blocking anticyclones over Russia. All these precursors able to generate dry spells and have almost the same probability during all warm half of the year however polar anticyclones are unable to initiate drought in spring and autumn seasons. Other low frequency circulation modes, i.e. zonal or sub-zonal flow, also could contribute to the drought maintenance (figure 1).

Tracks of polar anticyclones affecting Lithuania in summer extend either from Norwegian Sea to the southern Russia (polar trajectory, relatively frequent) or from Northern Siberia to the Central Europe (ultra-polar trajectory, very rare). Air circulating around the center of such anticyclones is very dry and stable while all polar air mass is comparatively shallow – at most 3-5 km above sea level. Further displacement of such air mass to the south warms up and even more dries up the air; air mass becomes even shallower with multiple inversion layers at different levels. Such dry and stable air is the main actor contributing to the drought formation.

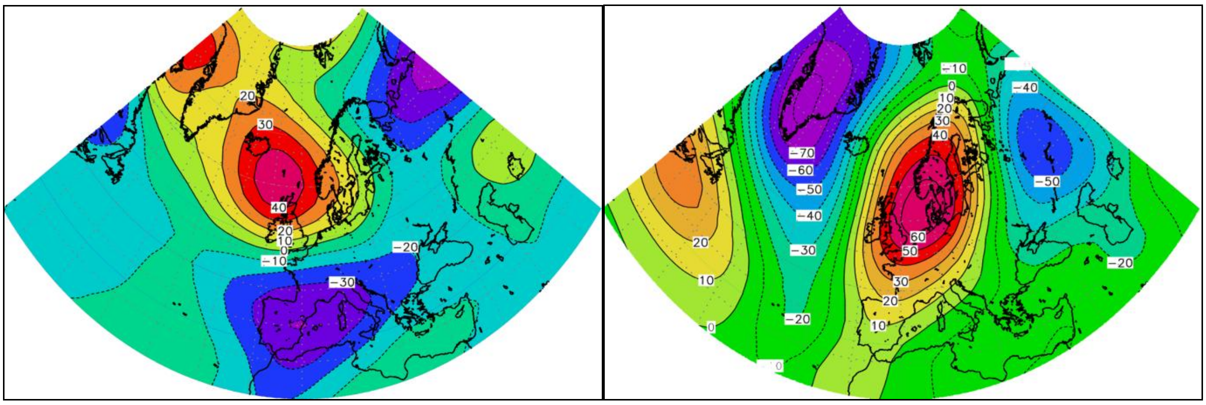


Figure 1: Two clusters of the atmospheric circulation – precursors to the droughts. 500 hpa height anomaly composites generated from 30 days periods prior to the drought onset. Composites include all severe droughts during last 50 years.

Quasi stationary anticyclones over Central Europe usually originate from the northeastern ridges of Azores High. Their track from southwest to the northeast is accompanied by heat wave or warm air advection that enhances drought development in summer or favors drought formation in autumn.

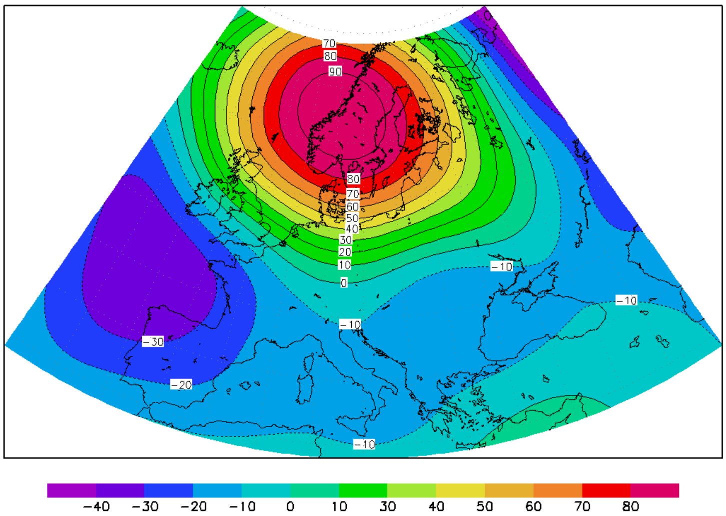


Figure 2: Composition of 500 hPa geoptential height anomalies (gpm) for the 4 most extreme and persistent droughts in Lithuania. Contour interval 10 gpm. Anomalies calculated according 1981 -2010 year reference period.

Blocking over Russia in warm half of the year is not very rare circulation mode. Blocking anticyclone usually occupies Northern part of European Russia, while cut-off-low situates over Ukraine or Northern Caucasus. Such weather pattern is very persistent in space and time, and permanent dry and warm southeasterly winds at the southwestern flank of blocking anticyclone able to maintain drought conditions for longer time.

Atmospheric circulation analysis of the most extensive and severe droughts showed very distinctive dipole pattern with positive anomaly center located over Scandinavia and negative center (negative anomaly belt) – over Western Europe, Mediterranean and Balkans (figure 2). That averaged situation seems to be the main actor in the long-lived drought maintenance in the Southeastern Baltic region.

Poland

Poland is situated in the Great European Plain between the Baltic Sea and the Carpathian mountains. It covers an area of 312 684 km^2 (ca 31 mln ha), from which 60% is a farmland (arable land – 14 046 000 ha, meadows – 2 598 000 ha, pastures – 1 480 000 ha, orchards – 268 000 ha) and 29 % is a woodland. Almost entire territory lies in the Baltic Sea basin with only a small area in the south–eastern corner belonging to the Black Sea basin. Polish main rivers, Oder and Vistula, run across the whole country and collect water from the majority of territory while a number of small rivers discharge directly to the Baltic Sea.

Situated on the Central European Plain, Poland is a lowland country (75% of the area lies below 200 m above sea level), however the landscape is diversified as a result of its geographical location and glaciations processes.

On average the soil quality in Poland is fairly low. Only about 23% of arable soils may be considered as good or very good (classes I - IIIb), while poorest soils (classes V - VI) account for over 30% of the arable land. Soil quality classification in grasslands is even less favourable: soils of classes I – III account for only about 15%, soils of class IV - for 38%, while soils of class V - VI are most common, accounting for as much as 47% of total area of grassland. The share in total sown area of basic cereals is 57.1%, potatoes - 9.6%, oil-bearing - 2.7%, sugar beets - 2.7%, field vegetables - 2.0%, orchards - 1.0%. In the last 12 years (from 1991) the agricultural land area decreased of about 250,000 ha. A substantial area of agricultural land in Poland is equipped with hydraulic structures, mainly for soil drainage.

Poland is located in a transitory temperate climate zone, influenced by a mild oceanic climate from the west and a dry continental climate from the east. The geographical location of Poland facilitates the occurrence of a great diversity of weather and climatic conditions. The major atmospheric systems shaping the weather conditions in Poland are the yearlong Icelandic Low and Azorian High in the west and, to a lesser extent, the seasonal Asian High (Woś, 1999). Climatic conditions in Poland are characterized by a considerable variability in weather during long periods of time (years) as well as short periods (days, weeks, months).

The annual precipitation amounts to 600 mm. It reaches 350 mm on the average during the growing period (April - September). In this period precipitation ranges from 300 mm in the central part to 400 mm in the northern Poland and to 600 mm in the southern Poland (figure 3). Taking into account precipitation tendencies in the period 1891-2000, it can be distinguished, in general, three main regions: northern – with an increasing precipitation tendency, central – with a decreasing precipitation tendency and the southern one – without any significant tendency. The clearest tendencies are visible between individual meteorological stations. The statistically lowest difference of 55 mm should be accepted as the value characteristic for the total area of Poland (Zawora, Ziernicka, 2003).

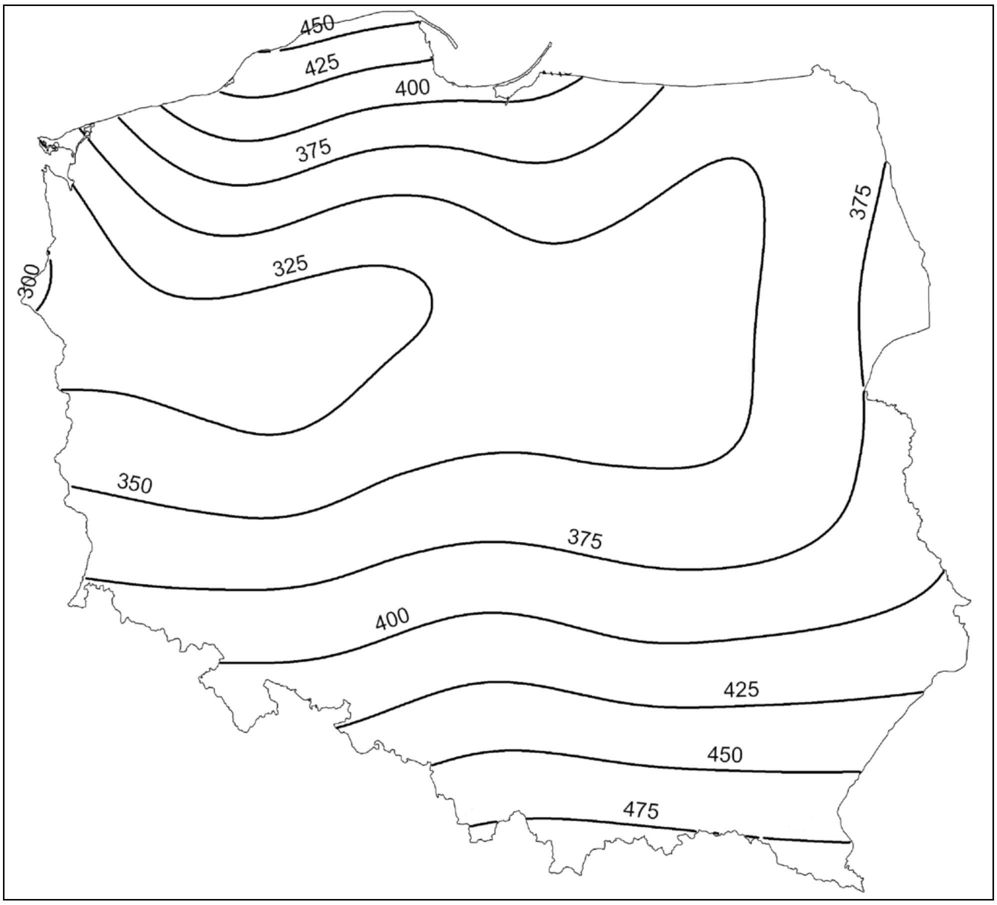


Figure 3: Precipitation sums [mm] in the growing season (Apr-Sep), mean values in 1971-2010 *Source: own study*

The annual mean temperature is 7.5 ^{o}C and in the growing season is 14.3 ^{o}C (figure 4). Averages of temperature in Poland in the 20th century varied from 6 ^{o}C to over 9 ^{o}C, with tendency for 7-year periodicity and revealed an increasing trend, which means the warming up reaching 0.9 ^{o}C per 100 years (Kożuchowski, Żmudzka, 2003). The mean temperature amounts from -2.5 ^{o}C in January to 18 ^{o}C in July. The daily maximum temperature often rises to above 30 ^{o}C in summer.

According to Kejna et al. (2009) the spatial distribution of the mean annual value of daily minimum air temperature (T_{min}) is meridional, with high values in the west and on the Baltic coast (4–5 ^{o}C), and lowest in the east (2.5 ^{o}C). In the period 1951–2005 a statistically significant increase of T_{min} occurred in north-west Poland, reaching 0.2–0.3 ^{o}C per 10 years. The mean annual value of daily maximum air temperature (T_{max}) is the highest in the western part of Poland (up to 12 ^{o}C) and decreases eastwards and on the coast (to below 10.5 ^{o}C). In most of the country T_{max} grew by 0.26 ^{o}C/10 years between 1951 and 2005, though the changes in south-east Poland were not significant.

The *Climate Atlas of Poland* (Lorenc, 2005), containing a spatial distribution of numerous climate indices, shows certain differences in T_{min} and T_{max}. Kejna et al. (2009) used grid data, whereas Lorenc (2005) drew the maps based on measurements taken at stations. The general pattern of isotherms is similar. The differences reach 0.5–1.5 ^{o}C (the values of T_{min} and T_{max} on the grid maps are lower), and this is partially due to different periods analysed. *The Climate Atlas of Poland* (Lorenc 2005) uses data from 1971–2000, i.e. a very warm period, whereas Keyna et al. (2009) also make use of the much cooler decades of the 1950s and 1960s.

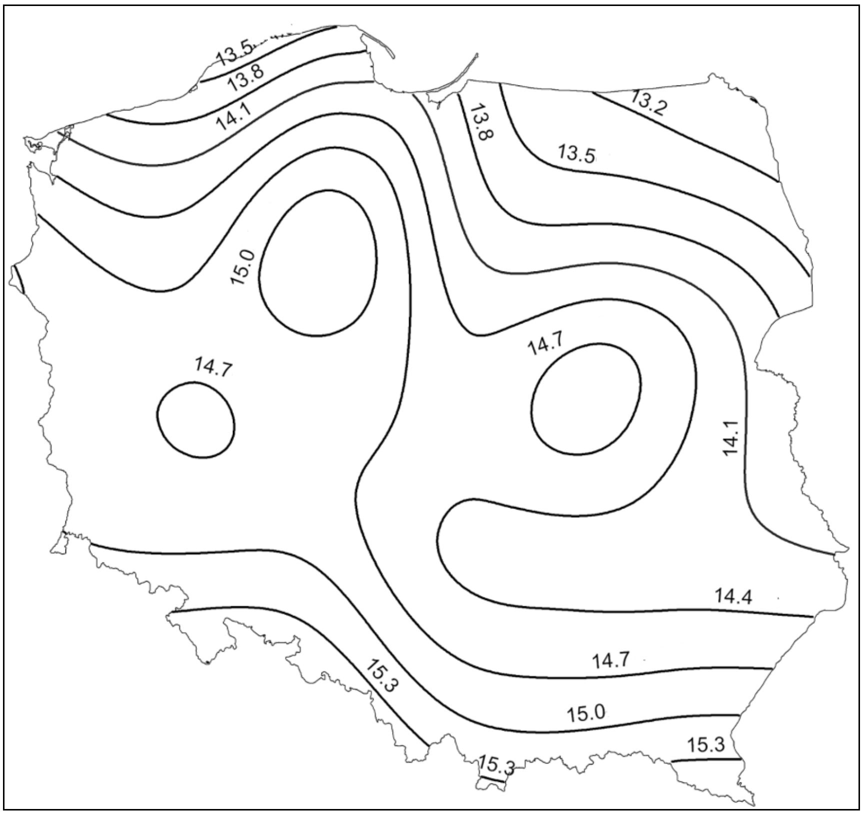


Figure 4: Temperature [oC] in the growing season (Apr-Sep), mean values in 1971-201, *Source: own study*

Due to the shortage of precipitation and the increase trend of temperature, drought frequency has increased, particularly during the last decade. The dry regions of Poland are almost the entire central region, as well as north-western and mid-eastern parts. These are the regions most threatened by droughts. The average annual precipitation sum for this area is about 500 mm. The average sum of precipitation in the growing season is 300 mm, but it varied within the range of 500 mm (in 1985) to 90 mm (in 1989). The most frequent and most severe droughts occur in this area, which sometimes experiences extremely long periods without rain. Besides the average mean daily values of air temperature are high and air humidity - low. It causes the occurrence of the severe and frequent droughts and scarcity of water resources. The periods of rainfall excess also occur, especially in spring and in July. Meteorological conditions of evapotranspiration (generally evaporation) can be characterized by evaporation demand of the atmosphere expressed as reference evapotranspiration. The value of reference evapotranspiration according to the Penman-Montheith method is much higher than precipitation in the growing season. The precipitation deficit reaches 200 mm in an average year (at the 50% probability) and can be equal to 330 mm in a dry year (at the 20% probability). The spatial distribution of climatic water balance (i.e. the difference between precipitation and Penman-Montheith reference evapotranspiration) in the period April-September is shown in figure 5.

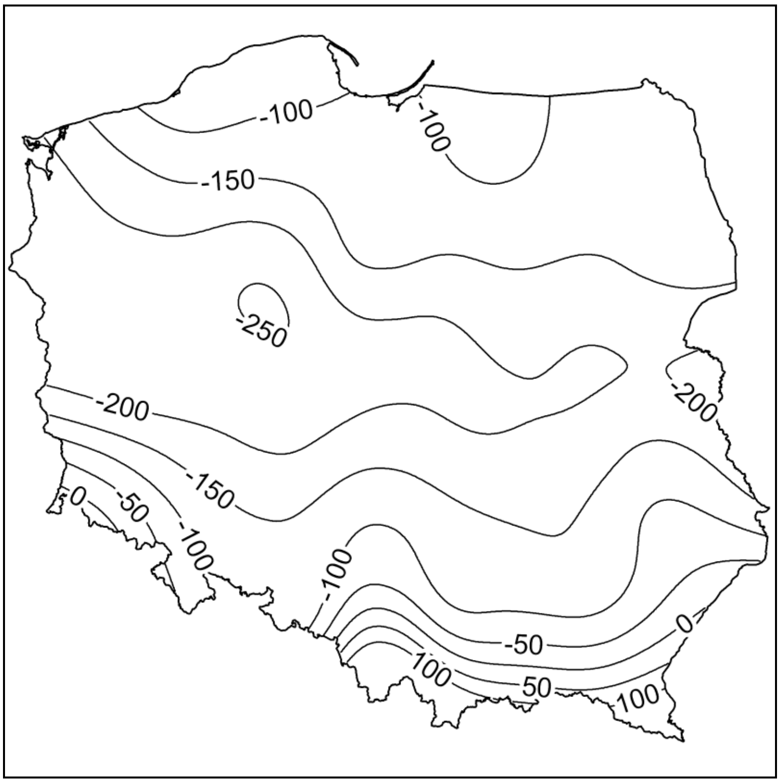


Figure 5: Climatic water balance [mm] in the growing period (Apr-Sep), mean values in 1971-2010, *Source: own study*

It is commonly assumed that droughts appear in Poland once every 4-5 years (Labedzki, 2007). Drought usually begins in western Poland, moves through the central part and eventually reaches eastern side. Droughts have become a severe problem in Polish agriculture. They are the main reason for decline in crop yields.

Drought phenomena in Poland have been mentioned in the chronicles since the fourteenth century and were found to occur many times a century (Kaca, Stąpel, Śniadowski, 1993): in the XIV century - 20 times, in the XV - 25 times, in the XVI - 19 times, in the XVII - 24 times, in the XVIII - 22 times. Since the XIX century, when permanent precipitation records have been started, the number of droughts were estimated as 23 in the XIX century and 20 in the XX century. It is assumed that droughts appear in Poland once every 3 years; sequences of years with precipitation deficit are observed to be followed by sequences of years with excessive or close to average precipitation. In the last 60 years, deep droughts occurred in the years: 1951, 1953, 1959, 1963, 1964, 1969, 1971, 1976, 1982-1984, 1988-1995, 2000-2006 (Bąk, Łabędzki, 2002; Bobiński, Meyer, 1992a, 1992b; Czaplak, 1996; Łabędzki, 2006). Between 1951 and 1990, twenty one atmospheric droughts were distinguished (Farat et al., 1995). They lasted a total of 107 months, which is 22% of the analyzed period. The longest took place in the years: 1982 - 11 months, 1959 - 10 months, 1951-1952 - 9 months, 1983 - 7 months and in 1989 - 7 months. Droughts in the years 1951 - 1995 varied in their intensity, duration and the period of their occurrence, but the most intensive and widespread was in 1992.

Romania

Drought is one of the major natural processes of interest for agriculture. In Romania, from a total surface of 237.500 km^2, 62% are agricultural lands – approx. 14.7 million ha – categorized according to usage in arable land, pastures, vineyards and orchards. The most frequent, the agricultural surfaces in Romania are affected by drought (cca. 7 mil. ha), erosion by water and landslides (cca. 6.4 mil. ha), temporary water excess (cca. 4 mil. ha.), compaction (cca. 2.8 mil. ha) etc. The area subjected to desertification, characterized by an arid, semiarid or subhumid-dry climate is cca 30% of the total surface of Romania, being mostly situated in Dobrudja, Moldavia, the south of the Romanian Plain and the Western Plain (Figure 6). This area is prevailingly used for agriculture (cca. 80% of the total, 60% of which is arable land), sylviculture (cca. 8%) and waters (source: National Strategy for the mitigation of the drought effect, preventing and combating land degradation and desertification in the short, mean and long range, Ministry of Agriculture and Rural Development, 2008).

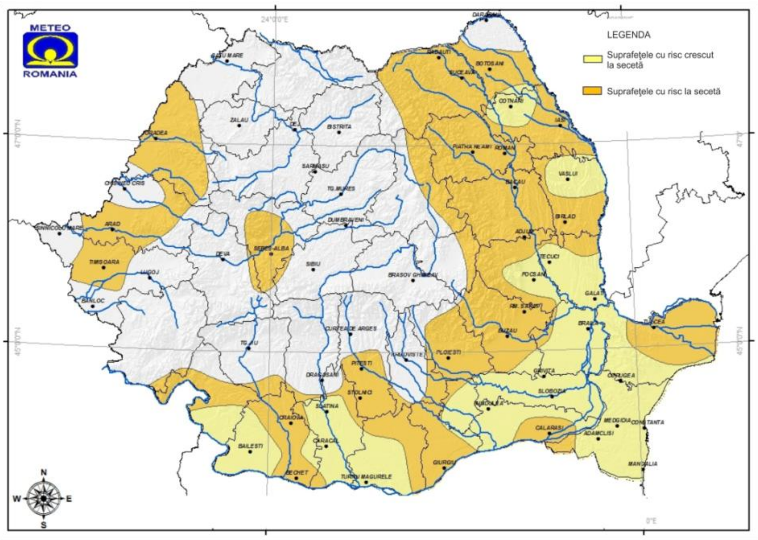


Figure 6: Agricultural surfaces in Romania affected by drought

In Romania, every climate regime shift can be included into a global context, taking also into consideration the geographical characteristics of this region. In Romania, the mean annual air temperature rose by 0,6°C in the last 100 years. The evolution by decades of the mean multiannual air temperature over the 1961-2010 period show that the air temperature rose by 0,4...0,6°C in the 2001-2010 interval in comparison with every decade. The increasing trend is obvious especialy begining with 1971.

An analysis of the evolution of scorching heat intensity from 1961 to 2010 shows an increasing trend especially after 1981. Given the multi-annual means of scorching heat intensity it has become apparent a significantly higher thermal stress over the summer months (June-August), which are critical interval for agricultural crops, an increase from 13 units of scorching heat between 1961 and 1990 to 28 units over 1981-2010. Focusing now on the decade 2001-2010, it was during the summer of 2007 that a scorching heat reached the highest intensity (95 units), in nine years out of decade's ten the records showing figures that top the multi-annual mean of 1961-1990. Here are some data: 2007/95 units, 2003 and 2008/41 units, 2010/38 units, 2002/35 units, 2001/34 units, 2009/26 units, 2006/18 units, 2004/14 units and 2005/11 units. In summer 2007, the most severe scorching heat

(∑Tmax≥32°C) was seen between 14 and 24 of July, when air temperature highs frequently topped 35...40°C across large areas from south, south-east and west Romania. 44.3°C was recorded at Calafat on July 27, 2007, exceeding the highest air temperature on record for July in Romania, namely 43.5°C on July 5, 2000, at Giurgiu. During the same summer, the maximum intensity of scorching heat reached 223 units over a total of 61 days with Tmax≥32°C at Giurgiu, as follows: 46 units/17 scorching heat days in June, 127 units/27 days in July and 50 units/17 scorching heat days in August.

As to precipitation, analyses of the historical data showed a general decreasing trend in annual precipitation amounts, as well as intensifying droughts across south and east of Romania particularly after 1961. Figure 7 shows the zonal precipitation amounts over the excessively droughty agricultural years in Romania, namely 1945-1946, 2006-2007 and 2011-2012, south, south-east and east Romania being the most affected agricultural regions.

Also, based on the historical data, since 1901 until now, Romania has seen in every decade one to four extremely droughty/rainy years, an increasing number of droughts being more and more apparent after 1981 (table 1).

DECADE	XX-TH CENTURY	
	EXTREMELY DROUGHTY YEARS	**EXTREMELY RAINY YEARS**
1901-1910	1907-1908	1910
1911-1920	1917-1918	1911, 1912, 1915, 1919
1921-1930	1923-1924, 1927-1928	1929
1931-1940	1934-1935	1937, 1939, 1940
1941-1950	1945-1946, 1947-1948, 1949-1950	1941, 1944, 1947
1951-1960	1952-1953	1954, 1955, 1957, 1960
1961-1970	1962-1963, 1964-1965	1969, 1970
1971-1980	1973-1974, 1975-1976	1972, 1974, 1975, 1976
1981-1990	1982-1983, 1985-1986, 1987-1988	1981, 1990
1991-2000	1992-1993, 1997-1998, 1999-2000	1991, 1997
	XXI-ST CENTURY	
2001-2010	2000-2001, 2001-2002, 2002-2003, 2006-2007, 2008-2009	2005, 2006, 2010

Table 1: Droughty/rainy years in Romania, 1901-2010

The projections of climate scenarios show an increased duration, frequency and intensity of heat waves, and decreasing precipitation totals, exacerbated water scarcity and droughts mainly during the summer time. In the context of predictable climate scenarios, it has been estimated a broadening of the crop areas affected by annual precipitation deficits of higher intensity – according to the drought classes: excessive drought (less than 350 mm/year) and drought (351-450 mm/year) especially in the South and East part of Romania. In the conditions in which the climatic scenarios estimate a decrease of the precipitation amounts, it is expected that the intensity of pedological drought phenomena increased in the most vulnerable areas already known today. Thus, regions that are dry now are projected to become drier still and could be more affected by desertification in the future. In these areas, the pedological drought will reach the highest intensity values (extreme/Co-300 m^3/ha and severe/600-900 m^3/ha), figure 8.

The climate data recorded over the last decades have therefore shown a progressive warming of the atmosphere as well as a higher frequency of extreme events, rapid alternations of severe heat/drought and heavy precipitation being more and more apparent.

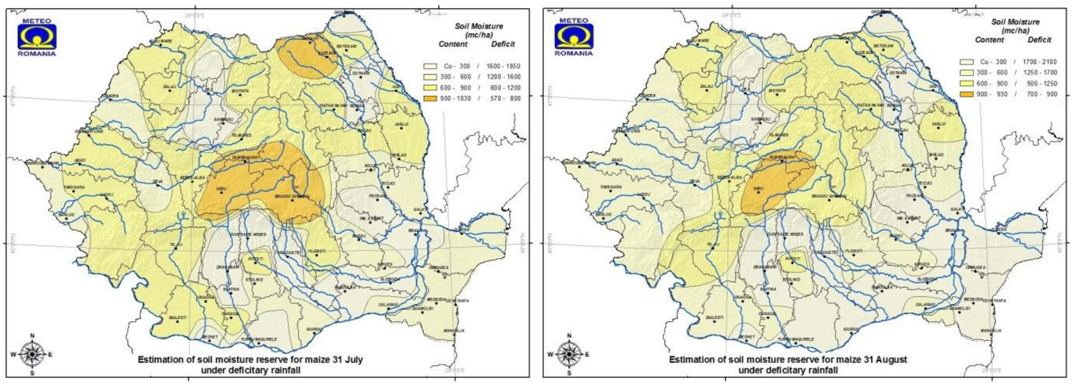


Figure 7: Estimations of the distribution of soil moisture reserve in Romania in the context of predictable climate change

As it can be seen, the climate change effects in Romania have been clearly mirrored by modifications in the temperature and precipitation regimes, mainly since 1961 until now, with significant influences upon plant growth and development. In this context, water scarcity and pedological droughts in south, south-east and east of Romania can cause drastic yields decreases, particularly during the excessively droughty agricultural years (such as 2006-2007 and 2011-2012), and the higher/lower than optimum temperatures are reflected by metabolically reactions in plants, causing thermal stress especially in summer and winter, while every modification in the trend of their lows can easily aggravate frost injury in sensitive plants. For this reason the adaptation of crop species to climate change can be mainly based on the experience obtained from their reactions to extreme climate events by implementing climate change risk adaptation and management plans as well as on the new researches approaching the regional and local effects related to the behavior of genotypes in current and predictable climate change conditions. Basically, every solution and recommendation aimed to support the actions and procedures for climate risk prevention and mitigation in agriculture should include the complete range of known measures (agro-technical, cultural, irrigation etc.) as well as actual interventions to locate and confine every extreme weather phenomenon in order to avoid aggravated consequences.

Taking into account those aspects, it is necessary to implement the drought risk management system and elaborate several methodologies that lay the agricultural planning and sustained development process on a scientific basis. The extreme events can produce losses up to several percent of national GDP. Taking average annual weather losses as a percentage of national GDP, the drought issue is particularly severe in Romania, the losses cause 34% of the total.

All Weather Losses 1980-2011 (million US $, 2011 values)	**Weather impact** (losses as % of GDP)	**% drought in total losses**
8,452	0.26	34.0

Source: Support to the development of EuAdaptStrat to Climate Change: Background report to the IA, Part I. Problem definition and policy context (2013)

It is difficult to evaluate the contribution of climate change to this, since the natural variability of the weather is very high. But, considering the major changes in exposure and vulnerability in recent decades of agriculture and other economic sectors to extreme weather, it is evident that loss trends are heavily influenced by those factors.

3. Drought monitoring and early warning systems

Lithuania

There is no permanent drought monitoring and early warning systems in Lithuania however the responsibility of this function completely depends to Lithuanian Hydrometeorological Service under the Ministry of Environment of the Republic of Lithuania (LHMS).

Not all droughts and/ or dry spells are equally assessed. There is approved Order of the Minister of Agriculture of the Republic of Lithuania concerning specific criteria for identification of the severity of droughts that matches requirements for severe meteorological phenomena. However approved criteria seem to be very important only for agriculture. According this document the main diagnostic tool for identification severity of drought is hydrothermal coefficient (HTC) of Selyaninov. Drought as extreme weather event is recognised only for vegetation season (from April to October). Official drought is identified (officially announced) when HTC < 0.5 and soil moisture reserve (SMR) is less than or equal to 10 mm and 60 mm at the upper soil layer (0- 10 cm) and 1 meter thick layer (0-100 cm) respectively. When such hydrothermal conditions persist at least for one month LHMS announces severe drought level at particular area; when such conditions expand for more than 1/3 of Republic territory – this is named as natural disaster.

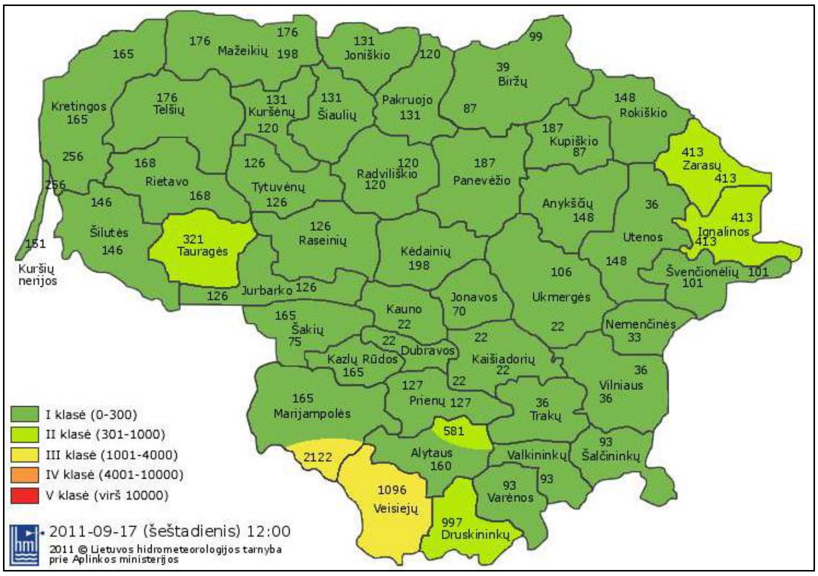


Figure 8: An example of forest fire risk mapping - daily report for 17 September 2011. Numbers inside

Another drought severity problem – risk of forest fires. Therefore a special criterion is applied for forest fire early warning - Forest Fire Risk Index (figure 9). Although this index is very universal additional information is required - natural flammability class factor, which depend on prevailing forest type (also on soil structure, stands bonitet etc). The forest fire risk within administrative regions and/ or within forest enterprise activity areas is assessed and published daily by LHMS from April to October.

Forest enterprise activity areas (or administrative regions) indicate forest fire risk class (colours) which is defined according forest fire risk index.

The hydrological outcome of the drought is the low run-off conditions. The threshold measure for such low run-off is the environmental water flow (EWF) volume defined for the different streams (rivers) at the different cross-sections. All methodology how to assess EWF at particular point of interest is presented in the approved special Order of the Minister of Environment of the Republic of Lithuania in 2005. This order also includes the requirements for the water flow regulations in the dams, sluices and other hydrotechnical facilities.

Poland

There are several drought monitoring systems that have been under operation in Poland since 2005.

Hydrometeorological drought monitoring and prediction system (Institute of Meteorology and Water Management National Research Institute)

The main objective of the system was to create a comprehensive, multipurpose application for drought hazard assessment supporting the operational work of hydrological forecasts offices. Operational drought hazard assessment covers the key aspects for drought phenomena study: meteorological and hydrological drought detection, analysis of drought intensity, duration and extension as well as assessment of susceptibility to drought and drought hazard prediction. The system was launched to run operationally for the selected catchments of the Odra River and the Wisła River basins and crucial resulting products are presented on the website operated by IMWM-NRI: **POSUCH@ (Operational System for Providing Drought Prediction and Characteristics)** (http://posucha.imgw.pl/).

In order to facilitate the work of hydrological forecast office it was beneficial to incorporate the drought indices estimations and analysis routines into the System of Hydrology (SH) which is operated at IMWM-NRI within the framework of SMOK system (the Hydrological and Meteorological Monitoring, Forecasting and Protection System). SH is a software platform aimed at data harmonization and management, data analysis and visualization, effective hydrological modeling, multi-task applications and product generation. The specific requirements for each analytical component of the developed software package for drought hazard assessment were determined by the data availability, functional objectives and requirements of end-users.

Database requirements

The measurements of meteorological and hydrological conditions are available within the monitoring network operated by IMWM-NRI. The data are being archived in Central Historical Database (CBDH) which consists of climatological historical database and hydrological historical database covering the period since 1951. Climatological database contains information from 350 meteorological stations and 1680 precipitation stations (with daily data from 333 stations) while hydrological historical database contains data from 900 gauge stations with records of daily discharges from around 30% of the stations. Operational data are obtained from the network of meteorological and hydrological stations supplied with telemetry facility. Meteorological and water gauge stations provide information on air temperature and humidity, wind speed and direction, precipitation and water level. These data are collected every 10 minutes, transmitted automatically and are operationally available in the SH.

In order to analyze the current meteorological and hydrological conditions in relation to their long-term meteorological and hydrological characteristics, a consistent set of meteorological and hydrological stations having both homogenous long-term daily data as well as telemetry facility had to be selected. The reference period required to estimate drought indices was set to 1966-2005. A compilation of these requirements resulted in selection of 69 gauge stations and 195 precipitation stations for 25 study basins located all over the territory of Poland (figure 10). The selected study basins differ in terms of climatological conditions and river regimes due to geographical location, dominant atmospheric circulation pattern as well as altitude above sea level and surface features.

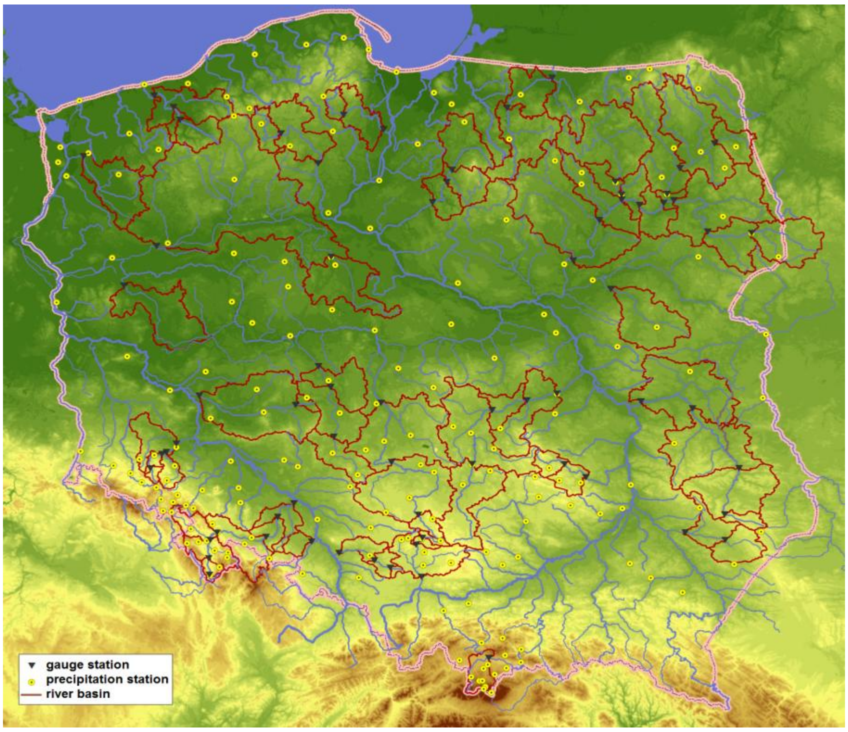


Figure 9: Location of the selected precipitation (a) and water gauge (b) stations and river basins

Functional requirements

A review of the existing and commonly applied methods for drought assessment was performed in order to identify a set of them adjusted to the availability of the required data, facility to be defined as operational, analytical routines and ability to characterize required drought features and indicate drought hazard. The detailed functional requirements embodied (i) detection of various stages of drought including meteorological and hydrological drought identification, (ii) tracing temporal variability of drought up to daily time step, (iii) mapping spatial distribution of a drought, (iv) providing a standardized and dimensionless measure of drought intensity, (v) giving information on susceptibility to drought formation.

Considering data availability, functional objectives and end-users requirements, a scheme of drought hazard assessment includes the following analytical components: (i) estimation of meteorological and hydrological drought indices, (ii) evaluation of susceptibility to drought, (iii) drought hazard assessment, (iv) generation of products. The concept of operational drought hazard assessment scheme is being developed in the form of computational applications, procedures defining input and output data flow, data acquisition and dissemination routines of products.

A set of four drought indices was selected to be used for the system of a drought hazard assessment and prediction:

EDI (Effective Drought Index) – meteorological drought detection, intensity and duration analysis, temporal variability presentations, hazard evaluation;

SPI (Standardized Precipitation Index) – mapping spatial distribution of meteorological drought, infer on regional susceptibility to drought;
FDC (Flow Duration Curve) - hydrological drought detection, intensity and duration analysis, temporal variability presentations, hazard evaluation;
SRI (Standardized Runoff Index) – mapping spatial distribution of hydrological drought, infer on regional susceptibility to drought.
Operational drought hazard assessment was preceded with the analysis of a long term data in order to identify the susceptibility to drought for the particular river basin. Susceptibility to drought was evaluated in terms of two major factors triggering droughts: precipitation (climatological susceptibility) and characteristics of a discharge (streamflow susceptibility).
Climatological susceptibility was evaluated from the long-term time series (1966-2005) of monthly SPI values in selected meteorological stations. The performed analysis included development of Markovian models according to the method presented by Paulo et al.. A non-homogenous Markov chain was formulated to estimate the probabilities of drought/wet states which depended on the considered month. Drought/wet states were defined according to a scale modified and adopted to Polish conditions namely the scale of SPI values by Łabędzki et al. On the basis of 7 defined classes, a drought severity is defined as a moderate drought (-0.50 to -1.49), a severe drought (-1.50 to -1.99) and an extreme drought (< -2.00). For the aim of the assessment of meteorological drought's susceptibility, this scale was compressed to three conditions: wet (SPI>0.50), normal (-0.49<SPI<0.49) and dry (SPI<-0.50). The susceptibility to drought is evaluated from transition matrix with monthly time step pending on the conditions observed in the previous month. The actual proneness to drought of a region is reflected in the probability for dry conditions and varies from month to month and from station to station.
In the same manner, the stream flow's susceptibility was estimated on the basis of the values of SRI. The adopted SRI classes were following SPI classes and hydrological drought severity levels are defined as: a moderate drought (-0.50 to -1.49), a severe drought (-1.50 to -1.99) and an extreme drought (< -2.00). Consequently, three types of conditions were set as a wet (SRI>0.50), normal (-0.49<SRI<0.49) and dry one (SRI<=-0.50).

<u>Drought hazard prediction</u>

Prediction of a drought hazard is performed twofold: a short-term drought hazard prediction and a long-term drought hazard prediction.
A short-term prediction is based on daily time step for the need to issue warnings in case of a detection of a severe drought. Time series of EDI and FDC values calculated from daily precipitation and discharge observations are extrapolated for next 3 days on the basis of precipitation and discharge forecasts provided by a hydrological forecast office.
A long-term drought hazard prediction is done with the use of the results obtained from a susceptibility to drought analysis. After each month, the prediction in the form of values of probability for dry, normal or wet meteorological and hydrological conditions for the next month is prepared pending on the conditions observed in previous month.

<u>Generation of products</u>

Comprehensive analysis of values of selected drought indices coupled with long-term data studies and short-term precipitation and discharge forecasts consists of the system for drought hazard assessment.
Crucial results obtained with the use of the operational drought hazard assessment scheme are presented on the website: http://posucha.imgw.pl/. This web-site has a public access and it is

intended to provide information on drought prediction and its characteristics. It consists of three basic components: reports on historical droughts, current state of moisture conditions and drought characteristics and finally a component of drought hazard prediction (figure 11). The last two components includes interactive links enabling selection of the location for which the required information is to be presented.

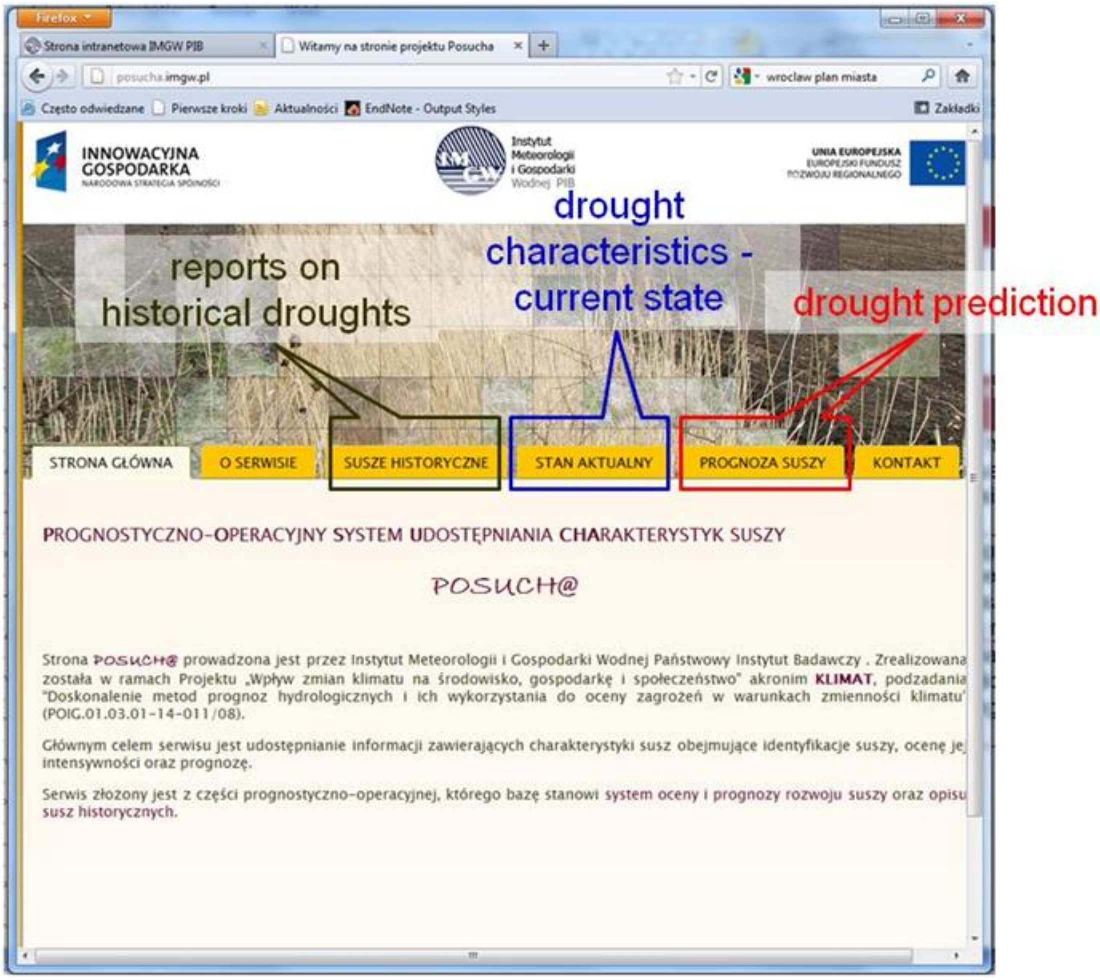


Figure 10: Web-site POSUCHA

Current state of moisture conditions

The area of application of the operational drought hazard assessment scheme is presented in the form of maps showing locations of the selected meteorological and hydrological stations. Each location of a site on the map of meteorological stations is an interactive link which opens the figure presenting temporal variation from last 16 weeks of daily EDI indices. The plots are useful for analyzing the current state of atmospheric moisture, detecting meteorological drought, evaluating its intensity and duration as well as tracing the temporal variability of surplus or deficit precipitation. figure 12 presents the pattern of EDI values developed operationally for the selected location (Bolkow) in the Middle Odra River basin from the beginning of September till the end of December 2011.

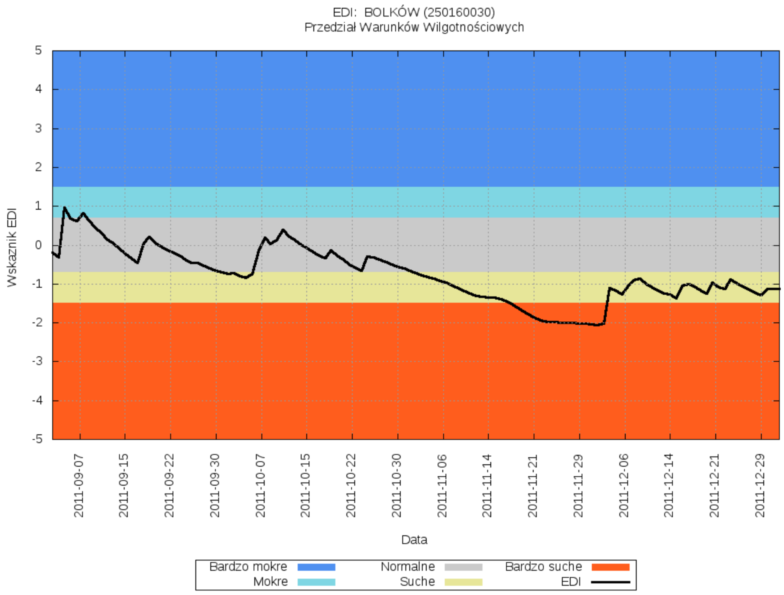


Figure 11: Time series of EDI values from 04/09/2011 to 03/01/2012 for Bolkow meteorological station. Color codes of conditions: dark blue- very wet, blue –wet, grey – normal, yellow – dry, orange – very dry

In the same manner, each location of a site on the map of hydrological stations is an interactive link which opens the Flow Duration Curves (FCD) representing 5 classes of probability of exeedence for streamflow values developed for each calendar day. Superimposing on the FCD plots the actually measured values of streamflow assimilated operationally to the scheme, it is possible to interpret the current hydrological conditions. This is useful for detecting a hydrological drought, assessing its intensity and duration as well as visualizing its temporal variation. Figure 13 presents the pattern of FDC values developed for the selected location (Bystrzyca Klodzka) from the end of September 2010 to the beginning of January 2012.

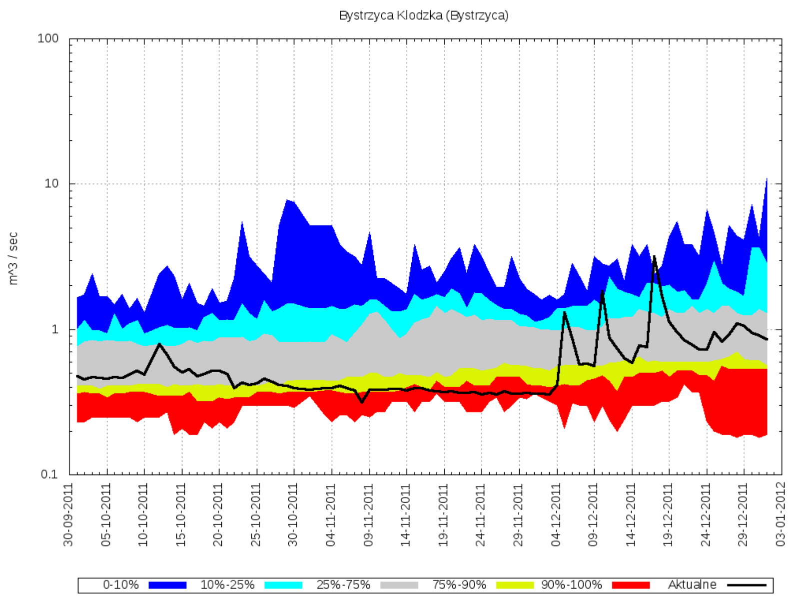


Figure 12: Time series of FDC plots from 30/09/2011 to 03/01/2012 for Bystrzyca Klodzka gauge at Nysa Klodzka river (River Odra basin). Color codes of conditions: dark blue - very wet, blue –wet, grey – normal, yellow – dry, orange – very dry

On the web-site, the spatial distribution of the meteorological drought severity is presented with the use of SPI values developed on monthly basis. The spatial distribution is generated for each month and it is helpful to assess the spatial extension of meteorological drought and its severity. The classes of the meteorological drought divide severity into 3 classes: a moderate dry, very dry or extremely dry. Figure 14 presents the spatial distribution of SPI values for the territory of Poland in October 2011.

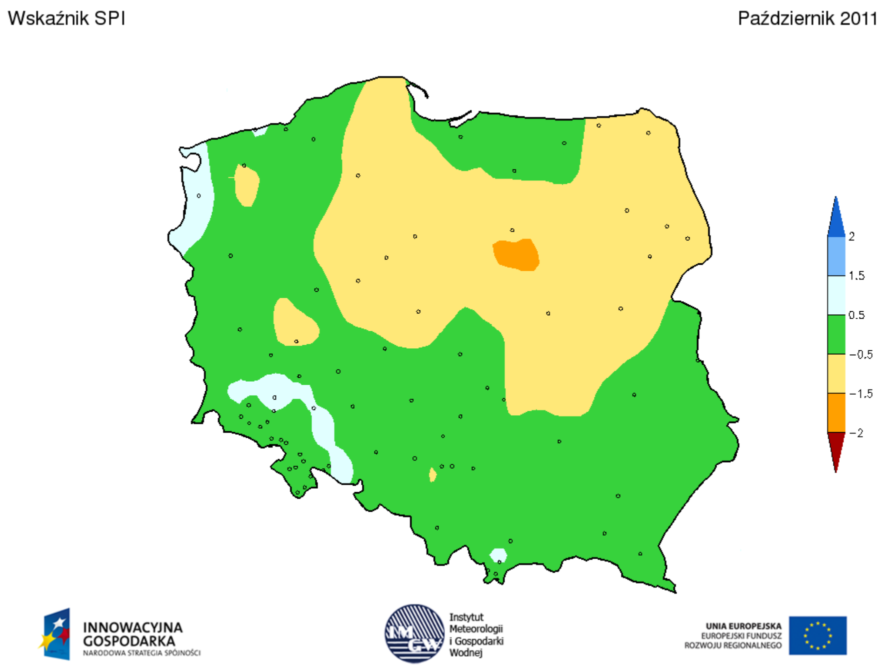


Figure 13: Spatial distribution of SPI classes for October 2011. Color codes of conditions: dark blue- wet, blue –wet, grey – normal, yellow – dry, orange – very dry. Color codes of conditions: dark blue - very wet, blue –wet, light blue – moderate wet, green – normal, yellow – moderate dry, orange – very dry, red – extremely dry

Drought hazard prediction

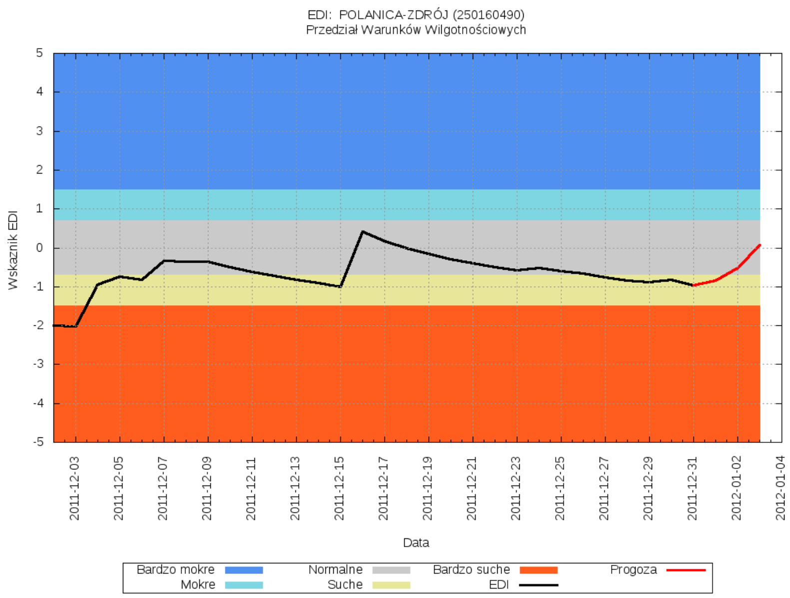
A stochastic analysis of long-term values of SPI and SRI indicators were used to construct the transition probability matrix which is applied for a long-term drought hazard prediction. For each location after the end of a month, the probability of moving to wet, normal or dry conditions in the next month is evaluated. The probability is conditioned by the state of the previous month. In Poland, a drought formation is usually observed in a warm period. In a cold season, other factors like a snow cover has impact on the hydrological cycle. In the case of low flows it may not be fully informative for a drought hazard assessment. Therefore, a long-term drought hazard prediction is restricted to the period from May to October. Figure 15 presents the form of drought hazard communication with the window for the selection of the looked-for station and values of the probabilities to reach dry, normal or wet conditions in next month. This prediction is done at the beginning of each month.

Stacja: BARDO ŚLĄSKIE

Nazwa stacji	Zlewnia	Warunki w poprzednim miesiącu Październik 2011	Prawdopodobieństwo przejścia do warunków wilgotnych Listopad 2011	Prawdopodobieństwo przejścia do warunków normalnych Listopad 2011	Prawdopodobieństwo przejścia do warunków suchych Listopad 2011
BARDO ŚLĄSKIE	Nysa Kłodzka	normalne	26%	53%	21 %

Figure 14: Example of drought hazard prediction for November 2011 done for the Bardo Slaskie location performed at the end of October 2011. Description of columns: 1 – name of the station, 2 – name of the basin, 3 – conditions recognized for the previous month, 4 – probability to move to wet conditions, 5 – probability to move to normal conditions, 6 – probability to move to dry conditions in next month

The short-term forecast of meteorological drought hazard is done with the use of EDI values. Time series of EDI values are extrapolated for the next 3 days basing on the information on predicted daily precipitation totals from a numerical weather prediction model Locally Model COSMO. The forecast is updated on the daily basis (figure 16).



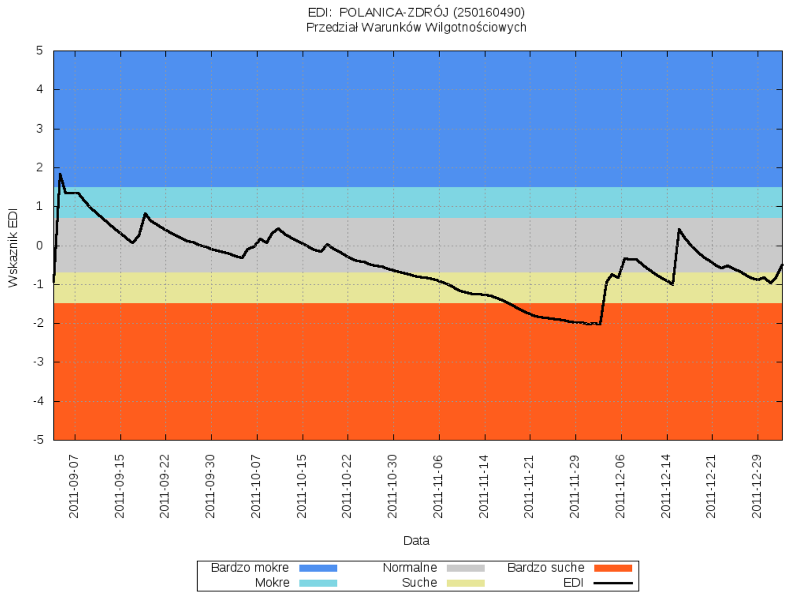


Figure 15: Short-term prediction (30/12/2011-03/12/2011) of meteorological drought for Polanica Zdroj station (upper panel) and the actual pattern done three days later obtained from measured data (lower panel). Color codes of conditions: dark blue - very wet, blue –wet, grey – normal, yellow – dry, orange – very dry

Monitoring and forecasting water deficit and surplus in agriculture (Institute of Technology and Life Sciences)

Since 2012 Institute of Technology and Life Sciences (ITP) has lead a national agro-meteorological monitoring in rural areas. The project is financed by Polish Ministry of Agriculture and Rural Development Programme: *Monitoring, Predicting of Progress and Risk of Water Deficit and Surplus in the Rural Areas, 2011 – 2015*. The system has been developed using the experiences gathered during the operation of the regional drought monitoring system for Kujawy Region in Poland. The region is the driest region in Poland where periods of short or long-term drought spells are very often. The system has been developed and operated by Kujawsko-Pomorski Research Centre of ITP in Bydgoszcz in the years 2008 – 2011. The results of the monitoring of meteorological and agricultural drought were presented on the website of ITP.

The present nationwide system provides current and forecasted evaluation of water deficit and surplus for agriculture in selected, representative agricultural ecosystems and estimates potential reduction of crop yield due to water shortage. Required meteorological data are provided by a network of automatic stations located in 13 regions on Polish territory. Among all operating agrometeorological monitoring systems in Poland, the nation-wide system of monitoring and forecasting water deficit and surplus created by researchers from ITP, has enhanced the module of medium- and long-term forecasting. Weather forecasts, necessary to develop predictions of water deficit or surplus in the next 10 and 20 days, come from the meteorological service of MeteoGroup Poland.

Monitoring of water deficit and surplus and their consequences is carried out on using an indicator method. Precipitation conditions are monitored using standardized precipitation index *SPI*, soil moisture - soil moisture index *SMI*, the deficit of water for crops - agricultural drought index *CDI* and the potential reduction of final yield - yield reduction ratio *YR*. The indices and the methods used to calculate them are described in the chapter “Measures for the assessment of susceptibility to drought (drought hazard)”.

The *SPI* is calculated at the 1-, 2-, 3-, 6-, 12-, 24-, 36- and 48-month time scales and for the 30/31-day periods moved every 10 days by 10 days, on the basis of precipitation data from 35 meteorological stations. Using the forecasted precipitation in the next 10 and 20 days the predictions of 30-day *SPI* are created.

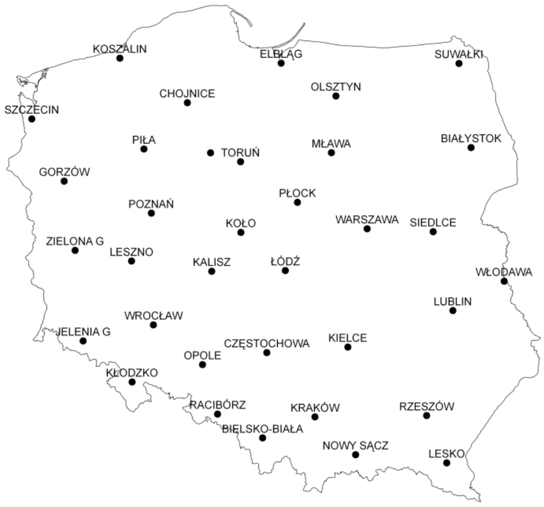


Figure 16: Localization of meteorological stations in Poland for which the SPI is calculated

Soil moisture (soil moisture index *SMI*), deficit of water for crops (agricultural drought index *CDI*) and potential yield reduction *YR* are evaluated every 10/11 days for the previous 10/11 days and forecasted in the next 10 and 20 days. The assessment is done in 13 regions distinguished on the basis of diversity of climate and agro-climatic conditions in Poland. The total area of the selected region under monitoring is 204 000 km^2.

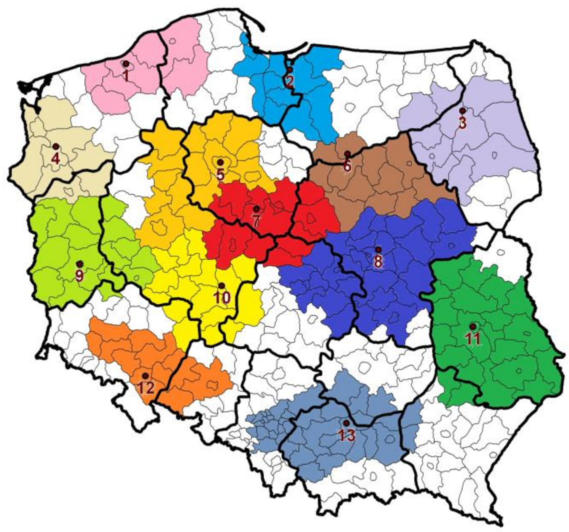


Figure 17: Selected agricultural regions in Poland and meteorological stations

Results of the monitoring and forecasts are presented as tables and maps in the Internet on the website **www.agrometeo.itp.edu.pl.** Examples of monitoring results presented every 10 day on the website are shown below.

Figure 18: Web-site AGROMETO

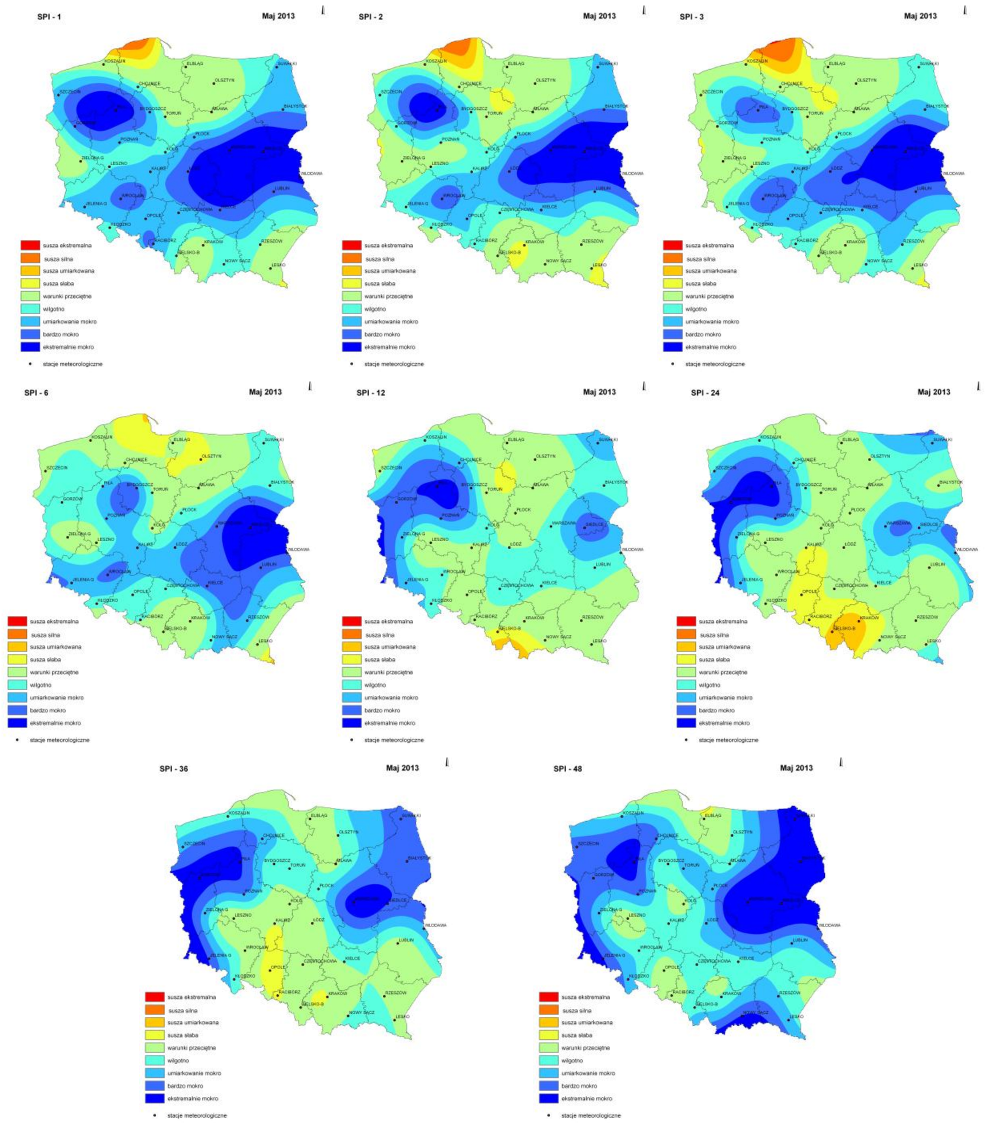


Figure 19: The precipitation conditions in Poland according to SPI in May 2013 at different time scale

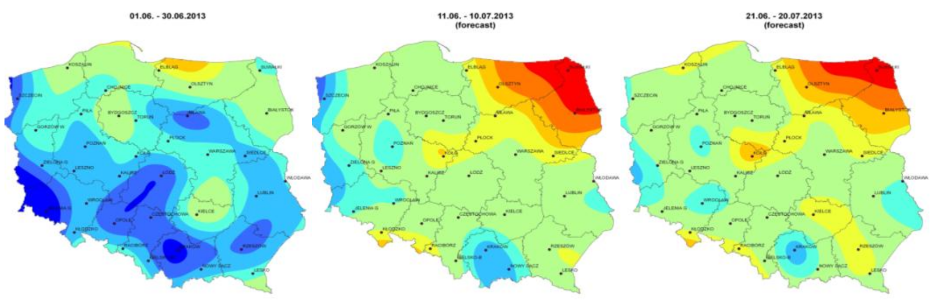


Figure 20: The precipitation conditions in Poland according to SPI-1 in June 2013 and 10- and 20-day forecast

21-30 June 2013 | 10-day forecast | 20-day forecast

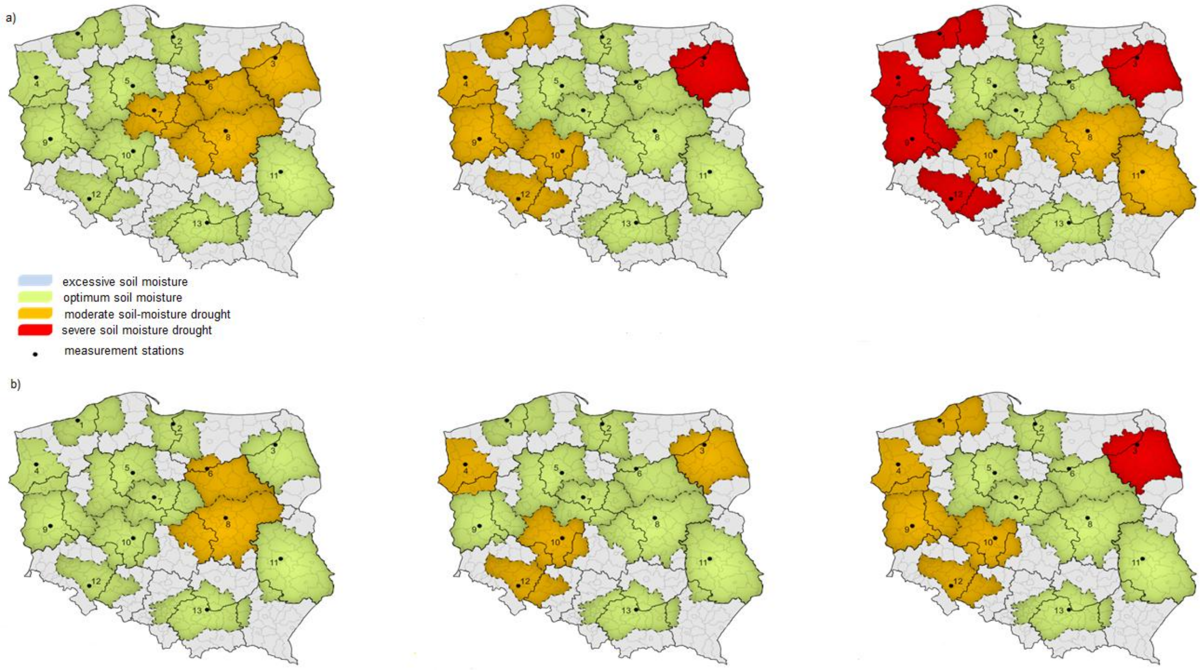
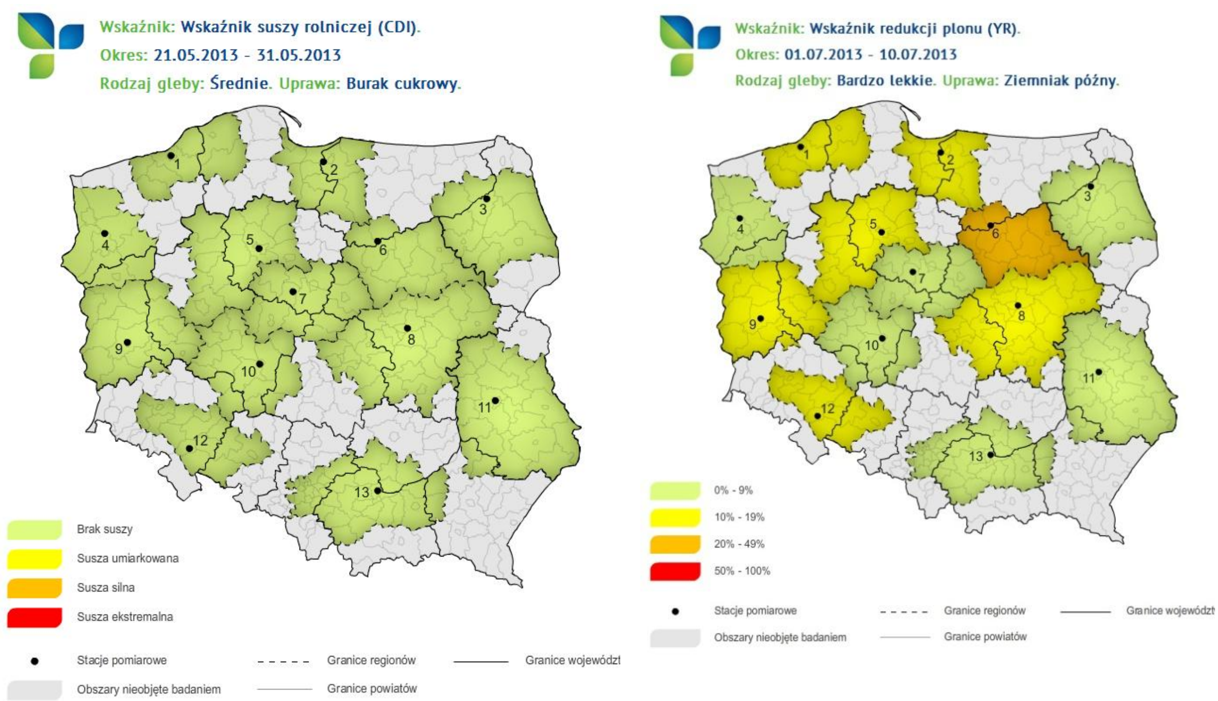


Figure 21: Soil moisture conditions in late potato cultivation based on the SMI index in the period 21-30 June 2013 and 10- and 20-day forecast; a) light soil, b) medium-heavy soil



Agricultural drought for sugar beet on the base of *CDI* on medium-heavy soil | Crop yield reduction *YR* (%) of late potato on very light soil

Figure 22: The examples of drought estimation

Agricultural Drought Monitoring System (Institute of Soil Science and Plant Cultivation)

The Drought Monitoring System for Poland (ADMS) is provided by the Institute of Soil Science and Plant Cultivation - State Research Institute (IUNG-PIB) on behalf of the Ministry of Agriculture and Rural Development. ADMS supports the fulfillment of an insurance policy established by the Polish Government, according to the Act of 7 July 2005 on subsidies to the insurance of agricultural crops and farm animals (Dz. U No. 150, item 1249, 2006, No. 120, item 825).

The Agricultural Drought Monitoring System (ADMS) is designed to identify areas where there are crop losses caused by drought conditions, which are listed in the "Act on subsidies to insurance of agricultural crops and farm animals".

In the Agricultural Drought Monitoring System, meteorological conditions that are causing droughts are evaluated by the climatic water balance (*CWB*). *CWB* expresses the difference between the precipitation and potential evapotranspiration calculated with Penman equation.

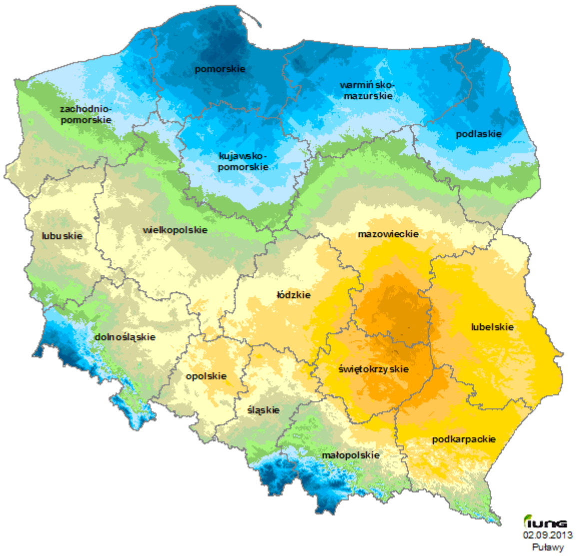
In the system drought is defined by losses in crop yields caused by the occurrence of climatic water balance (*CWB*) in the 6 continuing ten-days period below a defined value for an individual species or groups of cultivated plants as well as the soil category in the period from 1 April to 30 September. In determining the areas affected by the drought, besides the value of climatic water balance, the characteristics of the soil retention are determined by soil category, and are identified based on soil and agricultural maps. In this way, a strong diversification of the susceptibility of Polish soil cover to the effects of a shortage of water is taken into account. Spatial differentiation of soil cover in Poland according to a susceptibility of different categories of soil to the drought comprises the categories: a very light soil (very susceptible), light soil (susceptible), medium-heavy soil (medium susceptible), heavy soil (less susceptible).

The appearance of a specified value of *CWB* causes on average a 20% reduction in the yield, this relates to the value of the long-term average. Critical values of the climatic water balance means the appearance of the drought for plant species or groups of cultivation plants and soil categories and periods of development. The table with critical values of *CWB* and the examples of monitoring results presented on the website http://www.susza.iung.pulawy.pl/en/ are shown below.

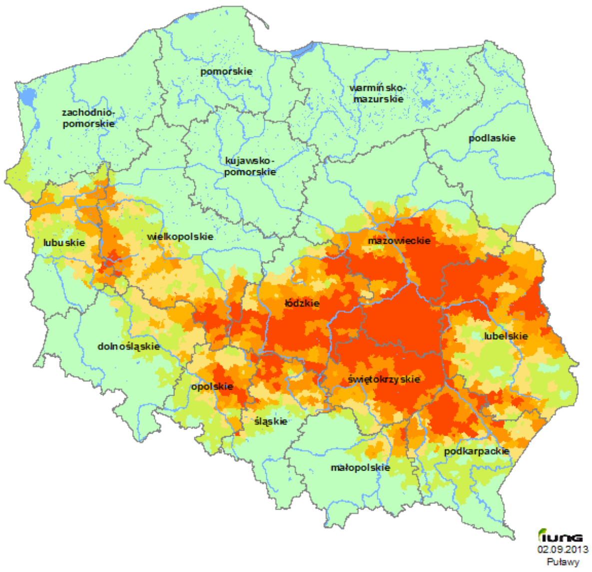
Crops	Period																			
	April-May				May-June				June-July				July-August				August-September			
	Soil category																			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Winter cereals	-150	-170	-210	-240	-180	-200	-250	-280	-230	-260	-300	-320	x	x	x	x	x	x	x	x
Spring cereals	-150	-160	-200	-220	-150	-170	-200	-230	-220	-250	-290	-310	x	x	x	x	x	x	x	x
Maize	x	x	x	x	-	-220	-280	-300	-	-280	-340	-360	-	-200	-240	-260	x	x	x	x
Rape and turnip rape	-	-230	-280	-290	-	-180	-240	-270	x	x	x	x	x	x	x	x	-	-170	-220	-250
Potato	x	x	x	x	-240	-260	-300	-320	-220	-250	-280	-300	-160	-170	-200	-220	x	x	x	x
Sugar beet	-	-250	-290	-310	-	-250	-290	-310	-	-240	-270	-290	-	-210	-240	-260	-	-170	-190	-210
Hops	x	x	x	x	-230	-250	-290	-320	-210	-240	-270	-290	-190	-210	-250	-270	x	x	x	x
Tobacco	x	x	x	x	-190	-200	-230	-250	-200	-220	-240	-250	-200	-210	-240	-250	x	x	x	x
Field grown vegetables	x	x	x	x	-190	-210	-250	-270	-220	-240	-280	-310	-200	-220	-250	-270	x	x	x	x
Fruit shrubs	-140	-160	-200	-220	-180	-200	-240	-270	-200	-230	-270	-300	-160	-170	-200	-220	x	x	x	x
Fruit trees	-170	-190	-230	-240	-210	-240	-290	-300	-220	-250	-290	-320	-210	-240	-290	-320	x	x	x	x
Strawberries	-150	-160	-200	-220	-190	-200	-240	-270	-210	-240	-270	-300	x	x	x	x	x	x	x	x
Leguminous crops	x	x	x	x	-170	-190	-240	-270	-210	-240	-270	-300	-130	-170	-210	-220	x	x	x	x

Table 2: Crop and soils specific climatic water balance levels indicating crop drought conditions

Climatic Water Balance (CWB)
Year: 2013; period: 10 (1.VII - 31.VIII)



Share of soils affected by drought
Year: 2013; period: 10 (1.VII - 31.VIII) - Potato



The drought benchmark not exceeded
< 10 % soils
10 - 30 % soils
30 - 50 % soils
50 - 80 % soils
> 80 % soils

Figure 23: Results of the CWB and percentage of soils affected by drought

Local drought monitoring system for the Upper Vistula River Basin (Regional Board of Water Management in Cracow)

The specific system of drought analysis is realised by Regional Board of Water Management in Cracow for the area of Upper Vistula River Basin District (available http://oki.krakow.rzgw.gov.pl).
The analyse is performed on the base of:
spatial distribution of monthly precipitation deficit or surplus according to classification:

0%-25%	much below the threshold level
25%-75%	below the threshold level
75%-125%	normal conditions
125%-175%	above the threshold level
>175%	much above the threshold level

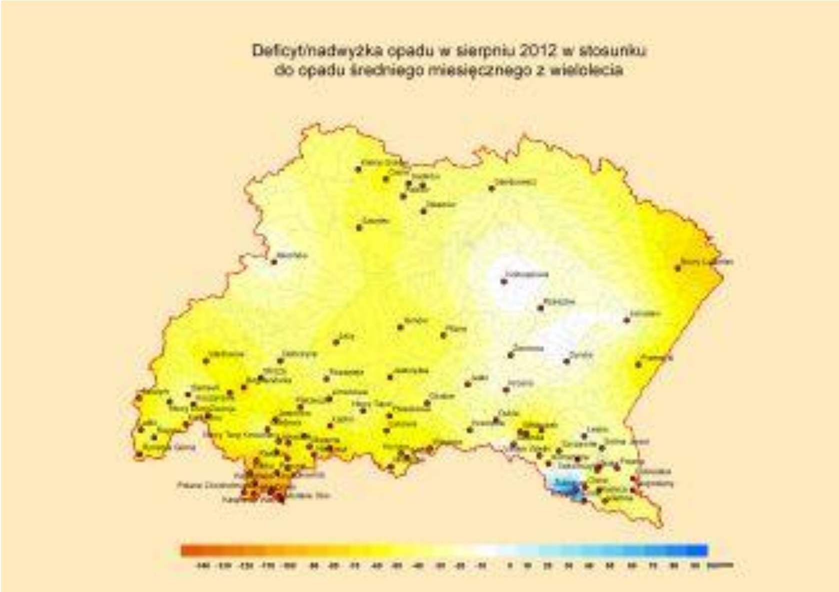


Figure 24: Deficit/surplus of precipitation in August 2012 in relation to average values.

spatial distribution of groundwater drought index:

$$k_n = 1 - \left(\frac{G}{SNG_W}\right)$$

k_n – the index of groundwater drought

G – the present water table

SNG_W – the average low water table for the period of years (average minimum annual water tables for the period of years), according to classification:

$k_n > 0{,}1$	No groundwater drought
$0{,}1 \geq k_n > -0{,}1$	The threat of groundwater drought occurence
$-0{,}1 \geq k_n > -0{,}3$	Shallow groundwater drought
$-0{,}3 \geq k_n$	Deep groundwater drought

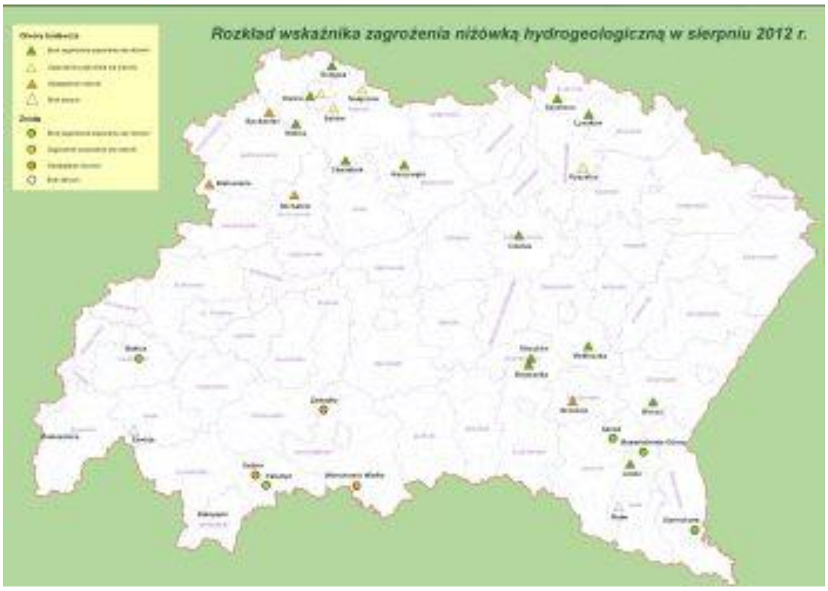


Figure 25: Hazard of groundwater drought in August 2012.

Agrometeorological service for farmers (Institute of Meteorology, Hydrology and Water Management, National Research Institute)

For a number of years, the Institute of Meteorology and Water Management – National Research Institute has been operating agrometeorological service for farmers – at first as the Agrometeorological Review (printed on a monthly basis), and presently in the form of the Internet system of agrometeorological protection of Poland. Internet service for farmers provided by IMGW-PIB was initiated in 2002. Its purpose it to provide an uninterrupted access to current information, agrometeorological forecast indispensable for farming operations. Presently, the area under protection includes the entire country with the exception of mountains. The system functions in the operational mode (continuous) providing agrometeorological forecasts and warnings and warnings concerning threats to crops; and in information-analytical mode presenting meteorological and climatological information and characteristics, commentaries for farmers and data on plant growth conditions.

Agrometeorological service consists of the following components: 1/ Meteorological forecast; 2/ Current conditions of crop cultivation (based on measurements on synoptic stations and satellite images); 3/ Threats of crop agrophags; 4/ Advisory component (suggesting works that may be performed in the forecasted conditions); 5/ Course and change trends of climate and agroclimate indices (in the last three decades). Forecasts and measuring elements are updated on a daily basis, whereas agricultural commentaries are posted according to agrotechnical work schedule. Products are presented as numerical data, pictures/maps/graphs and text.

Data presented on agrometeorological website inform also about risk of extreme phenomena occurrences, including droughts. In tab “Current conditions of crop cultivation” there are information about rainfall and temperature course during last nine 10-days periods and about their deviation from the 30-years average. The deviation from the average is one of drought indices. Additionally, satellite images showing spatial distribution of evapotranspiration (sum for lat 24-hours, last 10-days and last 30 days); down-welling surface short wave flux (for the same periods) and soil moisture for four layers: surface to 7cm, 8-28cm, 29-100cm and 101-289cm (for last 24-hours) are presented. They are important factors for development of meteorological, agricultural and hydrological droughts and the knowledge of their spatial distribution and changes in the last period allows for monitoring of these phenomena.

From the next growing period this component will be expanded and will include the next satellite data concerning plant vegetation status which allow for drought assessment.

Additionally, data included in tab “Course and change trends of climate and agroclimate indices” allow for the comparison of current climatic and agroclimatic indices with their the mean values (30-years averages) indicating for risk of extreme phenomena occurrence unfavorable for plant cultivation, including droughts.

Monitoring meteorological and agricultural drought in Kujawy region (Institute of Technology and Life Sciences)

The system has been performed by the Institute of Technology and Life Sciences since 2008 in Kujawy region located in central Poland (figure 27). The region is most threatened by droughts. The average annual precipitation sum for this area is about 500 mm. The average sum of precipitation in the growing season is 300 mm. The most frequent and most severe droughts occur in this area, which sometimes experiences extremely long periods without rain.

Drought monitoring is carried out using the network of automatic stations for measuring agrometeorological and agrohydrological elements (figure 28). The monitoring helps to estimate spatial variability of drought intensity. Using those information and meteorological forecasts the progress of drought is predicted. Results are presented in Internet.

Figure 26: Location of Kujawy region

Figure 27: Location of measurement stations

Meteorological drought monitoring is carried out using Relative Precipitation Index (*RPI*), Standardized Precipitation Index (*SPI*) and Standardized Climatic Water Balance (*SCWB*) (Figure 29). Agricultural drought monitoring is carried out using Crop Drought Index (*CDI*). The monitoring results are updated on the website on 10 days basis (Figure 30). Monitoring and estimation of drought were the base of decision and activities making in agricultural production, water management in the rural areas, irrigation and nature resources protection in agriculturally used river valleys. Since 2012 the regional system has been included in the national wide system of monitoring water deficit in agriculture.

Period	*P* (mm)	*CWB* (mm)	Drought intensity according to		
			RPI	*SPI*	*SCWB*
01.04-30.04	31	-30			
11.04-10.05	38	-35			
21.04-20.05	47	-38			
01.05-31.05	50	-49			
11.05-10.06	50	-59			
21.05-20.06	52	-61			
01.06-30.06	58	-54			
11.06-10.07	66	-45			
21.06-20.07	76	-36			
01.07-31.07	82	-32			
11.07-10.08	77	-33			
21.07-20.08	67	-36			
01.08-31.08	62	-30			
11.08-10.09	57	-23			
21.08-20.09	53	-15			
01.09-30.09	43	-11			

P - mean precipitation in 1945-2008
CWB – mean climatic water balance in 1945-2008

extreme drought
severe drought
moderate drought
no drought

Figure 28: Meteorological drought intensity in 2009 according to adopted indices.

Period	*TASW*	Meteorological drought intensity according to *SPI*	Root crops		Grassland sites		
			late potatoes	sugar beet	wet	drying	dry
IV – V	120 mm				-	-	
	200 mm						
IV – VI	120 mm				-		
	200 mm						
IV - VII	120 mm						
	200 mm						
IV - VIII	120 mm						
	200 mm						
IV – IX	120 mm						
	200 mm						

TASW – available soil water;
- no significant relationship between meteorological and Agricultural drought

extreme drought
severe drought
moderate drought
no drought

Figure 29: Agricultural drought intensity in 2009 according to adopted indicies.

Experimental automatic Monitoring of Fitophenological Cycle (Institute of Meteorology and Water Management National Research Institute)

In the year 2013 IMGW-PIB together with Poznan Supercomputing and Networking Center started the innovative project “Automatic Monitoring of Fitophenological Cycle”. In the PL-Grid Plus Ecology domain grid, a platform has been established for a continuous, automated, remote fitophenological monitoring of selected plants in the context of the observed weather conditions variability. The project involving the development of a system comprising IT services and infrastructure enabling phytophenological monitoring is the first endeavor of this type attempted in Poland. The developed platform was a pilot project. The site of phenological observations has been located in the central part of the Wielkopolska National Park, 20 km south-west from Poznan, a city located on the River Warta in central-west Poland.

The dynamics of phenological changes in a given area is affected by the total conditions of the environment in the region, however, the most changeable factor is the pattern of weather conditions in a year. In order to monitor weather conditions, therefore, the observation set beside camera includes the automatic weather station DAVIS VANTAGE PRO2. The station measures the following meteorological elements: barometric pressure (1 m above the ground level), wind speed and wind direction (10 m), solar radiation (9m), rainfall (1 m), air temperature and relative humidity (1 and 2 m), soil temperature (at depths 5, 20, 50 cm) and soil moisture (5, 20, 50 and 100 cm). In the distance of 80 m from the station, an additional site of precipitation measurements has been installed, i.e. Hellmann rain gauge. At this site, snow cover is also measured during winter. The analysis of weather conditions of plant growth will also use evapotranspiration values calculated by the meteorological station. Evaporation values are calculated using the Penman-Monteith for a as implemented by California Irrigation Management Information System. Daily precipitation totals (P) and evapotranspiration totals (E) are then used to determine climatic water balance (KBW = P-E).

The measured values of meteorological elements are recorded in the database. Users of the project website can both follow weather conditions through direct measurements and perform own calculations of characteristics of interest. This is possible due to the module calculating daily, decadal, monthly, seasonal values as well as growing period and annual values. Depending on the meteorological element, it is possible to analyze total, mean, maximum and minimum values, variability, number of days with given values, wind rose plot, etc. Presentation of meteorological conditions pattern is available in both graphic form and tables according to the user’s preference.

The database and the tools enabling the analysis of its contents creates possibilities to conduct research projects by a wide spectrum of specialists: phenologists, climatologists, agrometeorologists or foresters. All observed meteorological parameters and calculated indices, especially evapotranspiration, climatic water balance, soil moisture and fitophenological observation can be used particularly for monitoring of meteorological and agricultural drought and its impact for plant vegetation.

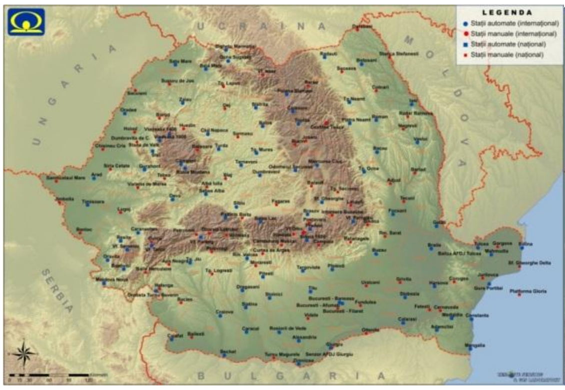
Romania

The Romanian Government is assisted in taking decisions on drought, land degradation and desertification issues by the interdisciplinary National Committee to Combat Drought, Land Degradation and Desertification, which is a consultative body. This Committee is coordinated by The Ministry of Agriculture and Rural Development. The National Meteorological Administration (NMA) is one of the three institutions that collaborate with the Technical Secretariat of the National Committee to Combat Drought.

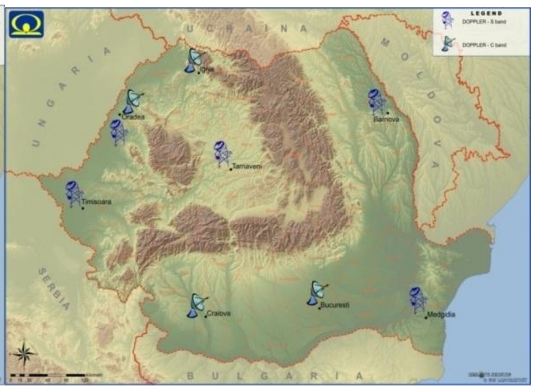
The National Meteorological Administration (http://www.meteoromania.ro/) is the national authority in the meteorological field in Romania, with a continuous service since 1884 and operates under the authority of the Ministry of Environment and Climate Change (MECC). The NMA is responsible for carrying out the weather forecasts and warnings as well as operationally disseminate them to decisional factors and all end-users. The National Meteorological Observation Network within the NMA includes 7 Regional Meteorological Centers (RMC). Romanian agrometeorological observation network of NMA provides weekly in-situ monitoring and information are collected, analyzed and compiled by the Agro-meteorological Service. The agrometeorological of NMA investigates the impact of climate variability and change on crops (including phenology and yield), and on the main components of soil water balance. Currently this service enabled monitoring of drought dynamics and assessing the spatial extent and intensity of drought phenomenon. The monitoring is done daily for agro-meteorological parameters and the changes in the soil moisture content at the plant level, identifies periods and agricultural areas seriously affected by extreme events, elaborates weekly bulletins, and carries out long-term agro-meteorological forecasts upon soil moisture reserves. Modeling and GIS techniques are used to monitor the spatial extent of extreme weather phenomena, including drought, and to assess the most vulnerable areas.

The meteorological profile (2013):

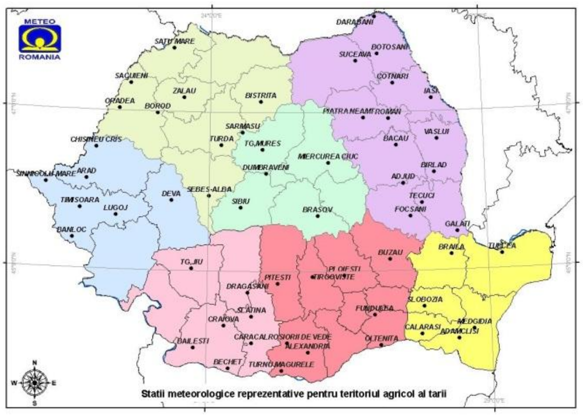
- Synoptic and climatological observations and measurements: 159 stations (a)
- Number of automatic weather stations (MAWS): 126
- Radar network: 8 radars (5 C-band and 3 S-band Doppler radars) (b)
- Agrometeorological observations and measurements stations: 55 (c)



a)



b)



c)

Figure 30: The monitoring system in Romania

Department of Water, Forests and Pisciculture from the Ministry of Environment and Climate Change (MECC) coordinates at national, regional and local level the necessary procedures for the management of emergencies produced by the hydrological drought, such as management of irrigation systems during the extended drought periods including adjustment of irrigation systems which supply water from the Danube River Basin during conditions of hydrological drought. The "Romanian Waters" National Administration (RWNA) togheter with the National Institute of Hydrology and Water Management (NIHWM) produces river basin plans for restriction and use of the water during critical periods, elaborated for each of the 11 Water Basins Administrations (WBA). These plans are elaborated in conformity with Ministerial Order on the methodology for water restrictions.

The National Climate Change Strategy (2013-2020) approved by the GO 529 in July 2013 addresses two main components: the reduction in the concentration of greenhouse gases (Mitigation) and the adaptation to climate change (Adaptation), which is under approval by Romanian Government. On the Adaptation component were identified 13 sectors vulnerable to climate change: Food, Agriculture and Fisheries, Tourism, Public Health, Construction and Infrastructure, Transportation, Water Resources, Forestry, Energy, Biodiversity, Insurance, Recreation, Education. In this context, the integration of the adaptation in the sectorial strategies will help to have a comprehensive approach and select appropriate measures for the direct and indirect effects of climate change (including drought and floods). According to the provision of the National Strategy on Climate Change - Adaptation Component, the strategy has to be assumed and continuously improved at the local government level, through relevant, specific measures for the geo-political conditions, economical context and local public needs. At the same time, local authorities will develop action plans on climate change.

In order to address the issue of water scarcity and droughts in the EU, in 2007 the European Commission issued a Communication 'Addressing the challenge of water scarcity and droughts in the European Union (EC, 2007h). The communication lists a set of policy options that are implementable as a concerted EU action to increase water efficiency and water savings, and to improve drought preparedness and risk management. Furthermore, as land and water resources are essential for farming, grazing, forestry, wildlife, tourism, urban development, and transport infrastructure it is now widely accepted that future land use and land planning in water scarce areas is a crucial factor for mitigating water stress. Planned adaptation driven by public authorities, addressing the whole sector, and tailored to the diversity of regional and local agriculture will be needed to facilitate a broader range of responses. The second Pillar of the Common Agricultural Policy, which focuses on Rural Development, also includes climate adaptation measures targeted at the agricultural sector.

To address the above mentioned challenges and to ensure that EU's water policy goals are reached, EU initiated in 2010 the Blueprint to Safeguard Europe's Water Resources). The Blueprint to Safeguard Europe's Water Resources will try to do this with the long-term aim to ensure availability of good quality water for sustainable and equitable water use in line with the WFD objective. The time horizon of the Blueprint is 2020 since it is closely related to the EU 2020 Strategy and in particular to the recent Resource Efficiency Roadmap. The Blueprint will be the water milestone on that Roadmap. However, the analysis underpinning the Blueprint will in fact cover a longer time span up to 2050.

4. Measures for the assessment of susceptibility to drought

Drought risk mapping is used to identify local, regional and national measures and method to assess drought hazard and mitigate drought impacts. Thematic drought maps illustrate the most vulnerable areas to drought and water deficit at different spatial and temporal scales. In order to choose the best decision it is needed a more detailed description of current situation regarding the current conditions and forecast of limitative conditions (water deficit and drought) in order to elaborate the disaster management plan in timely manner. In this way the farmer and not only may get benefit by the complex analyses (anomalies of air temperature and rainfall, extreme dates of severe conditions occurrence, duration, etc.) and advisories to mitigate the effects of limitative conditions.

4.1. Drought indicators – meteorological, hydrological, agricultural and others

Drought indicators are the common measures for drought assessment being designed to provide a concise overall picture of phenomena derived from massive amounts of hydro-climatic data and are used for making decisions on water resources management and water allocations for mitigating the negative impacts.
According to the recent studies and investigations, droughts should be defined as a natural but temporary imbalance of water availability, consisting of a persistent lower-than-average precipitation, resulting in diminished water resources availability (Paulo, Pereira 2006; Pereira *et al*. 2002). Generally the definitions state that drought is due to the break down of the rainfall regime. Drought indices are widely used for drought monitoring, assessment and prediction, drought early warning. Drought indices constitute a useful decision-making information for policy-makers in water management. Their practical implementation allows for detection of various stages of drought including meteorological and hydrological drought identification, providing a standardized and dimensionless measure of drought intensity which is comparable for different climatological regions, tracing temporal variability of drought up to daily time step and mapping the spatial distribution of drought.

Lithuania

In the midlatitudes, the existing long-range weather forecasts are of very limited reliability. The ability that does exist is primarily the result of empirical and statistical relationships. In the tropics, contrarily, the empirical relationships have been demonstrated to exist between precipitation and ENSO events etc. Therefore drought prediction at least for periods 1 month and more ahead in many countries within temperate climate zone – task still unresolved. From the other hand it is well known, that forecast reliability strongly depends on diagnostics of forecasted variable or phenomena. The simplest and widely used drought diagnostics are drought indices. A drought index value is typically a single number, far more useful than raw data for decision making. At present exist many different drought indices according their application field (meteorology, agriculture, hydrology etc), index construction methodology (simple arithmetic formula, derived parameters, complex algorithm etc) or data type used (*in situ* measurements, remote sensed data, numerical model data etc). The following are drought indices applied for various tasks in Lithuania.

No.	Denomination	Index construction charcteristic	Advantages	Disadvantages	Application area
1.	***Thornthwaite's moisture index (PET)***	Combination of two of his other climatic indices: it is derived by subtracting his aridity index from his index of humidity. Input data: - precipitation; - temperature.	- easy to use - climatic data - able assess both dry and wet spells	Not always potential evaporation fits to the actual values of evaporation	Has many applications, however only for particular tasks concerning water balance calculations at specific areas
2.	***Palmer drought severity Index (PDSI)***	Index assess soil moisture content Input data: - precipitation; - temperature; - available water content in the soil - local geo-data (soil type, local climate)	- good measure of long-term drought - provides information about wet spells - area comparable - drought intensity measure	- not enough for short-term drought - overestimate the drought length; - computation of the coefficients highly sensitive to base period used standardization process has little statistical or physical justification	Limited usage for the long time drought (wet spell) dynamics because of the reorganisation of the national agroclimatic observation network in 2000 (large inhomogeneities)
3.	***Percent of Normal (PN)***	Based on precipitation climatology Input data: - precipitation.	- one of the simplest measurements of dryness - very effective when used for a single region or a single season	- the mean precipita-tion is often not the same as the median precipitation - non comparable between different areas	Widely used in operational work as well as in academic research in defining wetness or dryness anomalies
4.	***Deciles (PD)***	Arrangement of monthly precipitation data into deciles Input data: - precipitation	- provides an accurate statistical measurement of dryness - good for extreme wet and dry periods	- accurate assessment requires a long climatic data record	Well known in scientific papers and academic research, however negligible usage in operational service
5.	***Standardized Precipitation Index (SPI)***	Based on the probability of precipitation for any time scale Input data: - precipitation	- can be computed for different time scales - can provide early warning of drought and drought severity - accurate but less complex than PDSI - allows comparing drought severity in regions with very different climates	- values computed on preliminary data may change	Advised by EC. Widely used in operational analyses as well as in scientific research however no applications in the national early warning systems (fig. 4)
6.	***Hydrothermal***	Based on the sum of	- easy to use	- no soil data	In use for the

No.	Denomination	Index construction charcteristic	Advantages	Disadvantages	Application area
	coefficient (HTC)	precipitation and the temperature for particular period Input data: - precipitation; - temperature.	- enough accurate - applicable to the droughts or wet spell of different duration	included - not applicable for comparison of two or more different regions	official drought warning Involved in many regional climate diagnostics applications
7.	***Effective Drought index (EDI)***	Based on precipitation amount needed to recover from the accumulated deficit since the beginning of a drought	- can be computed for different time scales - can provide early warning of drought and drought severity - easy to use - enough for identifi-cation of short-term drought	Uncertainties in climates with long periods with solid precipitation	Increase of usage during last 10 years however for research purposes only
8.	***Streamflow Drought Index (SDI)***	Based on calculations of the total monthly discharge starting from the beginning of the hydrological year	- can be computed for different time scales - can provide early warning for low flow conditions - good correlation with SPI	Unable to represent long term dryness dynamics	Comparatively new index, recently applied in various environmental research Currently the index is adapted for Lithuanian conditions
9.	***Persistent dry spell***	Period without precipitation ≥30 days with exception of daily precipitation rate not exceeding 0.5 mm	- very simple - comparable between different sites and areas - easy interpretable	- not always has links with real droughts - contains no information about preconditions as well as about precipitation climatology	In use for the official drought warning Serves as simple drought diagnostic tool in many environmental applications

Table 3: Characteristics of drought (dryness) indices used in Lithuania

Many of listed drought indices are very common in research. Some of them serve as indicators of regional climate change or long-range dryness dynamics in Lithuania. For meteorological drought identification most popular are SPI and EDI calculated for different time scales (figure 32) and for hydrological drought – SDI (table 3).

The remote sensing data was never used in droughts identification in Lithuania. The GIS is used only for simple mapping of drought extent. Maps are based on drought intensity in administrative units.

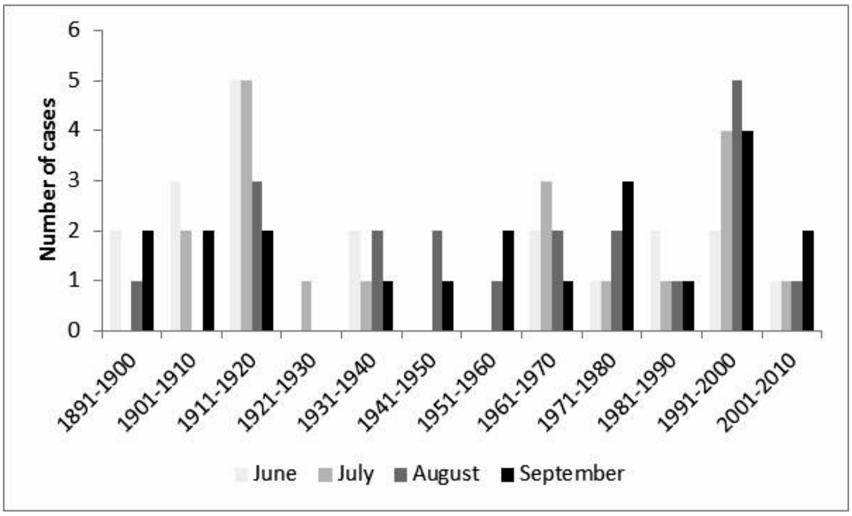


Figure 31: Frequency of drought conditions in Vilnius according SPI3 index values lower than -1 in different decades from 1891 to 2010 (Rimkus et al 2013)

Poland

Measures for meteorological drought assessment

Meteorological drought is most often expressed in terms of rainfall in relation to some average amount and the duration of the dry period and can be defined as a period with the lack of precipitation or with rainfall lower than average, lasting sufficiently to cause hydrological and agricultural hazards. The object of this part of the report is meteorological drought defined in that way. Many indices and methods have been developed and are used to identify and determine the intensity of meteorological (Vogt, Somma 2000). Among them the standardized precipitation index *SPI* has been received the special attention in recent years since it was introduced by McKee *et al*. (1993, 1995). It was applied to the analysis of regional droughts in Portugal (do Ó 2005; Paulo, Pereira 2006; Paulo et al. 2002), in Crete (Tsakiris, Vangelis 2004), in Sicily (Bonaccorso *et al*. 2003), in Hungary (Szalai, Szinell 2000; Szalai *et al*. 2000) and for the whole Europe (Lloyd-Hughes, Saunders 2002). It is widely recommended as a very simple and objective measure of meteorological drought (U.S. National Drought..... 2006; Vermes 1998; Vermes *et al*. 2000).

There several drought indices used to assess the meteorological drought. The report presets the ones that are used in Poland on the national level.

Standardized Precipitation Index (*SPI*) is a standardized deviation of precipitation in a particular period from the median long-term value of this period. *SPI* is calculated for each calendar month at the 1-, 2-, 3-, 6-, 12-, 24-, 36- and 48-month time scales using the long-term series of precipitation measurements at different meteorological stations all over the country. *SPI* values for periods longer than 1 month are calculated for moving totals of precipitation. For each month of the calendar year the new series is created with the elements equal to corresponding precipitation moving sums. For example, the 3-month SPI calculated for June 2013 utilized the precipitation total of April 2013 through June 2013 in order to calculate index. Likewise the 12-month SPI for June 2013 utilized the precipitation total for July 2012 through June 2013. Thus SPI values describe meteorological drought at the end of a month, caused by a deviation of precipitation during the 1-, 2-, 3-, 6-, 12-, 24-, 36- and 48-month time periods in relation to the median value (values with the 50% probability).

SPI is calculated using the normalization method. Precipitation is a random variable with the lower limit and often positive asymmetry and does not conform to the normal distribution. Most often periodical (10-days, monthly or annual) sums of precipitation conform to the gamma distribution and therefore precipitation sequence is normalised with the transformation function *f*(*P*):

$$f(P) = u = \sqrt[3]{x}$$

where: *x* – the element of precipitation sequence.

Values of the *SPI* for a given *P* are calculated from the equation:

$$SPI = \frac{f(P) - \mu}{\delta}$$

where: *SPI* – standardised precipitation index, *f(P)* – transformed sum of precipitation, μ – mean value of the normalised precipitation sequence, δ – standard deviation of the normalised precipitation sequence.

The negative values of *SPI* are compared with the boundaries of different classes of drought. There are many classifications used by different authors. Originally McKee *et al*. (1993) distinguished 4 categories of drought: mild, moderate, severe and extreme, with the threshold value of SPI for the mild drought category equal to *SPI* = 0 (table 4). Agnew (2000) writes that in this classification all negative values of SPI are taken to indicate the occurrence of drought – this means that for 50% of the time drought is occurring. He concluded that it was not rational and suggested alternative, more rational thresholds. According to Vermes (1998) three categories are proposed with the first class starting at *SPI* = -1. The class of mild drought (-1<*SPI*<0) was aggregated with the slightly wet class (0≤*SPI*≤1) into the near normal class. Because of great variability of precipitation in Poland, modification of the *SPI* in the scope of the threshold of the moderate drought class was proposed (Labedzki 2007). It was an attempt of applying this index to detect periods of mild drought, especially in shorter periods, e.g. months. According to this the threshold value of the first class of drought was changed to *SPI* = -0.5 (table 5). Nowadays two classifications are used in Poland, dependently of the system of drought monitoring and the institution which carried it out. (tab. 3). Institute of Meteorology and Water Management (IMGW) uses the 3-category classification according to Labedzki (2007) in the drought monitoring system as shown in the table 2. The 4-catogory classification as shown in the table 6 is used in the system of “Monitoring and forecasting water deficit and surplus in agriculture” (www.agrometeo.itp.edu.pl) conducted by Institute of Technology and Life Sciences (ITP).

SPI	Meteorological drought category according to	
	McKee (1993)	Vermes (1998)
0 to -0.99	mild drought	near normal
-1.00 to -1.49	moderate drought	moderate drought
-1.50 to -1.99	severe drought	severe drought
≤ -2.00	extreme drought	extreme drought

Table 4: Classification of the SPI values and meteorological drought category

SPI	Meteorological drought category
0.50 to -0.49	normal
-0.50 to -1.49	moderate drought
-1.50 to -1.99	severe drought
≤ -2.00	extreme drought

Table 5: Classification of the SPI values and meteorological drought category according to Labedzki (2007)

SPI	Meteorological drought category
0.50 to -0.49	normal
-0.50 to -1.00	mild drought
-1.00 to -1.49	moderate drought
-1.50 to -1.99	severe drought
≤ -2.00	extreme drought

Table 6: Classification of the SPI values and meteorological drought category used by ITP (www.agrometeo.itp.edu.pl)
Source: own study

Climatic Water Balance (*CWB*) is the other indicator used in Poland for meteorological drought monitoring and assessment of its intensity. Meteorological drought is a phenomenon manifested by precipitation deficit in relation to average values. It is the most common approach in defining and identification of this type of drought. However, a broader approach to this phenomenon is needed. A parameter which provides a more complex characteristic of meteorological drought is climatic water balance. It describes moisture conditions determined by atmospheric precipitation as water input and evaporation as water loss. Climatic water balance, therefore, is a comprehensive indicator which includes all basic meteorological factors that are decisive for meteorological drought generation, i.e. precipitation and evaporation. Balance of precipitation and evaporation is also essential in terms of meteorological drought impact on development of successive drought stages, i.e. soil drought, agricultural and hydrological drought. Unlike precipitation based assessment, climatic water balance can weaken or strengthen drought evaluation by the incorporation of the essential additional information about moisture conditions.

Climatic water balance is calculated as a difference between precipitation total and the reference evapotranspiration total in a particular period:

$$CWB = P - ET_o$$

where: *CWB* – climatic water balance in a given period [mm], *P* – precipitation in a given period [mm], ET_o – reference evapotranspiration in a given period [mm] calculated using the Penman-Monteith method.

Similar to *SPI*, Standardized Climatic Water Balance (*SCWB*) is also used. It is a standardized deviation of climatic water balance values in a given period from the median long-term value of this period [Łabędzki, Bąk, 2004; Łabędzki, 2006]. It is calculated using the normalization method which normalizes the historical time series of climatic water balance. Next, the standardized value is calculated using the following formula:

$$SCWB = \frac{CWB_n - \overline{CWB_n}}{d_{CWB_n}}$$

where: *SCWB* – Standardized Climatic Water Balance, CWB_n – normalized time series of climatic water balance [mm], $\overline{CWB_n}$ - mean value of normalized time series of climatic water balance [mm], d_{CWB_n} - standard deviation from the normalized time series of climatic water balance [mm].

The 3-catogory classification as shown in the table 4 has been is used in the regional system of drought monitoring conducted by Institute of Technology and Life Sciences (ITP) in Kujawy region.

SCWB	Meteorological drought category
0.50 to -0.99	normal
-1.00 to -1.49	moderate drought
-1.50 to -1.99	severe drought
≤ -2.00	extreme drought

Table 7: Classification of meteorological drought according standardized climatic water balance (SCWB)

Effective Drought Index (EDI) is a measure of precipitation needed for a return to normal conditions. It is calculated with daily time step and the concept of the EDI is a standardized daily difference between precipitation accumulation over a defined preceding period and the climatological mean for each calendar day. First step is a calculation of weighted precipitation accumulation over a defined preceding period (EP):

$$EP_i = \sum_{n=1}^{i}\left[\left(\sum_{m=1}^{n} P_m\right)\Big/ n\right] \qquad (1)$$

where EP_i represent the valid accumulations of precipitation, P_m is the precipitation m days before and the index i represents the duration of summation (DS) in days. Usually i=365 is used, that is, summation for a year which is the most dominant precipitation cycle worldwide. The 365 can then be a representative value of the total water resources available or stored for a long time. Therefore, EP becomes the valid accumulation of precipitation for 365 days from a particular date. Once the daily EP is computed, a series of indices can be calculated to highlight different characteristics of a station's water resources. The first step is the calculation of Mean Effective Precipitation (MEP). This is the about climatological mean of the EP for each calendar day. The MEP illustrates the climatological mean of stored water quantity.

The second step is to calculate the Deviation of EP (DEP) from the MEP. DEP represents the deviation of EP from MEP (long-term average EP for the calendar date).

$$DEP = EP - MEP \qquad (2)$$

The DEP shows the deficiency or surplus of water resources for a particular date and place. The next step is the calculation of the Standardized value of DEP (EDI):

$$\mathrm{EDI} = \mathrm{DEP} / \mathrm{ST(DEP)} \qquad (3)$$

Where the ST(DEP) denotes the standard deviation of each day's DEP. The EDI expresses the standardized deficit or surplus of stored water quantity. The EDI enables one location's drought severity to be compared to another location's, regardless of climatic differences. When DEP is negative for two consecutive days, "i" becomes 366 (=365 + 2 - 1) and the calculation begins once again. Therefore, the drying effect on the soil from a drought that occurred several years ago is reflected in the EDI.

EDI values are standardized, which allows comparing drought severity at different locations regardless of climatic differences among them. The detailed explanations can be found in Byun and Wilhite (1999). EDI values allows into 5 categories: very wet (1), wet (2), normal (3), dry (4), very dry (5). The EDI varies from −2.5 to 2.5. It has thresholds indicating the range of wetness – from extreme drought conditions to extremely wet conditions. The 'drought range' of the EDI indicates extreme drought conditions at EDI <−2.5, severe drought at −1.5>EDI >2.49 and moderate drought at − 0.7 > EDI > −1.49. Near normal conditions are indicated by − 0.69<EDI<0.69.

Measures for agricultural drought assessment

The negative effect of droughts in Poland is complex and can be observed in various branches of the national economy. It is particularly visible in agriculture. The effect in agriculture is differentiated and depends on the duration and intensity of meteorological drought before and during the agricultural drought. Droughts negatively affect crops, but the effect varies for various plants, soils and geographic regions. A crop decrease is a final effect of agricultural drought and depends largely on the duration and intensity of the drought. Autumn and early spring droughts usually cause a decrease in winter crops while spring droughts - a decrease in spring crops, the first hay cut and pasture efficiency. Summer droughts usually negatively affect potato crops, the second hay cut and the field fodder crops.

Most commonly agricultural drought is defined as soil water deficit of a particular crop at a particular time period or moment, affecting crop yield and leading to significant decline in crop yield. The meteorological drought is expressed solely on the basis of the degree of dryness (usually related to the departure of rainfall from average) and duration of the dry period. Agriculture drought links various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits etc. Any realistic definition of agricultural drought should account for the variable susceptibility of crops at different stages of crop development.

Agriculture drought is frequently described in terms of drought indices, which are convenient and relatively simple to use. Agriculture drought index should be based on crop water balance simulation modeling. The crop water simulation based analysis of drought is necessary for identification of agricultural drought because it account for evapotranspiration, soil water capacity, actual soil moisture, water deficit and others parameters of the soil-plant-atmosphere continuum essential in drought development.

Many indices and methods have been developed and are used to identify and determine the intensity of agricultural drought (Boken *et al*. 2005; Vogt, Somma 2000). Index-based assessment of agricultural drought has been used in Poland within the conducted drought monitoring systems since 2005. The indices and the soil-crop parameters are estimated by using the CROPBALANCE model, that has been developed in Institute of Technology and Life Sciences (Łabedzki 2006; Łabędzki *et al*. 2008). The following indices have been used:

Crop Drought Index *CDI* is used to quantify agricultural drought intensity (Brunini *et al*. 2005; Narasimhan, Srinivasan 2005; Tian, Boken 2005; Łabędzki 2006). It indicates the reduction of evapotranspiration in relation to potential evapotranspiration due to soil water deficit and is calculated as:

$$CDI = 1 - \frac{ET}{ET_p}$$

where:

ET – actual evapotranspiration under soil water deficit (mm)

ET_p – potential evapotranspiration under sufficient soil moisture content (mm).

CDI assumes the values within the range $\langle 0,1 \rangle$:

CDI = 0 when *ET* = ET_p

CDI < 1 when *ET* < ET_p

CDI = 1 when *ET* = 0

The actual evapotranspiration is calculated in ten-day periods, months and the whole growing seasons as a sum of daily values, using the crop and water stress coefficient approach and the methodology described by Allen *et al.* (1998). Evapotranspiration ET^t in a day *t* is calculated as:

$$ET^t = k_s^t k_c^t ET_0^t$$

where:

ET_0^t - reference evapotranspiration in a day *t*, according to the Penman-Monteith equation (Allen *et al.* 1998) ($mm \cdot d^{-1}$)

k_c^t - crop coefficient (dimensionless)

k_s^t - water stress coefficient (dimensionless).

Under excellent soil water conditions k_s^t = 1 and

$$ET^t = ET_p^t = k_c^t ET_0^t$$

where ET_p^t is potential evapotranspiration in a day *t* ($mm \cdot d^{-1}$).

Reference evapotranspiration ET_0^t incorporates the effect of weather conditions on evapotranspiration. Crop coefficient k_c^t predicts evapotranspiration under standard conditions, i.e. under excellent agronomic and soil water conditions.

The effect of soil water stress on crop evapotranspiration is described by reducing the value of the crop coefficient, multiplying it by the water stress coefficient k_s^t. The water stress coefficient is calculated as (Allen *et al.* 1998):

$$k_s^t = \frac{ASW_p^t}{(1-p)TASW_r}$$

where:

ASW_p^t - available soil water in the root zone at the beginning of a day *t* (mm)

$TASW_r$ - total available soil water in the root zone (mm)

p – soil water depletion fraction, fraction of $TASW_r$ that a crop can extract from the root zone without suffering water stress (dimensionless), according to Allen *et al.* (1998).
Total available soil water *TASW* is calculated in the 10-cm layers as the difference between the water content at field capacity (pF = 2.0) and wilting point (pF = 4.2), using the formula:

$$TASW = SWC_{pF2.0} - SWC_{pF4.2}$$

where:

$SWC_{pF2.0}$ and $SWC_{pF4.2}$ - the soil water content (in mm) at pF=2.0 and pF=4.2.

$TASW_r$ is calculated in the root zone, changing in time according to the root depth *d*.

The estimation of water stress coefficient k_s^t requires a daily water balance computation for the root zone. It is calculated as:

$$ASW_p^t = ASW_k^{t-1} = ASW_p^{t-1} + P^{t-1} - ET^{t-1}$$

where:

ASW_k^{t-1}, ASW_p^{t-1} - available soil water in the root zone at the end and at the beginning of a day *t-1* (mm), P^{t-1} - precipitation in a day *t-1* (mm), ET^{t-1} - evapotranspiration in a day *t-1* (mm)
This simple procedure assumes that the infiltration of daily precipitation to the root zone is within the same day as well as the time of deep percolation from the root zone when soil water content exceeds field capacity, is also 1 day.
To categorize and evaluate the severity of drought, *CDI* should be compared with the limits of different classes of drought. There is no unique, commonly acceptable classification of agricultural drought according to *CDI*. The three-category drought classification is used (moderate, severe, and extreme drought), with the threshold value for the moderate drought category equal to *CDI* = 0.1 (tab. 5). It means that 10% reduction of evapotranspiration in relation to potential evapotranspiration is not considered as a drought effect.

Agricultural drought category	CDI
Moderate drought	0.10 ÷ 0.19
Severe drought	0.20 ÷ 0.49
Extreme drought	0.50 ÷ 1.00

Table 8: Classification of agricultural drought according to CDI Source: own study

Soil Moisture Index *SMI* is used to evaluate soil moisture conditions and to quantify soil drought intensity. It is calculated as (Hunt *et al.* 2008):

$$SMI = -5 + 10\frac{ASW_a}{TASW}$$

where:
ASW_a – actual available soil water (mm)
TASW – total available soil water (mm)
ASW_a and *TASW* are calculated by using Eqs. (9) and (10).

This method is based on an assumption that evapotranspiration *ET* becomes limiting below the midpoint between field capacity and wilting point, or at 50% of total available water. No reduction in *ET* occurs until soil water falls below 50% of field capacity. Below 50% of field capacity the reduction in *ET* is linear below 50% of field capacity.
The four-category classification of soil moisture conditions is used and two categories of soil drought is distinguished within it (moderate and severe drought), with the threshold value for soil drought equal to *SMI* = 0.00 (table 9).

Soil drought category	SMI
No drought – excessive moisture	≥ 5.00
No drought – optimal moisture	[0.00; 5.00)
Moderate drought	[-2.00; 0.00)
Severe drought	[-5.00; -2.00]

Table 9: Classification of soil moisture according to SMI index Source: own study

Crop Yield Reduction *YR* is used to quantify the effect of water stress and agricultural drought on crop and is calculated from the equation (Raes 2004, Raes *et al*. 2006):

$$YR = \left(1 - \frac{Y_{re}}{Y_p}\right) = 1 - \prod_{i=1}^{N}\left[\prod_{j=1}^{M}\left(1 - k_y\left(1 - \frac{ET}{ET_p}\right)\right)_j^{\frac{\Delta t_j}{L_i}}\right]_i$$

where:
Y_{re} – actual yield reduced due to water stress,
Y_p – potential yield that can be expected under the given growing conditions for non-limiting water conditions,
k_Y - yield response factor,
ET – actual evapotranspiration under soil water deficit,
ET_p – potential evapotranspiration under non-limiting water conditions,
N – total number of growth stages,
M – number of time steps with length Δt_j (days) during the growth stage i,
Δt_j – the length of the period j in the growth stage i (days),
L_i – the total length of the growth stage i (days),
j – the number of the period in the growth stage i.
The three-category drought classification is used (moderate, severe, and extreme drought), with the threshold value for the moderate drought category equal to *YR* = 0.1 (tab. 7). It means that 10% reduction of crop yield in relation to potential yield is not considered as a drought effect.

Agricultural drought category	YR (%)
No drought – small yield loss	[0; 10)
Moderate drought – moderate yield loss	[10; 20)
Severe drought – heavy yield loss	[20; 50)
Extreme drought – very heavy yield loss	[50; 100]

Table 10: Classification of agricultural drought according to yield reduction YR

Measures for hydrological drought assessment

Flow Duration Curve (**FDC)** [15] represents the empirical cumulative frequency of discharges as a function of the percentage of time which the discharge value is exceeded. FDCs are constructed for each calendar day basing on long-term discharge data. Each FCD is divided into 5 classes which correspond to the humidity conditions.

Standardized Runoff Index (SRI) is based on the methodology developed for the SPI with the application for assessment of the hydrological runoff (Shukla & Wood, 2008). The computation of the SRI involves fitting a probability density function to a given frequency distribution of monthly runoff for a gauge station. Typically, the gamma probability density function is used. This cumulative probability is then transformed to the standardized normal distribution with mean zero and variance one, which results in the value of the SRI. The drought severity categorization follows the same gradation as the SPI. Despite being a relatively new index, the SRI is gaining more and more application (Kingtse 2008).. Temporal scale depends on the characteristics of the basin and the aims of the assessment. It can be assessed for different time periods: month (SR1), quarter (SRI3), year (SRI12), season or interannual periods (SRI18, SRI24, SRI36). SPI values are representing to the stream gauge stations Gauge stations must be therefore representative of the basin to built surface data by interpolation. Pristine conditions is that the runoff data should not be affected by human activities when ever is possible. Data series that are affected by human activities should be restored to natural conditions by discounting the abstraction produced upstream the station.

Romania

Drought indicators assimilate thousands of bits of data on rainfall, snowpack, stream flow, and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, far more useful than raw data for decision making.

Drought indices designed to provide a concise overall picture of droughts are often derived from massive amounts of hydro-climatic data and are used for making decisions on water resources management and water allocations for mitigating the impact of droughts. Ideally, the use of quantitative drought indices for drought management reduces the subjective preferences of decision makers.

Drought indices in table 11 use a big set of standard parameters (precipitation, air temperature, ETP) and characteristics dealing with water balance and soil water availability for the crops.

Crt. No.	Denomination	Computation formula and significance	Advantages	Disadvantages
1.	***Thornthwaite's aridity index (1948)***	IAR-TH (%) is calculated as percentage ratio between the sum of monthly climatic water deficit (precipitations minus ETo-PM, without taking into account the water excess in certain months of that period) and the sum of the monthly values of ETo-PM calculated for the vegetation period (April-October) in the first case, and with the help of ETo-TH in the second case. Iar–TH1 = 100 x (P – ETo-PM) /EToPM Iar–TH2 = 100 x (P – ETo-TH) / EToTH	- IAR-TH (%) measures aridity as a percentage of ETo for the growing season, being thus more suggestive than the former - the use of Iar–TH permits a more "realistic" framing of climate aridity the arid zones in this classification being closer to the climatic and agricultural findings.	If the rainfall exceeded the ETo, the value of this index is considered invalid.
2.	***Palmer Index for evaluating drought severity(PDSI, 1965)***	Index based on evaluating soil moisture on the basis of an algorithm calibrated for homogeneous regions. Necessary data for (local) computation: - precipitation; - temperature; - soil moisture state.	- the first complex index to quantify drought in the US; - its valus quantify drought intensity; - allows momentary and perspective evaluation of the moisture reserve; - allows spatio-temporal visualisation of the historical droughts.	- may overestimate the droughty periods; - less adequate in mountain areas or areas with climatic extremes; - too complex and unspecific; - snowlayer is disregarded; - ETP is computed with the Thorntwaite formula.
3.	***Crop Moisture Index (Palmer, 1968) (CMI)***	Derived from the Palmer Index, reflecting the soil moisture reserve available in the short termto certain crops. Computation elements: - mean weekly air temperature; - weekly precipitation; - CMI computed for the previous week.	- identifies areas with potential drought to agriculture; - weekly updatedl; - allows spatio-temporal visualisation of the values.	- not an indicator for long-term drought monitoring (yields errors); - at the beginning and end of the vegetation season it takes the 0 value, which limits its use beyond the vegetation season.
4.	***Surface Water Supply Index (SWSI) (developed by Shafer and Desman, 1982 to complete the Palmer Index)***	Computed at hydrographic basin level, based on the snow layer depth. Computation elements: - river discharge; - precipitation; - water reserve in the lake accumulated during winter.	- allows the evaluation of the reserve for surface waters at the level of each independent basin; - in winter it mainly uses for computation the snow layer, whereas in summer- the precipitation.	- changing the dataset or the measuring stations changes the algorithm; - the index has a unique value and does not allow inter-basin comparisons.

Crt. No.	Denomination	Computation formula and significance	Advantages	Disadvantages
5.	***De Martonne Aridity Index (1926)***	$A = \frac{P}{T+10}$ (annual) $A_i = \frac{12P_i}{T_i}$ (monthly) $0 < A < 5$ Arid climate $5 < A < 20$ Semiarid climate $20 < A < 30$ Semi-humid climate $30 < A < 55$ Humid climate	- allows delimitating semi-humid or arid climates; - the monthly index differentiates well the drought-affected areas.	- less adequate to the mountain, cold forest areas; - assumes values measured at standard weather stations.
6.	***Lang Index (1920)***	$L = \frac{P}{T}$ P = precipitation (mm) T = temperature (^oC) $0 < L < 20$ Arid climate $20 < L < 40$ Mediterranean climate $40 < L < 70$ Semiarid climate $70 < L < 1000$ Humid climate	- allows delimitating the climates in flat-terrain (agricultural) areas	- does not differentiate the forest mountain areas; - not adequate to delimitate affected areas in a certain drought period; - requires measurements în well-equipped weather stations; - not applicable to monthly values.
7.	***Percent of precipitation from the multiannual mean***	$P\% = \frac{P_i}{P_m} \times 100$ P_i = precipitation in the analysed period $P_m = \frac{\sum_{i=1}^{n} P_i}{N}$, i =year, season, month	- easy to compute; - based on reliable measurements; - serves to comparisons between different regions, periods or stations; - allows evaluating prolonged droughts; - updated monthly.	- the ″″normal” values are a mathematical mean of multiannual values; - he risk to drought occurrence is computed function of the multiannual mean, which includes the previous drought episodes in the droughty regions.
8.	***Standardized Precipitation Index (SPI) developed by McKee (1993),***	$SPI = \frac{\frac{P_i - P_m}{P_m} \times 100}{s\%}$ P_i = current precipitation in period i P_m = mean multiannual precipitation in period i $s\%$ = variation coefficient of mean precipitation in period i SPI = index based on precipitation probability at different time scales	- allows comparing drought severity in regions with very different climates; - it can be computed for different time scales (1…n months); - may highlight occurrence of droughts some months ahead and may highlight the drought severity; - updated monthly; - allows spatio-temporal visualization of values in a large number of points.	- requires computation of the mean precipitation statistical parameters at different time-scales; - values computed on preliminary data may change.
9.	***Moisture reserve -Rf*** (m^3/ha),	**Rf= Ri+a*p*10-ETR*10-D** ***Ri*** = initial moisture reserve ***(***m^3/ha***)***, ***a*** = precipitation infiltration coefficient ***p*** = precipitation recorded **in the**	- allows analysing the in-soil water reserve over various profiles / depths and at crop-specific calendar dates;	- requires in-situ measurements for validating data resulted from the in-soil water balance model.

Crt. No.	Denomination	Computation formula and significance	Advantages	Disadvantages
		preceding interval ***ETR*** = real evapotranspiration of plants ***D*** = drainage	- identifies areas potentially affected by pedological drought phenomenon dynamics (intensity, duration and spatial distribution)	
10.	***Decile frequency Gibbs and Maher (1967) Australia***	Monthly precipitation distribute by deciles, by default considered under normal if not exceeding 20% of the period.	- distribution of the precipitation multiannual frequency is distributed by deciles; - one decile represents the smallest precipitation amount.	- requires data for monthly precipitation over a period longer than 30 years; - requires special statistical programs.

Table 11: Characteristics of drought indices used in Romania

The Standardized Precipitation Index (SPI) developed in 1993, shows precipitation shortfall and excess over a variety of time scales:

SPI ≥ 2.0	Extremely wet
1.5 < SPI ≤ 2	Severely wet
1 < SPI ≤ 1.5	Moderately wet
-1 < SPI ≤ 1	Near normal
-1.5 < SPI ≤ -1	Moderately dry
-2 < SPI ≤ -1.5	Severely dry
SPI ≤ -2	Extremely dry

The SPI is an indicator to reflect drought situations, in comparison to historical records. This indicator can produce different time-related outputs, so meteorological drought evidence and evolution can be shown for the past month(s), season(s) and/or year(s), facilitating the establishment of links to other drought indicators. It can be also used by water supply planners before making a decision

The three-month SPI provides a comparison of the precipitation over a specific 3-month period with the precipitation totals from the same 3-month period for all the years included in the historical record. A 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. A 3-month SPI would capture precipitation trends during the important vegetation phases (reproductive and early grain-filling stages, the growing season etc).

Next figures (figures 33-36) show the Romanian maps highlighting and expanding the rainfall deficit intensity in the droughtiest years produced in the past 10 years, based on SPI indicator.

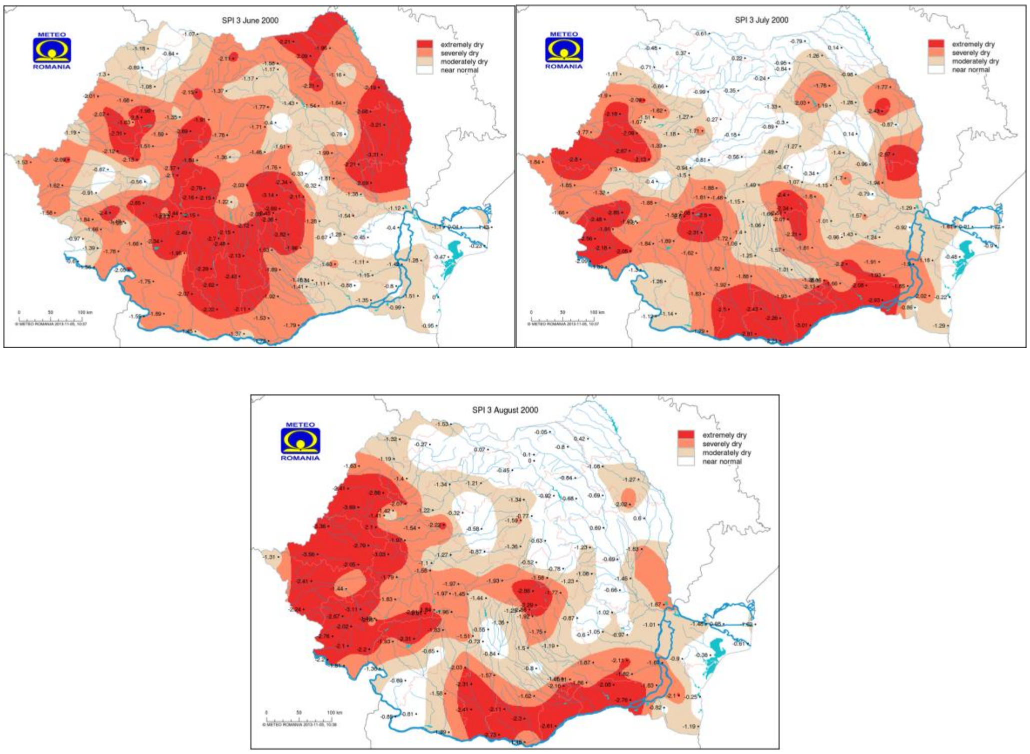


Figure 32: SPI - June – August 2000

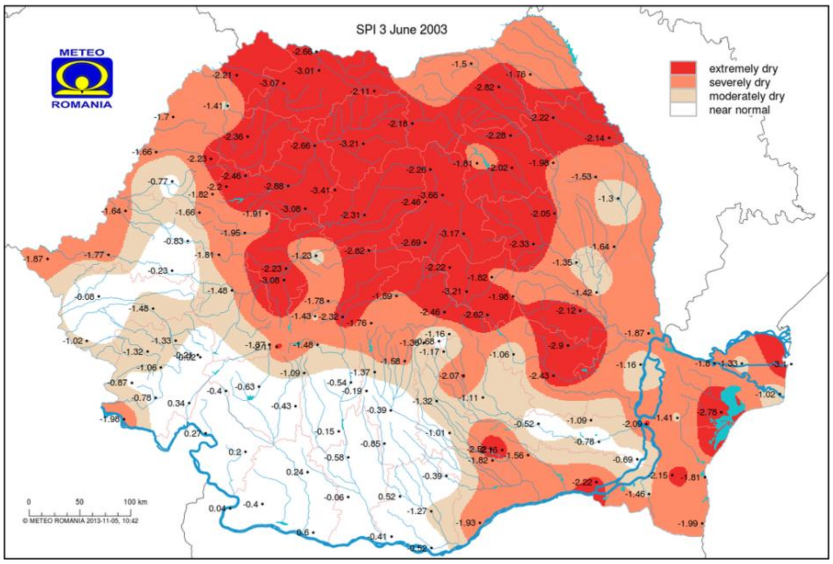


Figure 33: SPI - June 2003

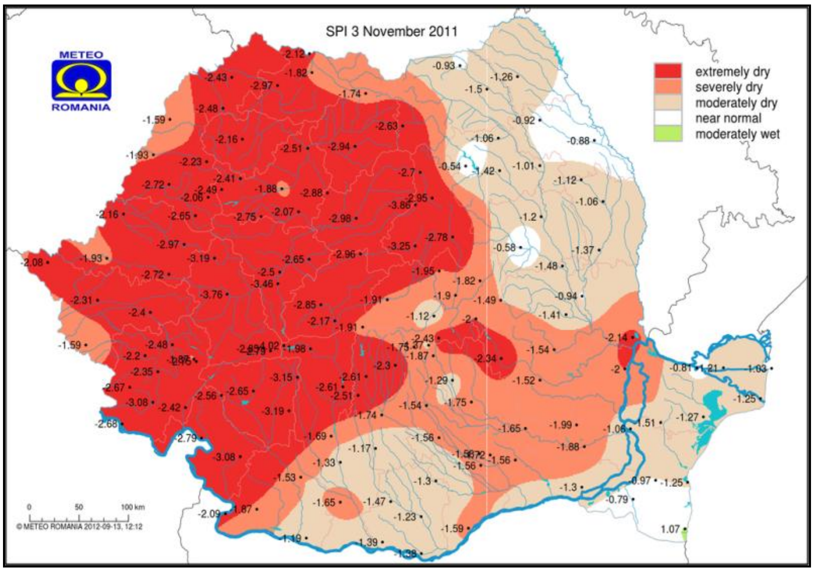


Figure 34: SPI - November 2011

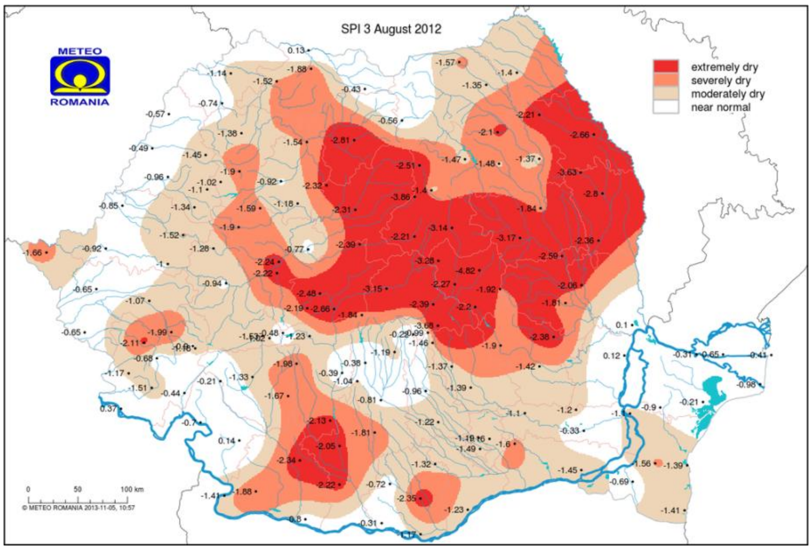


Figure 35: SPI - August 2012

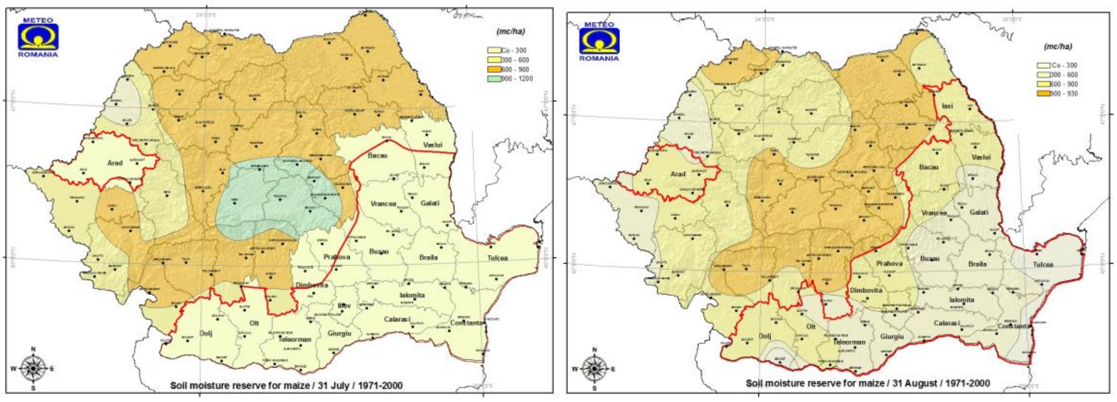
The Soil Moisture Reserve. Agricultural plant available soil water is defined as the water contained in the interval between wilting coefficient and soil water capacity in the field. The maximum amount of plant available water is the water capacity accessible or usable water capacity of soil. The *soil moisture reserve* is one of the most important agrometeorological indicators expressing the water supply degree of the soil function of the water demand of the agricultural plants at specific calendar dates and various depths (0-20 cm, 0-50 cm and 0-100 cm). Classification of the humidity classes is presented in the table 12.

% of AWC	Humidity classes
0 – 20 %	Extreme pedological drought / ED
20 – 35%	Severe pedological drought / SD
35 – 50%	Moderate pedological drought / MD
50 – 70%	Satisfactory supply / SS
70 – 100%	Optimal supply / OS
>100%	Above normal moisture values / EX

Table 12: The humidity classes

Mapping of the soil moisture reserves (m3/ha) for the maize crops shows that most of the country areas are in generally affected by deficit especially in July and August (critical period for maize and sun-flower crops), the most vulnerable areas to extreme and severe pedological drought being in the southern, south-eastern and eastern part of Romania (figure 37). In such conditions, corroborated with high water consumption during July-August interval, soil water reserve is often down to the wilting point in large agricultural areas.

31 July / Maize **31 August / Maize**



	Soil moisture classes
<300 mc/ha	Extreme pedological drought
300 – 600	Severe pedological drought
600 – 900	Moderate pedological drought
900 – 1200	Satisfactory supply

Figure 36: Soil moisture reserve in Romania (1971-2000)

A **heat wave** is a prolonged period of excessively hot weather. The definition recommended by the World Meteorological Organization is when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5ºC, the normal period being 1961–1990.

In Romania, a national heat wave is defined as a period of at least 3 consecutive days in which the maximum temperature reaches or exceeds 32°C. During the critical period for crops (June-August),

the intensity of thermal stress evolution is made obvious by the scorching heat phenomenon, described by sums of daily air temperature highs equal to or above 32°C. This level (32°C) is a critical biological threshold representing the maximum air temperature that, on being topped, affects the optimum growth and development in cereal species particularly during the interval of great requests of heat, namely June-August. Air temperature highs above the critical biological threshold of 32°C (scorching heat) associated with high levels of humidity deficits in air (atmospheric drought) and soil (pedological drought) define a complex phenomenon – the agricultural drought – with severe effects upon plants.
In the figure 38 are exemplified the areas in the phenomenon of heat intensity recorded the highest values (>31 scorching heat), maximum values recorded in the South of Romania.

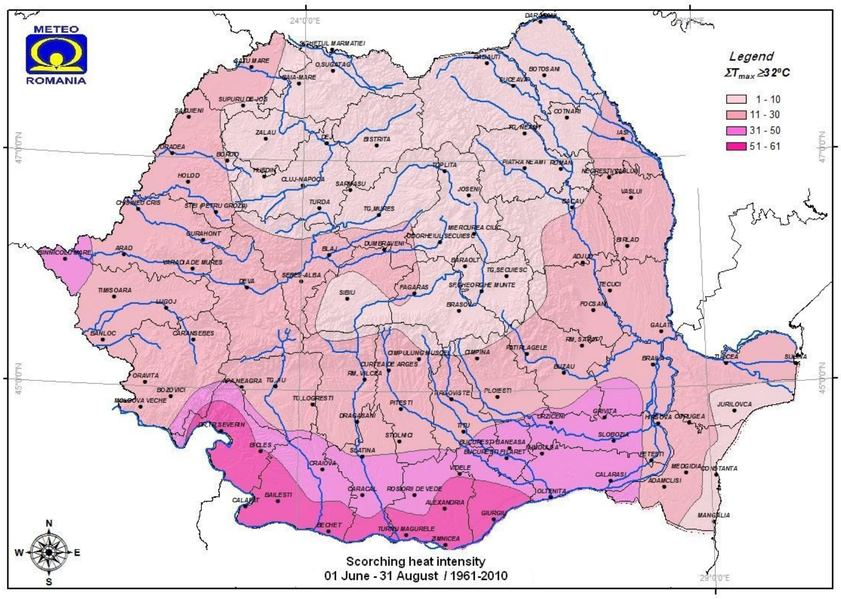


Figure 37: Scorching heat intensity in Romania over 1961-2010 period

Given the multi-annual means of scorching heat intensity, phenomenon quantified by sums of air temperature highs equal to or above 32°C recorded during the summer months, it has become apparent a significantly higher thermal stress over the critical interval for crops (June-August), an increase from 13 units of scorching heat between 1961 and 1990 to 28 units over 1981-2010 (table 13).

	Units of scorching heat ($\sum Tmax \geq 32°C$, VI-VIII)
1961-1990	13
1971-2000	18
1981-2010	28
	2007 / 95 units **2012 / 123 units**

Table 13: Intensity of scorching heat events in Romania, 1961-2010

The Index of ecosystem sensitivity to desertification processes. To analyse the sensitivity to desertification of the agricultural ecosystems at our country’s level, which is an aggregated effect of a number of factors, the index was studied of the ecosystems’ sensitivity to the desertification processes (ESAI). This is a complex indicator, widely used at EU level, being computed by resorting to a method that averages certain indicators that characterize various factors intervening in the occurrence of the desertification hazard. Weights are thus attributed to these indicators that characterize: topography (slope, exposure), soil (texture, useful edaphic volume, parental material, drainage, and frame), climate, vegetation/land use and agricultural management intensity.

Functions of the values of this index, the stages below become apparent as regards the land degradation and the desertification hazard:

- Critical: areas already degraded as a result of past faulty use. These areas are a danger to neighbouring regions. Examples might be the heavily eroded areas, where leakage and soil loss can be considerable;
- Fragile: surfaces where any modifications within the delicate balance between the natural processes and the anthropic-induced ones can lead to desertification processes if the land management is improper.
- Potential: surfaces threatened by desertification in case of significant climate change and/or in the case of specific structures of the land use. Abandoned or mismanaged surfaces can also be included in this category. For such surfaces proper planning is necessary as regards the agricultural activities

Figure 39. renders the ESAI index computed for the climate conditions of Romania over the 1961-1990 interval, topographic information supplied within a 100-m step grid, soil information processed from the digital maps at 1:1,000,000 and 1:200,000 respectively, information about the vegetation supplied by CORINE-Landcover, management information processed from the land use infoplane based on the FAO-LCCS methodology.

According to this index, Dobrudja, the Plain in the South of the country, the hillock areas in Moldavia, the Transylvanian Plateau and the Plain from the West of the country are the most critical areas.

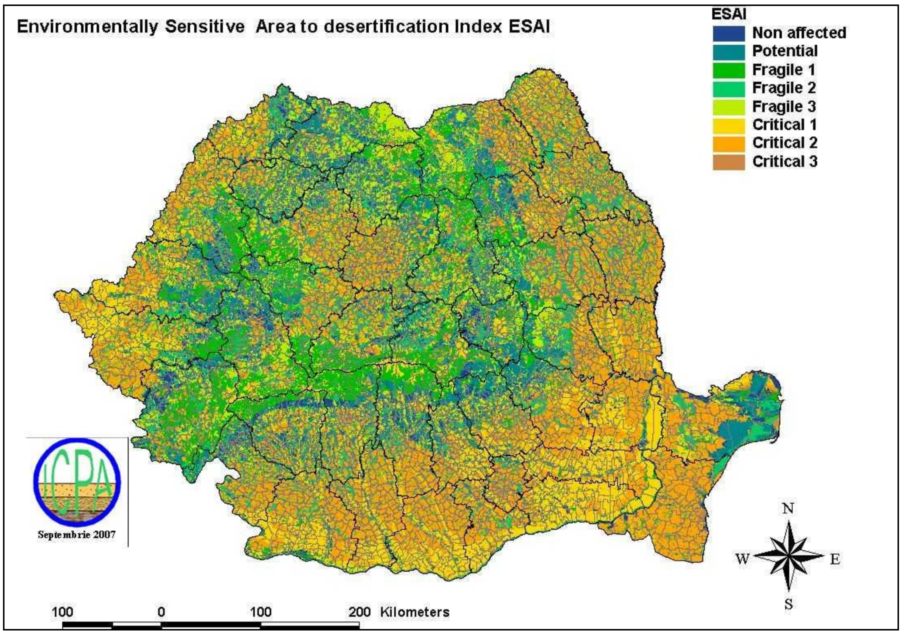


Figure 38: Index of ecosystem sensitivity to desertification processes (climatic parameters corresponding to the 1961-1990 period)

4.2. Drought monitoring and assessment using Remote Sensing and GIS methods

The Global Climate Observing System (GCOS) principles provide basic guidance regarding the planning, operation and management of observing networks and systems, including satellites, to ensure that high-quality climate data are available and contribute to effective climate and agrometeorological related information (GCOS, 2003, WMO, 2009). The specific issues are: (i) the effective incorporation of new systems and networks; (ii) the importance of calibration, validation and data homogeneity; (iv) the un-interrupted operation of individual stations and systems; (v) the importance of additional observations in data-poor regions and regions sensitive to change; and (vii) the crucial importance of data management systems that facilitate access, use and interpretation of the data. These principles have been adopted or agreed by the UN Framework Convention on Climate Change (UNFCCC), WMO, Committee on Earth Observation Satellites (CEOS) and other international bodies.

The satellite data useful for drought monitoring and assessment are available since the start of operational meteorological satellite systems. Data are archived by different satellite operators and users. Selected archives are freely available or require only registration. Use of satellite data for long-term drought-related studies requires access to long time-series data.

The ability to obtain data from inaccessible or isolated areas, high repetition rate and continuous coverage make remote sensing a very practical tool, particularly useful for monitoring natural phenomena such as drought. Because there is no simple, universal definition of a drought, a set of indicators is needed to capture the conditions that are symptomatic for this phenomenon. Characteristics of radiometers on board meteorological and environmental satellites allow for determination of many parameters characterizing the actual state of the biosphere and spatial and temporal changes.

Presently, Poland as a member of EUMETSAT has a free access to satellite data from all European meteorological satellites and products available operationally from EUMETSAT Central Application Facility and eight SAFs (Satellite Application Facilities). Until now, these data have not been used for drought monitoring in such a wide scope but has been limited to some weather services, agricultural websites and for research purposes. However, the recently create IMGW-PIB National Center of Flood and Drought Modeling is preparing for implementation in 2014 the Early Warning and Drought Forecast System. One of the System components is satellite data allowing to monitor, assess and model drought events.

Satellite data provide a wide scope of parameters including vegetation state, soil moisture, snow cover, evapotranspiration, land surface temperature and thermal anomalies, radiation, land cover (e.g. changes such as reduction in plant growth). In drought monitoring and assessment, the most prominently applied satellite product areis vegetation indices. Vegetation indices commonly include the following:

NDVI ***(Normalized Difference Vegetation Index)*** – it does not reflect drought condition directly but drought severity may be derived as NDVI deviation from its long-term deviation.

VCI ***(Vegetation Condition Index)*** – calculation based on NDVI minimum, maximum and actual values showing the deviation of NDVI in a current month from the long-term minimum NDVI value. The values below 50% indicate drought condition, values below 35% - a severe drought condition.

TCI ***(Thermal Condition Index)*** – reflects vegetation response to temperature. Because higher temperature is connected with more extreme drought, the TCI is used as a drought index as well.

VHI ***(Vegetation Health Index)*** calculated as a linear combination of VCI and TCI provides the estimation of moisture and thermal conditions.

SSI ***(Soil Saturation Index)*** estimates vegetation depression due to soil saturation followed by abnormal rains. It can be used to detect large area vegetation stress resulting from drought.

Other satellite products that are useful for drought monitoring and assessment include:

Evapotranspiration – one of the two components of climatic water balance (CWB) indicating deficit of precipitation in relation to evapotranspiration thus making it one of the direct indices of drought event. CWB can be useful for water resources estimation in case of the absence of hydrological data. Product 'Evapotranspiration" is generated operationally and distributed in a near real-time by EUMESTAT system in two time steps – 30 min (instantaneous values) and 24 hours (cumulated values). The product represents spatial distribution of the actual evapotranspiration and provides valuable information for drought assessment because of the absence of direct measurements of this parameter.

Soil moisture computed for four layer: surface to 7 cm, 8-28 cm, 29-100 cm and 101-298 cm. It is an essential parameter for agrometeorological and hydrological drought assessment. This product combines satellite measurements from ASCAT/METOP instrument and soil wetness model.

fAPAR ***(Fraction of Absorbed Photosynthetically Active Radiation)*** is the fraction of the incoming solar radiation in the Photosynthetically Active Radiation spectral region that is absorbed by a photosynthetic organism, typically describing the light absoprtion across an integrated plant canopy. This biophysical variable is directly related to the primary productivity of photosynthesis and some models use it to estimate the assimilation of carbon dioxide in vegetation. fAPAR has a capacity to detect droughts and offers an enhanced performance compared to NDVI.

All satellite data will be stored, analyzed and edited using Geographic Information System (GIS), which is the most common and useful tool in analyses of information about the environment, its components, their status and spatial and temporal changes.

Future work could be directed also to application of combined satellite/climatological drought index (e.g. VegDRI), merging spatial information from satellites with point ground measurements which cannot be obtained from space. Such hybrid product, integrate satellite-based observations of vegetation conditions with in situ climate data and other information such as land cover/land use type, soil characteristics, and ecological setting. It monitors the health of vegetation as it is specifically related to drought.

Studies of temporal and spatial changes of vegetation cover due to pedological and meteorological drought require long series of satellite data produced by the same sensors or sensors which can be inter-calibrated with sufficient accuracy (National Research Council, 2004). The most useful satellite missions which comply with this requirement are meteorological satellites continuously operational since 1960. Also environmental satellites holding the same instrument like Terra and Aqua with MODIS instrument provide long time-series of data.

Satellite characteristics

Focusing on European coverage, the most used satellites are:

For continental scale studies:

Geostationary METEOSAT Second Generation (since 2002).

The **Meteosat Second Generation** satellite series **(**MSG) are considered as the main weather- and climate-monitoring remote sensing system. Thus, the MSG satellites are carrying on the uninterrupted monitoring, generating a multitude of data essential to the understanding and modelling of our planet's climatic activity.

The two main instruments on board MSG satellites are:

SEVIRI (Spinning Enhanced Visible & Infrared Imager) is able to supply, at intervals of 15 minutes images of the Earth hemisphere, observed by the satellite in 12 different visible and infrared wavelengths (table 14). This enrichment of the spectrum of observations was a major advance, making for improvement of numerical climate modelling. By delivering data with high frequency, MSG satellites make it easier for climatologists and meteorologists to detect the start of sudden weather phenomena, such as thunderstorms. With the improvement of image resolution in the visible spectrum, to 1 km from 2.5 km previously, observation and monitoring of local phenomena have been improved as well.

Band	**Band width**
VIS 0,6	0,56 - 0,71 µm
VIS 0,8	0,74 - 0,88 µm
IR 1,6	1,50 - 1,78 µm
IR 3,9	3,48 - 4,36 µm
IR 8,7	8,30 - 9,10 µm
IR 10,8	9,80 - 11,80 µm
IR 12,0	11,00 - 13,00 µm
WV 6,2	5,35 - 7,15 µm
WV 7,3	6,85 - 7,85 µm
IR 9,7	9,38 - 9,94 µm
IR 13,4	12,40 - 14,40 µm
High Res VIS,1 km: HRV	0,5 - 0,9 µm

Table 14: SEVIRI spectral characteristics

The **GERB** (Geostationary Earth Radiation Budget) radiometer supplies useful data on the Earth's radiation budget - the balance between the incoming radiation from the sun and the radiation returned to space. The radiation budget, about which much has yet to be learnt, plays a key role in climate change.

For regional studies (continental to country scale):

Polar orbiting with AVHRR or similar instrument: NOAA (since 1978), METOP (since 2006);

Polar orbiting with MODIS instrument: Terra (since 2000), Aqua (since 2002);

Polar orbiting with VEGETATION instrument: SPOT 4 (since 1998) and SPOT 5 (since 2002);

Polar orbiting with PROBA-V ("V" standing for Vegetation, since April 2013).

The **NOOA/AVHRR** is a radiation-detection imager that can be used for remotely determining cloud cover and the surface temperature. This scanning radiometer uses 6 detectors that collect different bands of radiation wavelengths as shown below. The first AVHRR was a 4 channel radiometer, first carried on TIROS-N (launched October 1978). This was subsequently improved to a 5-channel instrument (AVHRR/2) that was initially carried on NOAA-7 (launched June 1981). The latest instrument version is AVHRR/3, with 6 channels, first carried on NOAA-15 launched in May 1998. The AVHRR channel characteristics are presented in table 15.

Channel Number	Resolution at Nadir (km)	Wavelength (□m)	Typical Use
1	1.09	0.58 - 0.68	Daytime cloud and surface mapping
2	1.09	0.725 - 1.00	Land-water boundaries
3A	1.09	1.58 - 1.64	Snow and ice detection
3B	1.09	3.55 - 3.93	Night cloud mapping, sea surface temperature
4	1.09	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	1.09	11.50 - 12.50	Sea surface temperature

Table 15: AVHRR/3 channel characteristics

Measuring the same view, this array of diverse wavelengths, after processing, permits multispectral analysis for more precisely defining hydrologic, oceanographic, and meteorological parameters. Comparison of data from two channels is often used to observe features or measure various environmental parameters. The three channels operating entirely within the infrared band are used to detect the heat radiation and hence, the temperature from of land, water, sea surfaces, and the clouds above them.

The **Meteorological Operation Satellites (MetOp**) is a series of three polar orbiting meteorological satellites operated by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The satellites carry a payload comprising 11 scientific instruments and two which support Search and Rescue services. In order to provide data continuity between MetOp and NOAA Polar Operational Satellites (POES), several instruments are carried on both fleets of satellites. For drought monitoring the Advanced Very High Resolution Radiometer (AVHRR) sensor-imager is used. It has 6 channels operating in visible/IR spectral domain (0.6-12 µm), with 2000 km swath and 1x1 km spatial resolution. The orbital period is about 101 minutes and the ground track repeat cycle is 29 days (412 orbits). The main characteristics of the MetOp/AVHRR sensor are presented in table 16.

Sensor	Spectral channels (6 visible and IR channels)	Spatial resolution	Applications
Advanced Very High Resolution Radiometer/3 (AVHRR)	1. 0.630 µm 2. 0.865 µm 3a. 1.610 µm 3b. 3.740 µm 4. 10.80 µm 5. 12.00 µm	1.1 km	Multi-purpose imaging instrument is used for global monitoring of cloud cover, sea surface temperature, ice, snow and vegetation cover characteristics

Table 16: MetOp/AVHRR characteristics

The **Moderate Resolution Imaging Spectre-radiometer (MODIS)** is a key instrument aboard the Terra and Aqua Earth Observation System satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days.

MODIS has a viewing swath width of 2330 km and views the entire surface of the Earth every one to two days. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment. In table 17 are presented the spectral bands of MODIS sensor used for vegetation monitoring and their potential applications.

Band	Pixel Resolution (m)	Reflected Bandwidth Range (nm)	Potential Applications
1	250	620-670	Absolute Land Cover Transformation, Vegetation Chlorophyll
2	250	841-876	Cloud Amount, Vegetation Land Cover Transformation
3	500	459-479	Soil/Vegetation Differences
4	500	545-565	Green Vegetation
5	500	1230-1250	Leaf/Canopy Differences
8	1 000	405-420	Chlorophyll
9	1 000	438-448	Chlorophyll
10	1 000	483-493	Chlorophyll
11	1 000	526-536	Chlorophyll

Table 17: MODIS band characteristics used for vegetation monitoring

The SPOT Vegetation sensor is carried aboard SPOT 4 and 5 which were launched in 1998 and 2002, respectively. The sensor is designed to monitor the Earth on regional and continental scales. It has the capability of imaging the entire Earth each day. It is particularly valuable for studying agriculture, deforestation, and other vegetation changes on a broad scale. There are currently two Vegetation instruments on Spot satellites (table 18): Vegetation 1 (located in SPOT 4 Satellite) and Vegetation 2 (located in SPOT 5 satellite).

Spectral bands	Specified	VEGETATION 1	VEGETATION 2	Surface reflectance range (%)
BLUE (B0)	0.430 - 0.470 µm	0.437 - 0.480 µm	0.438 - 0.475 µm	0.0 - 0.5
RED (B2)	0.610 - 0.680 µm	0.615 - 0.700 µm	0.615 - 0.690 µm	0.0 - 0.5
NIR (B3)	0.780 - 0.890 µm	0.772 - 0.892 µm	0.782 - 0.890 µm	0.0 - 0.7
SWIR (MIR)	1.580 - 1.750 µm	1.600 - 1.692 µm	1.582 - 1.685 µm	0.0 - 0.6
Resolution		1 000 m		
Sensor footprint		2 000 x 2 000 km		
Revisit rate		Daily		

Table 18: SPOT Vegetation general and spectral characteristics

The SPOT Vegetation products are systematically acquired, archived, and available on-line. The VGT-S10 products (ten day synthesis) with 1 km resolution are compiled by merging segments acquired in a ten days. All the segments of this period are compared again pixel by pixel to pick out the 'best' ground reflectance values. The products provide data from all spectral bands, the Normalised Difference Vegetation Index (NDVI) and auxiliary data on image acquisition parameters.

The **PROBA-V** is an European satellite, tasked with a full-scale mission: to map land cover and vegetation growth across the entire planet every two days.
This mission is extending the data set of the long-established Vegetation instrument, flown as a secondary payload aboard France's Spot-4 and Spot-5 satellites launched in 1998 and 2002 respectively.
Proba-V's Vegetation instrument boasts improved spatial resolution from to its Spot predecessors: 350 m resolution compared to 1 km for Spot Vegetation, with 100 m resolution available within its central field of view.
For finer scale studies (country to sub-region scale):
Polar orbiting **SPOT, LANDSAT, IRS, ASTER, FORMOSAT, PLÉIADES and future satellite as SENTINELS, etc.**

LANDSAT 8 is the last satellite of the American LANDSAT Earth Observation Program, launched on February, 2013. The parameters for Landsat 8 standard products are presented in the table 19.

Spectral Band	**Wavelength** (µm)	**Resolution (m)**
Operational Spectral Bands (OLI)		
Band 1 (visible)	0.433 - 0.453	30
Band 2 (visible)	0.450 - 0.515	30
Band 3 (visible)	0.525 - 0.600	30
Band 4 (visible)	0.630 - 0.680	30
Band 5 (Near Infrared)	0.845 - 0.885	30
Band 6 (Short Wavelength Infrared)	1.560 - 1.660	30
Band 7 (Short Wavelength Infrared)	2.100 - 2.300	30
Band 8 (Panchromatic)	0.500 - 0.680	15
Band 9 (Short Wavelength Infrared)	1.360 - 1.390	30
Thermal Infrared Sensor (TIRS)		
Band 10 TIRS 1	10.6 - 11.19	100
Band 11 TIRS 2	11.5 - 12.51	100

Table 19: Landsat 8 spectral bands

FORMOSAT-2 is a high-resolution optical satellite able to revisit the same point on the globe every day in the same viewing conditions. Its unique orbit and 2-metre resolution in panchromatic and 8-metre in multispectral are well suited to change detection and rapid coverage of large areas. With its 24-km swath and daily revisits, the FORMOSAT-2 can cover large areas in a matter of weeks.
The FORMOSAT-2 characteristics are presented in table 20.

Products	**B&W: 2 m** **Colour: 2 m (merge)** **Multispectral (R, G, B, NIR): 8 m** **Bundle (separate Pan and MS images)**
Spectral bands	P : 0,45 – 0,90 µm B1 : 0,45 – 0,52 µm (Blue) B2 : 0,52 – 0,60 µm (Green) B3 : 0,63 – 0,69 µm (Red) B4 : 0,76 – 0,90 µm (Near-infrared)
Sensor footprint	24 km x 24 km
Revisit rate	Daily
Viewing angles	Cross-track and along-track (forward/aft): +/- 45°
Pre-processing levels	Level 1A, 2A and Ortho
Delivery	Data are posted on an FTP site within 48–72 hours of acquisition

Table 20: FORMOSAT-2 characteristics

One of the main difficulties encountered at using the FORMOSAT -2 images is the cloud cover (FORMOSAT-2 having an optical sensor).

The **PLÉIADES (1A & 1B)**, represent a new constellation of satellites, ensuring continuity of Earth Observation up to 2023. A standard, 50-cm ortho product is delivered by the new high resolution Pléiades satellites. The first Pléiades (1A) satellite was launched on 2011 and the second (1B) in 2012, both offering an ideal combination of coverage, resolution and speed.

The Pléiades satellites have a panchromatic band: Pan=0.47-0.83 µm and four multispectral bands: Blue = 0.43-0.55 µm, Green = 0.50-0.62 µm, Red = 0.59-0.71 µm, Near Infrared = 0.74-0.94 µm (NIR), with a product resolution by 0.5 m for panchromatic and 2 m for multispectral. Figure 40 presents an example of a Pleiades image acquired over the Caracal agricultural area in South of Romania that evidenced the parcels cultivated with crops.

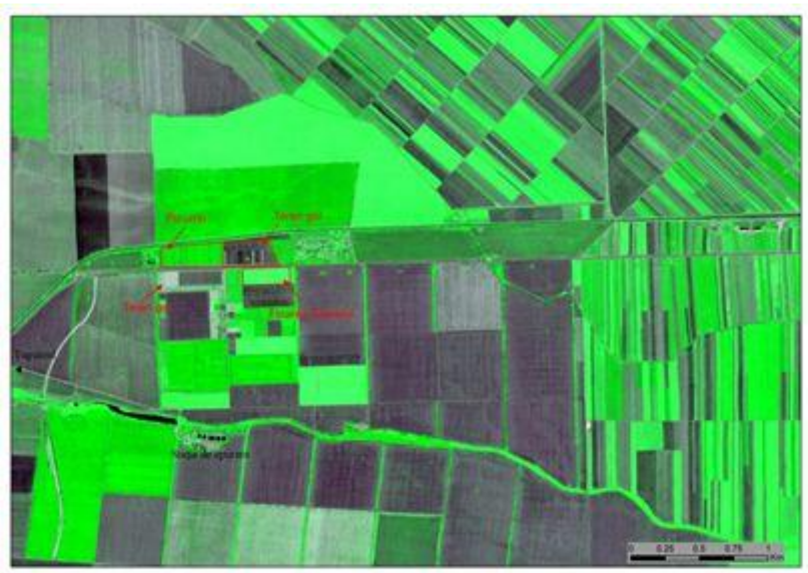


Figure 39: Pleiades 1A colour composite image (bands 3,4,2), 15 July 2013 on the Caracal area in South of Romania.

The revisit time is one day above 40° latitude within +/- 30° angle corridor (fig. 1), two days between equator and 40° latitude and one day revisit with two satellites and an increased angle (45°).

Pléiades has an impressive acquisition capacity; the maximum theoretical acquisition capacity reaches 1 million square kilometres per day and per satellite (2 million for both). Pleiades coverage capacity is also due in part to its swath (20 km), the largest in this class of resolution, providing a larger native image footprint (from 30% to 73% better coverage compared to its peers in a single image).

A great feature of Pléiades is to offer a high resolution stereoscopic cover capability. The stereoscopic cover is achieved within the same pass of the area, which enables a homogeneous product to be created quickly. The system offers the possibility to achieve a “classical” stereoscopic imaging, composed of two images for which the angular difference (B/H) can be adjusted, but also stereoscopic imaging with an additional quasi vertical image (tristereoscopy), thus allowing the user to have an image and its stereoscopic environment.

Tri-stereo images can be used to create more accurate 3D models than can be done with basic Stereo, as the near nadir acquisition minimizes the risk of missing hidden items. This is ideal for dense urban and mountainous areas.

The Pléiades products can be delivered in different raster formats like GeoTIFF or JPEG 2000, also rational polynomial coefficients are provided to easier ortho-rectification and geometric processing. A KMZ file format is included for easy and rapid display in Google Earth environment. Quality and cloud cover mask are also included.

The pair of Sentinel-2 satellites **(planned to launch started with 2014) will routinely delivered high-resolution optical images globally, providing enhanced continuity of SPOT- and Landsat-type data.**

Sentinel-2 will carried an optical payload with visible, near infrared and shortwave infrared sensors comprising 13 spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution, with a swath width of 290 km (Table 21).

The 13 spectral bands will provide consistent time series, showing variability in land surface conditions and minimizing any artifacts introduced by atmospheric variability.

The mission orbits at a mean altitude of approximately 800 km and, with the pair of satellites in operation, has a revisit time of five days at the equator (under cloud-free conditions) and 2–3 days at mid-latitudes.

The increased swath width along with the short revisit time allows rapid changes to be monitored, such as vegetation during the growing season.

Data from Sentinel-2 **will benefit services associated with, for example, land management by European and national institutes, the agricultural industry and forestry, as well as disaster control and humanitarian relief operations.**

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Instrument	**Spectral channels**	**Spatial resolution**	**Applications**
MULTI-SPECTRAL INSTRUMENT (MSI)	**13** visible and IR **channels:**		**L**and management by European and national institutes, the agricultural industry and forestry, as well as disaster control and humanitarian relief operations
	4 channels	10 m	
	6 channels	20 m	
	3 channels	60 m	

Table 21: **The SENTINEL-2 characteristics**

Imagery for the generation of high-level operational products, such as land-cover maps, land-change detection maps and geophysical variables that use, for example, leaf area index, leaf chlorophyll content and leaf water content will be provided. Images of floods, volcanic eruptions and landslides will also be acquired by Sentinel-2.

In essence, Sentinel-2 will combines a large swath, frequent revisit, and systematic acquisition of all land surfaces at high-spatial resolution and with a large number of spectral bands, all of which makes a unique mission.

Satellite-derived parameters and products

The most important satellite data and derived parameters and products, which are useful for agro-climatic analysis for drought study, are:

Pure vegetation empirical indices: Normalized Difference Vegetation Index (NDVI)

Soil Adjusted Vegetative Index (SAVI); Modified Soil Vegetation Index (MSAVI); Optimized Soil-Adjusted Vegetation Index (OSAVI); Enhanced Vegetation Index (EVI); Atmospherically Resistant Vegetation Index (ARVI); Perpendicular Vegetative Index (PVI); Weighted Different Vegetation Index (WDVI); Perpendicular Drought Index (PDI).

Canopy Water Content and Moisture Indices: Normalized Difference Water Index (NDWI); Normalized Difference Drought Index (NDDI); Moisture Stress Index (MSI); Normalized Moisture Index (NMI = NDVI+NDWI); Normalized Difference Infrared Index (NDII); Crop water stress index (CWSI); Water deficit index (WDI); Shortwave Infrared Water Stress Index (SIWSI).

Combined vegetation and temperature based indicators: Vegetation Condition Index (VCI); Temperature Condition Index (TCI); Vegetation Health Index (VHI);

Biophysical parameters and physically-based vegetation state indicators: Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), evapotranspiration, fraction of vegetation cover, biomass, Land Surface Temperature (LST), thermal anomalies, snow pack, etc.

Soil moisture data and indicators: Different sensors are used for this purpose according to their availability in the main spectral domains: visible – near IR, thermal IR, microwave (radar) passive and active. The assimilation of satellite data into models for the retrieval of soil moisture is also a reliable solution.

Vegetation indices

The spectral vegetation indices (VI) are among the most commonly used satellite data products for the evaluation, monitoring, and measurement of vegetation cover, condition, biophysical processes, and change. They have been used for over last decades in a broad variety of applications, including monitoring the effects of drought over regional, national, and even multinational areas.

The vegetation structure is characterized by the position, orientation, size and shape of the vegetation elements. The distribution of optical properties can be considered as part of the structure of the vegetation cover. The architecture of vegetation cover varies in time, from fractions of seconds and minutes (wind, water stress, etc.) to seasonal (phenological evolution, environmental constraints) and years (ecosystem dynamics). Vegetation indices are a subset of spectral indices and are based on spectral responses of the objects that interact with the incident solar radiation. The most useful spectral areas for vegetation monitoring by remote sensing are located between 600-700 nm and 750-1350 nm. Vegetation indices calculated using radiance or reflectance values of the two channels have applications in monitoring vegetation dynamics, determination of photosynthetic active radiation absorbed, vegetation conductance and photosynthetic capacity.

The vegetation indices using spectral characteristics of plants measured by satellite sensors are the most commonly used satellite products providing important observations related to: agricultural drought, climate, land cover change, management of natural resources and decision making processes for sustainable development (Schmidt et. al. 2003; Shin 2005).

The satellite observations of vegetation combine visible channels placed at the chlorophyll absorbing part of spectrum and near infrared spectrum where leaf reflectance is more significant. As a result measurement of vegetation cover photosynthetic capacity can be observed and monitored for long periods. Use of those data requires capability for consistent processing of data sets covering longer periods and incorporation cloud detection filters and compensation for changing observation geometry, observation solar time, atmospheric influence and satellite sensor degradation (Broge & Leblanc, E., 2000; Gitelson et al., 2001).

The vegetation indices are an important tool for drought monitoring and evaluation because of the accurate discrimination of vegetation, and correlations with biophysical parameters that determine the vegetation state.

Pure vegetation empirical indices:

The **Normalized Difference Vegetation Index (NDVI)** is computed using the red and near-infrared (NIR) bands of an image and is calculated with the expression:

$$NDVI = \frac{\rho NIR - \rho R}{\rho NIR + \rho R}$$

where: ρR is spectral reflectance from red band and ρNIR is spectral reflectance from near infrared (NIR) band.

NDVI is one of the most well-known and most frequently used vegetation indices.

The combination of its normalized difference formulation and use of the highest absorption and reflectance regions of chlorophyll make it robust over a wide range of conditions (Peters et al., 2002).

NDVI is very useful for deriving vegetation biophysical parameters, such as the leaf area index (LAI), the fraction of absorbed photo-synthetically active radiation (fAPAR) and percentage of green cover. NDVI can be also used for accurate monitoring of vegetation dynamics as well as for the determination of the beginning, the end and the duration of the vegetation season. The value of NDVI ranges from -1 to 1. The common range for green vegetation is 0.2 to 0.8.

NDVI saturates in dense vegetation conditions when LAI becomes high. A linearized NDVI (LNDVI) was derived by introducing a linearity-adjustment factor, into the NDVI equation to improve the linearity of the relationship with vegetation fraction and mitigate the saturation problem (Jiang &

Huete, 2010). Due to its improved linearity with vegetation fraction, this index would provide more accurate monitoring of vegetation dynamics and estimation of biophysical parameters.

The **Soil-adjusted Vegetation Index (SAVI)** (Huete, 1988) tends to minimize the effect of bare soil variations on the spectral response of the green vegetation, compared to NDVI. **SAVI** is defined as:

$SAVI = \left[\frac{(\rho NIR - \rho R)}{(\rho NIR + \rho R + L)}\right] x\ (1 + L)$where: L is a correction factor and its value is dependent on the vegetation cover.

The correction factor, in the SAVI equation, accounts for the first order soil-vegetation optical interactions. The optimal adjustment factor is: L = 0.25 for higher plants canopy density, L = 0.5 for intermediate plants canopy density and L = 1 for the low plants canopy density.

The **Modified Soil Vegetation Index (MSAVI)** is defined as:

$MSAVI = 2\ \rho NIR + 1 – [(2\ \rho NIR + 1)^2 –8(\rho NIR - \rho red)\ ]^{0.5} / 2$

MSAVI succeeds to further minimize the soil effect. MSAVI is highly unlikely to reach saturation easily, thereby resulting in larger adaptation potential for vegetation water stress and a better drought vulnerability assessment.

The **Enhanced Vegetation Index (EVI)** is an 'optimized' index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences.

EVI is computed using the formula:

$EVI = G\ x\ [(\rho NIR – \rho RED) / (\rho NIR + C1\ x\ \rho RED - C2\ x\ \rho BLUE + L)]$

where: *ρNIR, ρRED* and *ρBLUE* are partially atmosphere corrected surface reflectance;

L is the canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy;

C1, C2 are the coefficients of the aerosol resistance term;

G is the gain factor.

The coefficients adopted in the MODIS-EVI algorithm are: L=1; C1 = 6; C2 = 7.5 and G = 2.5.

The value of EVI ranges from -1 to 1. The common range for green vegetation is 0.2 to 0.8.

EVI is most useful in LAI regions, where the NDVI may saturate. EVI is strongly correlated with structural parameters of canopy, such LAI. However, EVI is limited to sensor systems designed with a blue band, in addition to the red and near-infrared bands, making it difficult to generate long-term EVI time series.

The **Atmospherically Resistant Vegetation Index (ARVI)** is defined as:

$ARVI = [\rho_{NIR} – (2\rho_{RED} - \rho_{BLUE})] / [\rho NIR + (2\rho_{RED} - \rho_{BLUE})]$

ARVI is an enhancement to the NDVI that is relatively resistant to atmospheric factors. It uses the reflectance in blue to correct the red reflectance for atmospheric scattering. ARVI is most useful in regions of high atmospheric aerosol content. The value of this index ranges from -1 to 1. The common range for green vegetation is 0.2 to 0.8.

Canopy Water Content and Moisture Indices:

The **Normalized Difference Water Index (NDWI)** (Gao, 1996) is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels, being defined as:

$NDWI = (\rho_{NIR} – \rho_{SWIR}) / (\rho_{NIR} + \rho_{SWIR})$

The value of NDWI ranges from -1 to 1. The normal range for green vegetation is -0.1 to 0.4.

NDWI index is a good indicator of water content of leaves and is used for detecting and monitoring the humidity of the vegetation cover. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content.

NWDI holds considerable potential for drought monitoring because the two spectral bands used for its calculation are responsive to changes in the water content (SWIR band). NDWI is influenced by both the desiccation and wilting of vegetation and may be a more sensitive drought indicator than traditional remote sensing-based indices such as NDVI, which do not account for changes in the vegetation's water content.

The **Normalized Difference Drought Index (NDDI)** is computed using the formula:

NDDI = (NDVI – NDWI) / (NDVI + NDWI)

The NDDI ranges between -1 and +1. A higher NDDI range indicates more severe drought.

NDDI can offer an appropriate measure of the dryness of a particular area, because it combines information on both vegetation and water. NDDI is characterized by its ease of calculation because it is based on normalized difference (addition and subtraction) and it does not depend on time series data. This index can be an optimal complement to in-situ based indicators or for other indicators based on remote sensing data.

NDDI had a stronger response to summer drought conditions than a simple difference between NDVI and NDWI, and is therefore a more sensitive indicator of drought. NDDI values increased during summer drought conditions.

The **Moisture Stress Index (MSI)** is computed using the formula:

MSI = ρ_{SWIR} / ρ_{NIR}

where: ρ_{SWIR} is the spectral reflectance from the short infrared band and ρ_{NIR} is the spectral reflectance from near infrared band.

MSI is sensitive to increasing leaf water content. As the water content of leaves in vegetation canopies increases, the strength of the absorption increases.

Applications include canopy stress analysis, productivity prediction and modeling, fire hazard condition analysis, and studies of ecosystem physiology. The MSI is inverted relative to the other water VIs; higher values indicate greater water stress and less water content. MSI higher values indicate greater water stress and less water content.

The value of this index ranges from 0 to more than 3. The common range for green vegetation is 0.4 to 2.

The **Water Deficit Index (WDI)** is by definition related to the ratio of actual and potential evapotranspiration, being useful for evaluating evapotranspiration rates of both full-cover and partially vegetated sites. WDI can be computed using remotely sensed surface temperature and reflectance (in red and near-infrared bands) with limited in situ meteorological data (net radiation, vapor pressure deficit, wind speed, and air temperature).

Combined vegetation and temperature based indicators:

The crop water stress can be assessed using combined vegetation and temperature based indicators like: Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI).

VCI, TCI and VHI are dimensionless and vary between 1 and 0, 0 indicates the worst condition ever encountered over the period of available images and one the best condition. If the period covered includes dry and wet years and under the assumption that the vegetation condition is mainly related to the water availability, these indicators have high potential for monitor water stress.

The **Vegetation Condition Index (VCI)** (Liu and Kogan, 1996), for a given period “I” (e.g. a given month), is calculated as:

$VCI_i = (NDVI_i - NDVI_{min})/(NDVI_{max} - NDVI_{min})$where: $NDVI_i$ is the NDVI for the analyzed period and $NDVI_{max}$, $NDVI_{min}$ are the multiyear absolute extreme values of NDVI calculated from a dataset of ’historical’ NDVI images of the area.

The VCI was developed in order to assess changes in the NDVI signal over time due to weather conditions only, minimizing the effects of local conditions and topography. The VCI can be calculated only if reliable records of satellite images for a sufficient number of years are available; this opens some issues since recent remote sensing instruments (e.g. MODIS or MSG) have been operational for less than a decade.

The significance of VCI depends on the strength of the relation between the vegetation index and the vitality of the vegetation cover under investigation, as well as on the number and quality of images available from the calculation of the absolute minimum and maximum.

Cloud or snow presence is a major issue. The availability of quality checked post-processed datasets of NDVI is therefore fundamental.

The VCI is an indicator of the vigor of the vegetation cover and allows comparison of different ecosystems. It is an attempt to separate the short-term climatic signal from the long-term ecological signal and in this sense it is a better indicator of the water stress conditions than the NDVI.

The **Temperature Condition Index (TCI)** (Kogan et al., 2003) is expressed by the equation:

$TCI = 100 \times [(BT_{Max} - BT)/(BT_{Max} - BT_{Min})]$Where: BT, BTmax and BTmin are the smoothed ten-day brightness temperature, its multi-year maximum and its multi-year minimum respectively, for each pixel, in a given area.

TCI is an indicator equivalent to the VCI, based on the fact that the skin temperature of a vegetation canopy or the soil surface will rise with increasing water stress due to the evaporative cooling. As VCI, TCI varies from zero, for extremely unfavorable conditions, to 100, for optimal conditions, and higher TCI values represent healthy and unstressed vegetation.

VCI and TCI characterize the moisture and thermal conditions of vegetation, respectively. Thermal conditions are especially important when moisture shortage is accompanied by high temperature, increasing agricultural drought severity and having direct impact on vegetation health.

TCI along with VCI has proven to be a useful tool for the detection of agricultural drought.

The **Vegetation Health Index (VHI)** (Kogan, 2002) is defined as a linear combination of VCI and TCI:

$VHI = a.VCI + (1-a).\ TCI$

Where: a is the coefficient quantifying a share of VCI and TCI contribution to the VHI, which is thus a weighted average of the two.

The VHI is a proxy characterizing vegetation health or a combined estimate of moisture and thermal conditions.

The VHI is a composite index, derived from most important crop growth variables such as leaf area index (LAI), Chlorophyll content (Cab), and leaf equivalent water thickness (Cw). In order to retrieve the biophysical parameters i.e. LAI, Cab and Cw, a statistical approach is used.

The VHI can be used for site specific crop management for better utilization of available resources and maximizing the crop yield.

Biophysical parameters and physically-based vegetation state indicators

The **Leaf Area Index (LAI)** represents the amount of leaf material in an ecosystem and is geometrically defined as the total one-sided area of photosynthetic tissue per unit ground surface area. It is a good indicator of vegetation condition, relevant for installation, duration and intensity of drought.

LAI is a key biophysical canopy descriptor that is directly related to photosynthesis, evapotranspiration, and productivity of agro-ecosystems. Assessment of crop LAI and its spatial distribution are of importance for crop growth monitoring, vegetation stress, crop forecasting, yield predictions and management practices. The crop LAI status at any particular stage in the growth cycle can be a consequence of several crop and soil variables, such as soil moisture, nutrient imbalances, and disease. Its spatial heterogeneity can be used as an indicator of the crop condition resulting from vegetation response to soil properties and specifically nutrients availability for given weather conditions.

Drought monitoring, corresponding to the state and dynamics of vegetation, in a given time interval may be accounting for LAI values derived from satellite data.

The **Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)** is a non-dimensional value that measures to the fraction of the incoming solar radiation at the top of the vegetation canopy that contributes to plants' photosynthetic activity, and thus indicates the presence and productivity of live green vegetation.

FAPAR is not directly measurable, but is inferred from models describing the transfer of solar radiation in plant canopies, using remote sensing observations as constraints. Space agencies, including NASA and ESA, and research institutions such as the EC JRC have been generating FAPAR products on a regular basis, using a variety of sensors. These efforts, including archiving and distribution, remain funded by research budgets and are in need of more systematic support to ensure the continuous, long-term operational availability of this product. Daily recovery of FAPAR is possible in principle, but cloud and thick aerosols often obscure the surface and result in incomplete maps. This issue is normally addressed by generating time-composited FAPAR maps that aim to convey information on central tendencies (statistical first moments of the distribution) while providing as complete a spatial coverage as possible. To detect trends in the presence of inter-annual variability requires long time series. To that end, existing archives of satellite data from instruments such as SeaWiFS have been reprocessed to generate long time series that are coherent and consistent with the most recent sensors. This is best achieved with sensors that include a blue channel, which is particularly sensitive to atmospheric aerosols.

Monitoring LAI and fAPAR on regional scale could help in tracking water stress and drought conditions in a given ecosystem. Droughts cause a reduction in the vegetation growth rate, which is affected by changes either in the solar interception of the plant or in the light use efficiency. A reduction in the intercepted radiation, and therefore in fAPAR, is always a consequence of droughts, both in early or late events. LAI greatly affects soil water balance: when LAI increases under constant soil water content and climate conditions, decrease in annual transpiration per unit of LAI is accompanied by an increase in drought stress. LAI and fAPAR biophysical parameters are used as satellite derived parameter for calculation of surface photosynthesis, evapotranspiration, soil water retention capacity and annual net primary production (Myneni et al., 2003).

Evapotranspiration (ET) is used to calculate regional water and energy balance, soil water status; hence, it provides key information for water resource management. With long-term ET data, the effects of changes in climate, land use, and ecosystems disturbances (e.g. wildfires and insect outbreaks) on regional water resources and land surface energy change can be quantified.

Remote sensing data with the increasing imagery resolution is a useful tool to provide ET information over different temporal and spatial scales. During the last decades important progresses were made in the determination of ET using remote sensing techniques.

The estimation of ET parameter, corresponding to the latent heat flux (λE) from remote sensing is based on the energy balance evaluation through several surface properties such as albedo, surface temperature (Ts), vegetation cover, and leaf area index (LAI). Surface energy balance (SEB) models are based on the surface energy budget equation. To estimate regional crop ET, three basic types of remote sensing approaches have been successfully applied (Su, 2002).

The most used satellite-derived ET products are: the EUMETSAT Land SAF products and the MODIS ones. For example the MOD 16 Global terrestrial ET, at 1km resolution is computed globally at 8-day, monthly and annual intervals.

The **Land Surface Temperature (LST)** is generally defined as the skin temperature of the ground. For the bare soil surface, LST is the soil surface temperature; for dense vegetated ground, LST can be viewed as the canopy surface temperature of the vegetation; and in sparse vegetated ground, it is the average temperature of the vegetation canopy, vegetation body and soil surface under the vegetation. Considering of the spatial resolution of satellite remote sensing data, the LST in remote sensing can be defined as the average surface temperature of the ground under the pixel scale mixed with different fractions of surface types.

The surface temperature is a main indicator of the surface energy balance of the Earth and it is used as input data in climate change and agro-meteorological to forecast the heat wave, to analyse heat islands in urban areas, to decide the optimal timing of agricultural activities, etc. (Peres and DaCamara, 2004).

The variation of vegetation temperature depends on vegetation moisture content and is able to detect a sign of damage from a drought, being useful for early diagnosis of crop water stress.

The combination of LST and NDVI can provide information about the condition of vegetation and then for the assessment of the crops affected by drought. The NDVI is a rather conservative indicator of water stress, because the vegetation remains green after the start of this stress and the LST increases rapidly with the water stress. For a given dry zone, the relationship between LST and the NDVI is presented by a cloud of dispersion in the LST-NDVI space. This relationship is often expressed by the slope of a line fitted to the dry edge of the space LST-NDVI (figure 41).

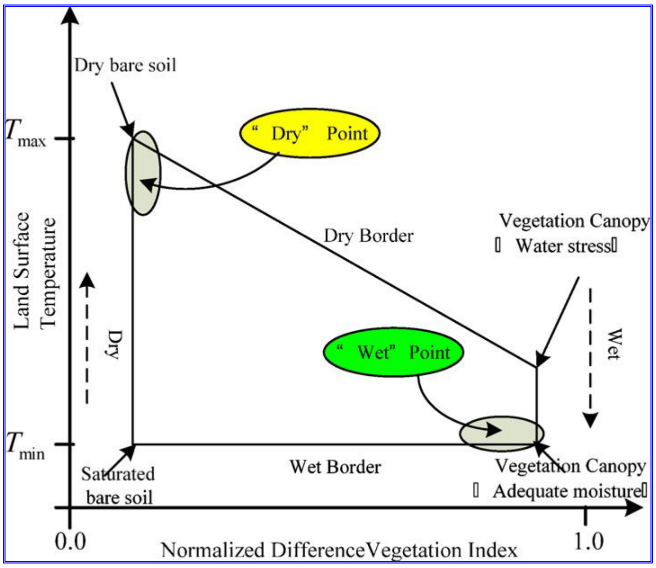


Figure 40: The LST-NDVI space, able to provide information about the vegetation stress and the soil moisture conditions

In the LST-NDVI space, the left edge represents bare soil from dry to wet (top-down) range. As the amount of green vegetation increases, the NDVI value also increases along the X axis and therefore the maximum LST decreases. For dry conditions, the negative relationship between LST and NDVI is defined by the upper edge, which is the upper limit of LST for a given type of surface and climatic conditions. The analysis of LST-NDVI space can be also used to derive information on conditions of regional soil moisture.

Soil moisture data and indicators:

Soil moisture observations from space cover practically last 30 years. Different sensors were used for this purpose according to their availability in individual periods: visible, thermal IR, microwave passive and microwave active. Soil moisture products derived from current and future active and passive microwave sensors operating in the low frequency range from 1 to 10 GHz include: ASCAT, SMOS, AMSR-E, ASAR, SMAP, Sentinel-1 and any combination thereof, like:

AMSR2/GCOM-W1, provided by the AMSRE sensor on Aqua, offers the soil moisture with a spatial resolution of 10km x 25km;

H-SAF surface soil moisture retrieved from METOP/ASCAT data H-07 with 25 km resolution;

H-SAF surface soil moisture retrieved from METOP/ASCAT data and downscaled to 1 km resolution with use of other microwave sensors;

H-SAF/ECMWF soil moisture in root region in 4 layers (0-7 cm, 7-28 cm, 28-100 cm, 100-289 cm) with 25 km resolution.

Also assimilation of satellite data into models for retrieval of soil moisture is interesting solution.

Soil moisture retrieval from active microwave data is subject of certain limitations: soil moisture cannot be retrieved if the signal is dominated by scattering from dense vegetation, open water, rough topography or a snow covered/frozen land surfaces. To avoid assimilating data contaminated by these effects a rigorous quality check has to be carried out before the soil moisture data is assimilated in models.

Satellite data and products archives

The analysis of vegetation anomalies resulting from drought impact requires access to different types of services:

<u>Long-term archives</u> (preferably freely available) consisting of satellite channel data. The most known archives containing information registered by the satellite sensors in individual spectral channels with an indication of data type, temporal coverage and geographical area, focusing on Europe are presented in Table 22. Archives cover entire periods of satellite instrument availability or in many cases are connected with certain projects or actions and in such case covers only the period of available data during realisation of the project. As a result, available datasets start in 1978 at the earliest when based on AVHRR/NOAA data or in 2000 when based on MODIS sensor and cover periods until the present time. Coverage of 10-30 years is sufficient for studies on relationships between agrometeorological parameters and drought conditions in Europe;

<u>Various processed indices</u> used for characterization of the actual state of the biosphere. Typical indices related to vegetation monitoring are based on visible/near-infrared spectral channels of satellite sensors like: AVHRR/NOAA, MODIS/Terra, Aqua, VGT/SPOT, MERIS/ENVISAT, SEVIRI/MSG and many others (Heute et. al., 2002; Congalton and Green, 2009). The available indices are closely related with a wide spectrum of physical, biophysical or agricultural parameters like: albedo, NDVI, LAI, FAPAR, vegetation percentage, biomass, land cover, fire and burned area, vegetation anomalies, thermal anomalies, vegetation health index, radiation balance components and many others.

Due to cloudiness, most of mentioned parameters are calculated with selected time step: individual orbit, weekly, 10 days and 16 days, monthly. Also anomalies of selected parameters are available, in comparison to other selected years or to multiannual means.

Software tools for exploitation of satellite archives

The access to required satellite data and products is less difficult when specialized search engines and selection tools are applied. Administrators of individual archives provide many interesting tools which allow for:

Product selection from the archive;

Geographical area selection;

Time period selection;

Ordering products or direct connection to FTP site for download;

Visualization software based on distributed data format is available.

Example of tools used for satellite products search and retrieval are presented in table 22.

Service	Internet link	Short description
EUMETSAT Product Navigator	http://navigator.eumetsat. int	Search engine to various satellite products both transmitted in real time and archived
Search and Preview Tool (www.landcover.org)	http://glcfapp.umiacs.umd. edu:8080/esdi/index. jsp?productID=19	Search engine to land cover products
USGS Global Visualisation Viewer GloVis	http://glovis.usgs.org	Online search and order tool for selected satellite data. The viewer allows access to all available browse images from the Landsat 7 ETM+, Landsat 4/5 TM, Landsat 1-5 MSS, EO-1 ALI, EO-1 Hyperion, MRLC, and Tri-Decadal data sets, as well as Aster TIR, Aster VNIR and MODIS browse images from the DAAC inventory.
NASA Warehouse Inventory Search Tool (WIST)	https://wist.echo.nasa.gov/~wist/api/imswelcome/	All LP DAAC data holdings available · Search and order earth science data from all NASA data centers · Replacement for EOSDIS Data Gateway (EDG).
LP DAAC MODIS Reprojection Tool on the Web (MRTWeb)	http://mrtweb.cs.usgs.org	Selected MODIS Land Product Tiles · Search, Visualize, Select · Mosaicking, Spatial Subsetting, Band Subsetting, Reprojection, Reformatting.
LP DAAC Data Pool	http://lpdaac.usgs.org/lpdaac/get_data/data_pool	Selected LP DAAC ASTER and MODIS data holdings · Direct FTP access · All data are at no charge.

Table 22: Selected tools helping with satellite products search and retrieval

Beside these tools, there are many other software (for geographic information and remote sensing), which incorporates geospatial image processing and analysis into a single powerful, convenient package.

The Geographic Information Systems (GIS) are designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. The GIS tools are based on digital cartography, statistical analysis, and computer science technology.

Satellite image processing and GIS techniques

Remote sensing techniques play an important role in crop identification, acreage and production estimation, disease and stress detection, soil and water resources characterization because they provide spatially explicit information and access to remote locations. These techniques allow examining the properties and processes of ecosystems and their inter-annual variability at multiple scales, over large areas of interest almost every day.

Data sets provided by satellite systems can be used in global, regional or local studies, to obtain input data used to produce various models of energy balance, water balance, etc.

The vegetation indices and biophysical and structural parameters offer significant information about drought. Each of these indices and parameters is computed using specific formula and dedicated software.

Methods for LAI and fAPAR estimation

LAI and fAPAR biophysical parameters are used as satellite derived parameters for calculation of surface photosynthesis, evapotranspiration, soil water retention capacity and annual net primary production (Myneni et al., 2003).

The methods to estimate canopy biophysical variables, like LAI and fAPAR, from reflectance data are mainly supported by statistical and process-based approaches (using radiative transfer models). The statistical approaches are based on in situ observations of the spectral reflectance and consist of fitting a relationship between the reflectances and some biophysical variables, mainly by the use of vegetation indices (Tripathi et al., 2012).

The estimation of LAI and fAPAR from surface reflectance is influenced by different sources of uncertainties:

uncertainties in surface reflectance measurements due to topography, view illumination geometry effects, calibration errors, residual atmospheric and cloud contamination, background under the canopy as bright soil or snow cover;

uncertainties generated by the representation of canopy architecture in the LAI retrieval algorithms: the spatial variation of leaf area density leading to foliage clumping;

uncertainties due to the applicability of the algorithm to a range of vegetation types and environmental conditions. Each algorithm which estimates LAI and fAPAR is based on empirical assumptions regarding the distribution of the parameters generated by the canopy and soil characteristics. For example, classification errors in the algorithms that update the land cover map for their spatial extension can generate LAI estimation error up to 50% of the actual value. The number of land cover classes can be too low to represent the global variability of vegetation structure.

The retrieval of LAI from remotely sensed data has led to the development of various approaches and methodologies at different scales and over diverse types of vegetation canopies. LAI are generated globally from satellite data like NOAA-AVHRR, Terra-MODIS and SPOT-VGT at different spatial resolutions (250 m to 1 degree) and temporal frequencies (4-day, 8-day and monthly).

Algorithm for LAI products assessment from moderate spatial resolution satellite data

Remote sensing observations acquired with moderate resolution optical sensors (with pixel sizes from 250 m to 1 km) allow monitoring the seasonal and inter-annual variability of LAI fields over regional to global domains.

The algorithm for generating the MODIS LAI products uses surface reflectance (MOD09) and land cover (MOD12) products. The MODIS LAI algorithm (figure 42) is based on three-dimensional radiative transfer theory and is developed for inversion using a look-up table (LUT) method.

LUTs are generated for each biome by running the algorithm for various combinations of LAI and soil type. A backup algorithm, based on relations between NDVI and LAI, associated with a biome classification map, is used to retrieve LAI values if the main algorithm fails.
The MODIS products were geo-referenced by using the MODIS re-projection tool (MRT) software. To build the optimal statistical regression model to estimate LAI for a study area, several sets of independent variables that are subset of a few spectral vegetation indices have been compared.

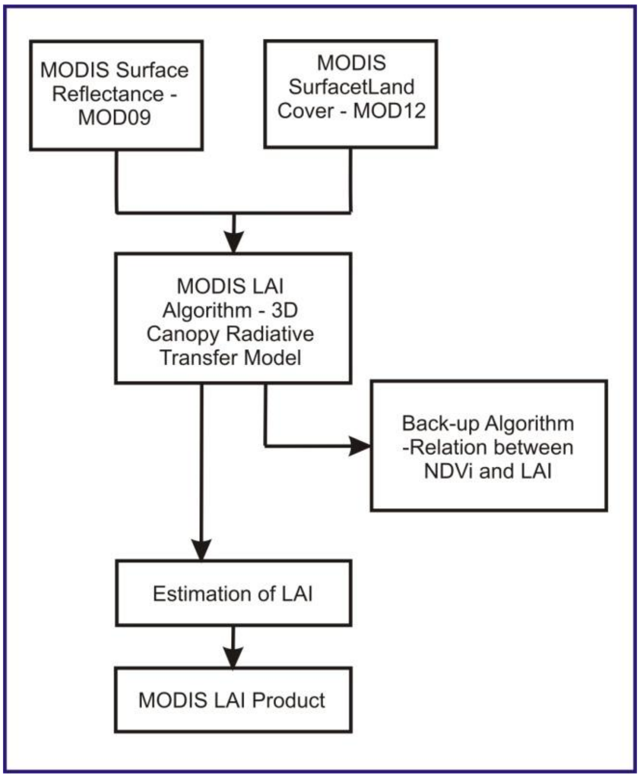


Figure 41: Flowchart for producing MODIS LAI product

The figure 43 presents an example of MODIS LAI product over a study area situated in the South of Romania (the Olt County)) for July 3, 2008' the LAI was obtained from MOD09 product acquired in the same day and MODIS Land Cover product.
The NDVI was used as independent variable for the regression to estimate LAI for the study area. Two multiple regression models were built for the crops (maize and sunflower). In addition, the land cover map was used in order to validate the empirical LAI estimation algorithm. A land cover map, in which the class categorization is comparable to the MODIS Land cover type 3-scheme (9 classes), was obtained by ordinary maximum likelihood classification method.
In this case the one dimensional radiative transfer model SAIL was used to create the LUTs in order to obtain canopy reflectance for MODIS bands 1 and 2 (Andrieu et al., 1997; Combal et al., 2002).
The LAI values estimated for maize and sunflower and the corresponding relative root mean square error are presented in the table 23.

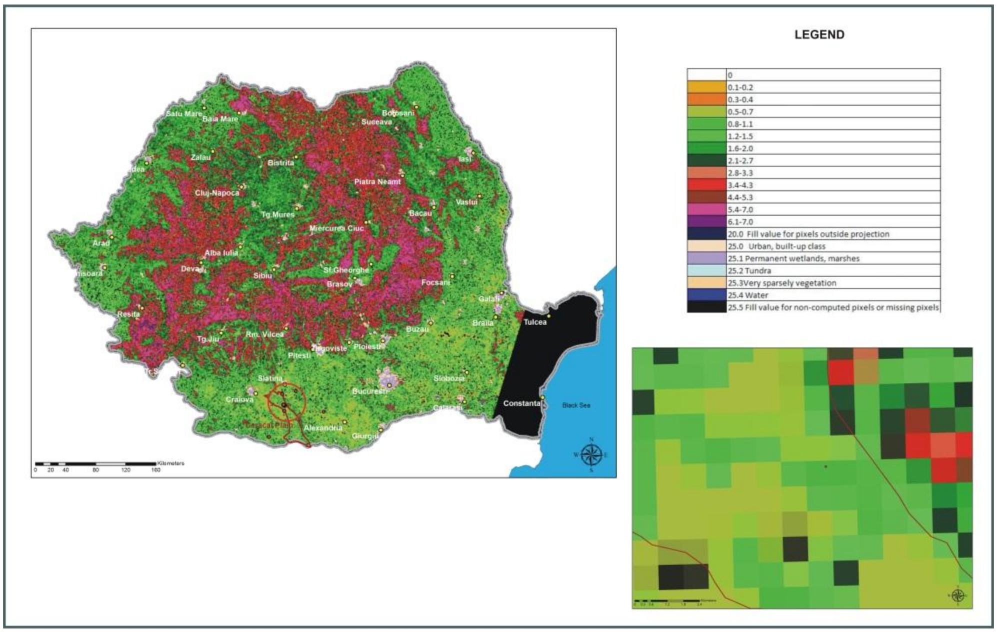


Figure 42: MODIS LAI product in the test-area situated in the South of Romania, on 03.07.2008

Site	Measured LAI	Retrieved LAI	RMSE
P3 – maize - 1	2.9	1.9876	0.2561
P3 – maize - 2	3.0	2.0466	0.2802
P3 – maize - 3	3.4	2.8914	0.3146
P3 – maize - 4	2.6	1.6827	0.2441
P3 – maize - 5	2.3	1.8420	0.2564
P3 – maize - 6	3.1	2.6430	0.2207
P3 – maize - 7	3.2	2.6742	0.2432
P3 – maize - 8	3.4	2.7020	0.2897
P3 – maize - 9	3.1	2.0030	0.2994
P3 – maize - 10	2.8	1.9067	0.3004
P4 – sunflower - 1	2.1	1.7863	0.2668
P4 – sunflower - 1	2.4	1.0463	0.3125
P4 – sunflower - 1	1.9	0.9081	0.2992
P4 – sunflower - 1	1.9	0.8965	0.2860
P4 – sunflower - 1	2.2	1.1240	0.8940
P4 – sunflower - 1	1.6	0.6064	0.3453
P4 – sunflower - 1	2.0	1.0372	0.3002

Table 23: LAI estimates for maize and sunflower

Algorithm for LAI products assessment from high spatial resolution satellite data

The recent satellites such as IRS, FORMOSAT-2, QuickBird, etc offer both a high spatial and temporal resolution, since they can revisit a same area, every day with a constant viewing angle, with a pixel of 8m (for FORMOSAT in multispectral range or 2m in black and white).

An example of FORMOSAT-2 image processing algorithm for LAI map elaboration is presented. The image data was acquired on 5 July 2008 over an area situated in the Southern part of the Romanian Plain (the Olt County) (figure 44). Several ground plots were selected to include different crop types as wheat, maize, alfalfa, sunflower, barley. For each crop plot the LAI was measured in situ using both SunScan Canopy Analysis System and hemispherical canopy photography.

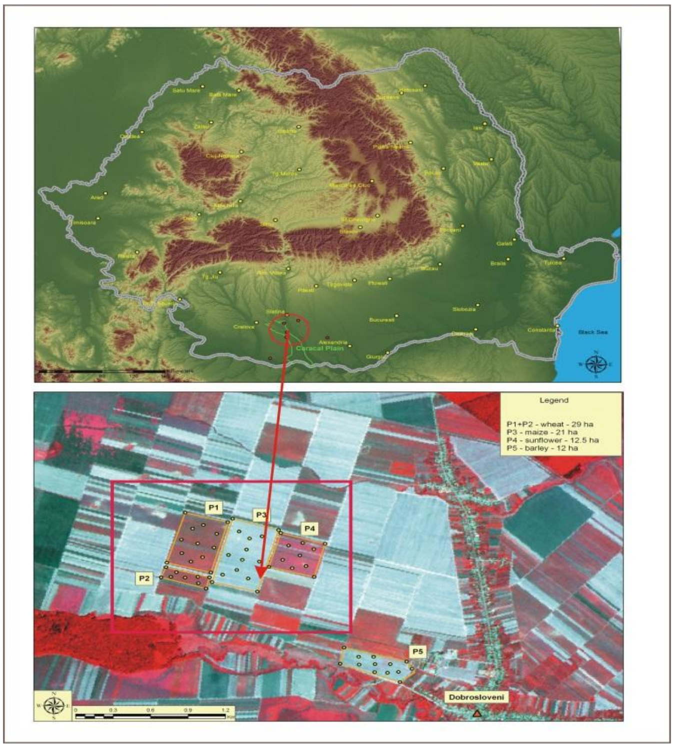


Figure 43: Location of the study area using a FORMOSAT-2 image with the main cover types

The figure 45 shows the overall procedure to construct LAI maps using high resolution data and in situ measured LAI.

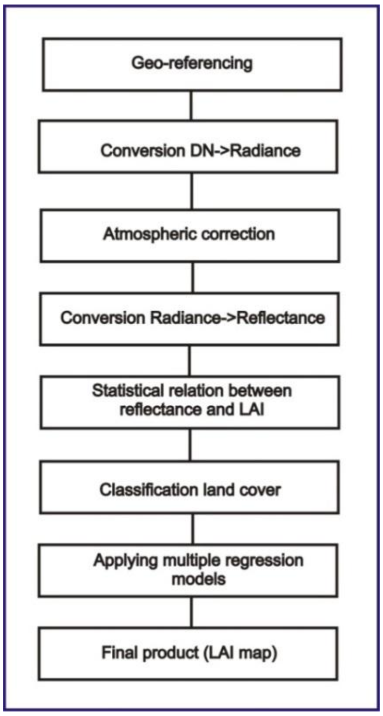


Figure 44: The procedure to construct the LAI map using a high resolution image and field measured LAI

The method to derive LAI map from high resolution satellite image includes the following main steps:

The georeferencing of the FORMOSAT image data to plane rectangular coordinate system by using a set of ground control points obtained from topographic maps. The Digital Number (DN) value of the original image have to be converted to radiance by applying sensor's gain and bias coefficients obtained from the image header.

The atmospheric and topographic effects corrections using ATCOR for ERDAS Imagine 9.3 tool.

Conversion of radiance to reflectance using the following formula:

$$\rho = \frac{\pi * L_\lambda * K}{E_{sun} * \cos\theta_s}$$

where: Lλ – radiance corresponds to the band λ;

K – correction factor for the distance Sun-Earth;

Esun – solar spectral irradiance in the Top of the Atmosphere (TOA) for a given spectral band;

θs – solar zenith angle.

Overlaying a vector map of ground plots of the field LAI measurement on the geo-referenced FORMOSAT reflectance data and extraction of the pixels corresponding to each crop plot.

Land cover classification to assure accurate retrieval of LAI for different crop types.

Appy a correlation analysis to compare the field measured-LAI and the image spectral reflectance. Linear or non-linear models were fitted based on the plot trends and best-fit R^2 values. When non-linearity existed, exponential or power or quadratic models were fitted. These equation forms were exponential (crop variable = $a.e^{b \cdot VI}$), quadratic ($a \cdot VI^2 + b.VI + c$), linear ($a + b \cdot VI$), and power ($a \cdot VI^b$); where a = slope and b = intercept of soil line (obtained by plotting RED versus NIR bands), and VI = vegetation index. Non-linear exponential relationships provided the best fits in most relationships and were hence adopted.

The figure 46 shows an example of the LAI obtained from a FORMOSAT-2 image in the test-area located in the South-Eastern part of Romania. In this case for the LAI estimation, a correlation function NDVI – LAI (Asrar et al.,1984) was used:

$$LAI - \frac{1}{K_{LAI}} \ln\left(\frac{NDVI - NDVI_\infty}{NDVI_s - NDVI_\infty}\right)$$

Where: $NDVI_\infty$ represent the asymptotic value of NDVI when LAI tends towards a maximum value and $NDVI_s$ is the bare soil NDVI. The parameter K_{LAI} is the extinction coefficient.

The best results was obtained for $\mathrm{NDVI}_\infty = 0.9$, $\mathrm{NDVI}_s = 0.1$ and $\mathrm{K}_{\mathrm{LAI}} = 0.8$. In this case the relative root mean square error ($RMSE_R$) was 31.2%.

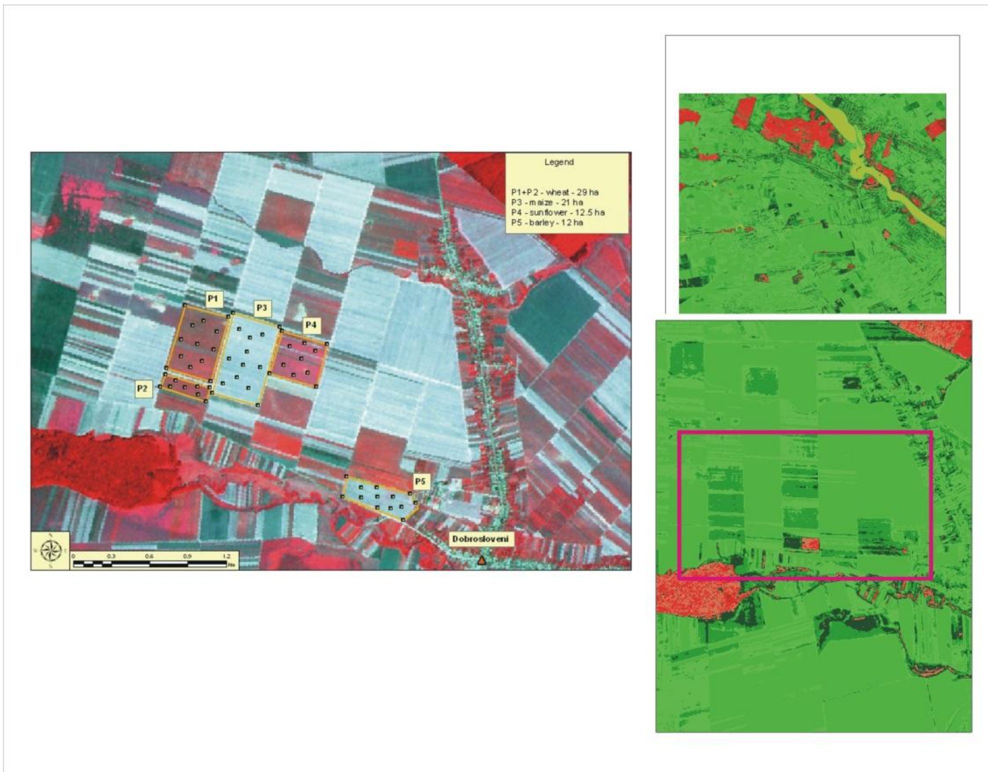


Figure 45: The LAI map obtained from the FORMOSAT2 image of 05.07.2008

<u>Algorithm for computing the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)</u>

FAPAR is recovered from a range of sensors by various algorithms using the visible and infrared parts of the spectrum, and the accuracy and reliability of these products is not always properly documented.

The FAPAR can be estimated from LAI using the Beer's law (Jarvis and Levernez, 1983), known as:

FAPAR=$1 - e^{-k*LAI}$)

where: *k* is an extinction coefficient measuring a canopy radiation attenuation. For randomly distributed leaves, k is estimated to 0.5 (Sprintsin et al., 2007).

Applications of satellite remote sensing and GIS techniques for drought monitoring and assessment in Romania

The vegetation indices and biophysical and structural parameters obtained from satellite data offer significant information about drought monitoring and assessment over large areas. In order to evaluate de drought affected areas, the vegetation indices, the biophysical parameters and physically-based vegetation state indicators as well as the auxiliary data (administrative units, crop parcels, etc.) are integrated into the GIS environment.

In the following part of this chapter are presented some examples of satellite-derived products useful for drought monitoring and assessment over the agricultural areas of Romanian territory.

The figure 47 presents the *SPOT Vegetation 10 days NDVI synthesis* for the period 31.07-10.08.2007 over Romania; the positive NDVI values are in colour shades of green to dark green and negative values are represented in colour shades from yellow to brown, indicating a lack of vegetation or bad vegetation condition state.

Comparing current NDVI images with older ones it is possible to assess the positive and negative deviations that occur during the growing season of vegetation and evaluate the state's relative vegetation throughout the growing season.

The *NDVI time series* analysis is very important for crop state monitoring. Such a complex analysis is explained bellow and was made using MODIS/TERRA NDVI products (MOD13A1) for the following years: 2000 as a drought year; 2003 as the year to be determined for if there was any drought occurrence or not; 2005 considered normal as climatic behavior and 2010 with a greater amount of precipitation that the normal average and for different vegetation phases. The study area is situated in the lower basin of the Mures River, located in the Western part of Romania (Pecica agricultural area) (figure 48).

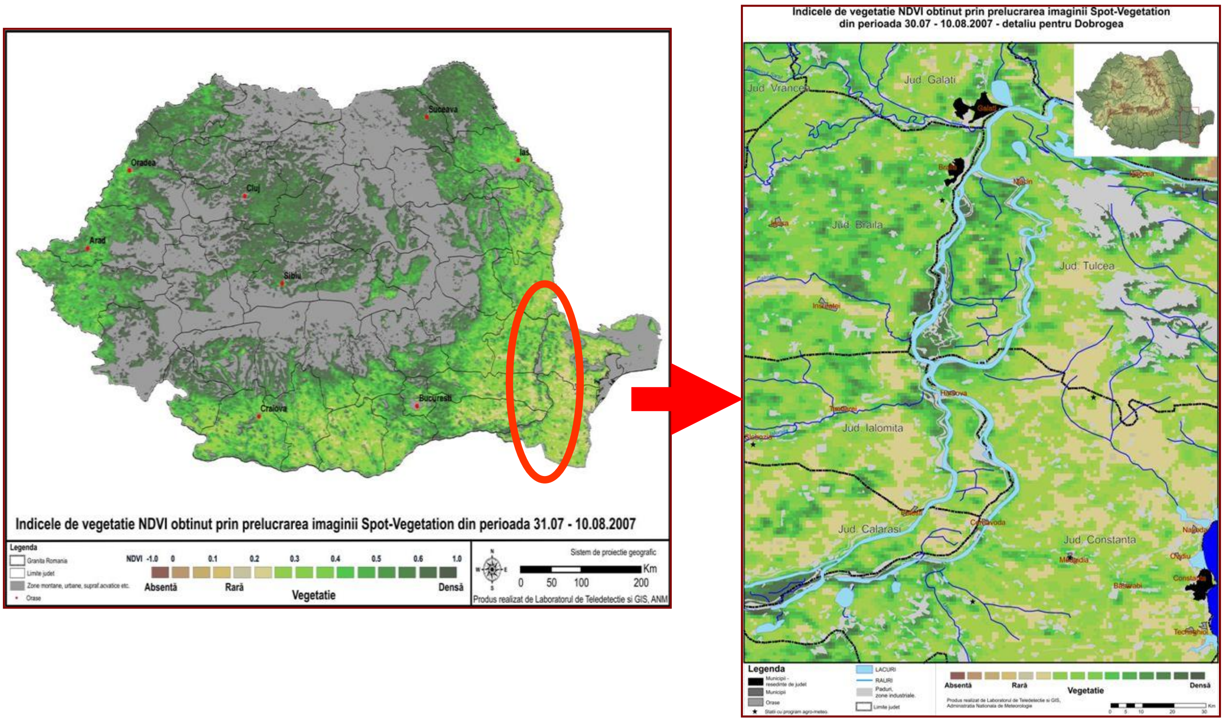


Figure 46: SPOT Vegetation 10 days NDVI synthesis over Romania, 31.07-10.08.2007; in the right part is highlighted the South-eastern region (Dobrogea) more affected by extremely droughty conditions.

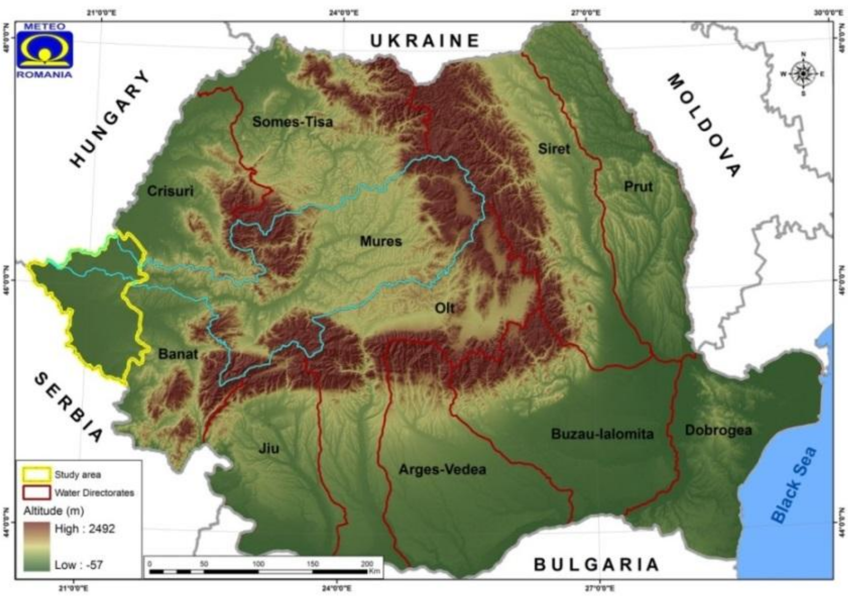
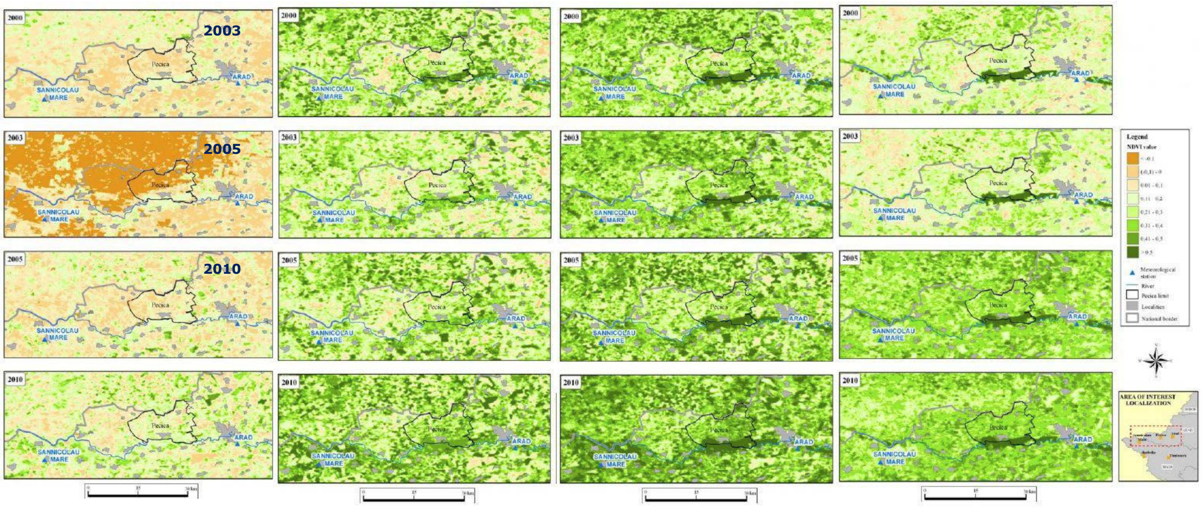


Figure 47: Location of the study area in the Western part of Romania

The figure 249 reveals that in the period 6 March - 6.April 2003, the NDVI values were lower, compared to the rest, mainly because of the lack of precipitations in March which have caused a delay of the vegetation season start. The year 2010, on the other hand, presents greater NDVI values due to high amount of precipitations. The NDVI maps show a rather equal set of values between the four years, with a slight grow in 2005 and 2010 compared to 2000 and 2003 for the periods: from the 7 April to 8 May and from 9 May to 9 June. Only during the last vegetation phenol-phase a visible difference occurs between 2000 and 2003 on one hand, and between 2005 and 2010 on the other hand. The analysis clearly shows the effect of low precipitation and high temperatures in 2000 and 2003 (very droughty years) over the agricultural areas.



a) b) c) d)

Figure 48: Spatial variation of average NDVI values for 2000, 2003, 2005 and 2010 for the periods: a) 6 March – 6 April; b) 7April – 8 May; c) 9.May – 9 June; d) 10.June - 28.August.

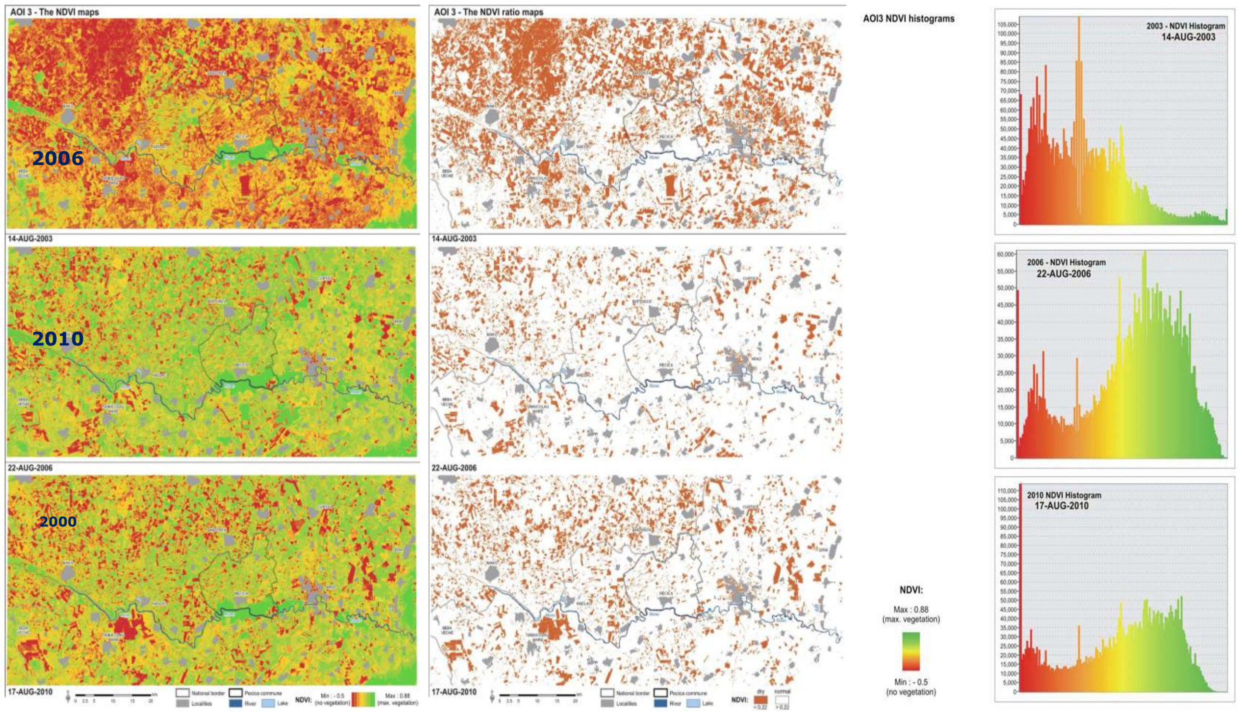
The NDVI-based analysis for crop state monitoring was also performed using high-resolution satellite images, such as LANDSAT TM/ETM+ data.

Figure 49 presents an example of using LANDSAT TM/ETM+ data for 14.08.2003, 22.08.2006 and 17.08.2010, in the same study area, located in the lower basin of the Mures River, Pecica agricultural area.

The figure 50a shows a “hot-spot” area, associated with very low NDVI values (pixels in orange and red), in the centre-eastern part of the image acquired on 14.08.2003 (up left image) and normal NDVI values in the other 2 images acquired in 22.08.2006 and 17.08.2010, respectively.

In order to isolate only the parts affected by drought a “low-vegetation” NDVI threshold was applied to highlight only two classes (figure 50b). The threshold value able to separate the dry and normal conditions was set up using the NDVI histograms (figure 50c).

For this study an NDVI value of 0.22 was used as “drought threshold“. This two-class representation excludes the “normal” NDVI values while keeping the low ones. Areas represented in brown in figure 50b can be therefore associated with dry areas.



a) b) c)

Figure 49: : a) The NDVI maps extracted from LANDSAT data; b) The two classes NDVI maps obtained by applying a "low-vegetation" NDVI threshold; c) NDVI histograms.

The *Enhanced Vegetation Index (EVI)* incorporates this atmospheric resistance concept, along with the removal of soil-brightness induced variations. The EVI additionally decouples the soil and atmospheric influences from the vegetation signal by including a feedback term for simultaneous correction. While the EVI is calculated similarly to NDVI, it corrects for some distortions in the reflected light caused by the particles in the air as well as the ground cover below the vegetation. The EVI data product also does not become saturated as easily as the NDVI when viewing rainforests and other areas of the Earth with large amounts of chlorophyll. Similar to the methodology used for NDVI analyses and representations, EVI values were also taken into account.

In figure 51 is presented an example of EVI synthesis map over Romania, for the period 14 -29 August 2007, derived from the MOD13A2 product, with 1 km spatial resolution. The EVI values distribution show the regions affected by drought in South-Eastern, and western parts of Romania.

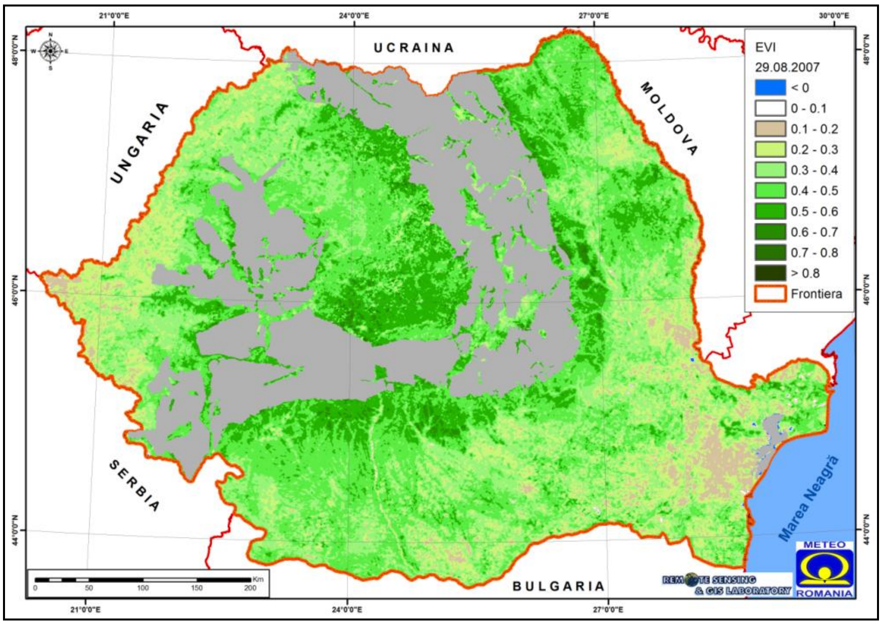


Figure 50: EVI derived from MOD13A2, 14 – 29 August 2007

The *Normalized Difference Water Index (NDWI)* is considered a good indicator of water content of leaves and is used for detecting and monitoring the humidity of the vegetation cover. NWDI holds considerable potential for drought monitoring because the two spectral bands used for its calculation are responsive to changes in the water content (SWIR band). As a result, NWDI is influenced by both the desiccation and wilting of vegetation and may be a more sensitive drought indicator than traditional remote sensing-based indices such as the NDVI, which do not account for changes in the vegetation's water content. This index increases with vegetation water content or from dry soil to free water.

The figure 52 presents the NDWI over Romania, obtained from MODIS MOD09A1 products (8-day composite) for 2005 (rainy year) and 2007 (droughty year). The figure clearly emphasized the large areas affected by drought in 2007, in the Eastern, South-eastern and Western agricultural regions of Romania.

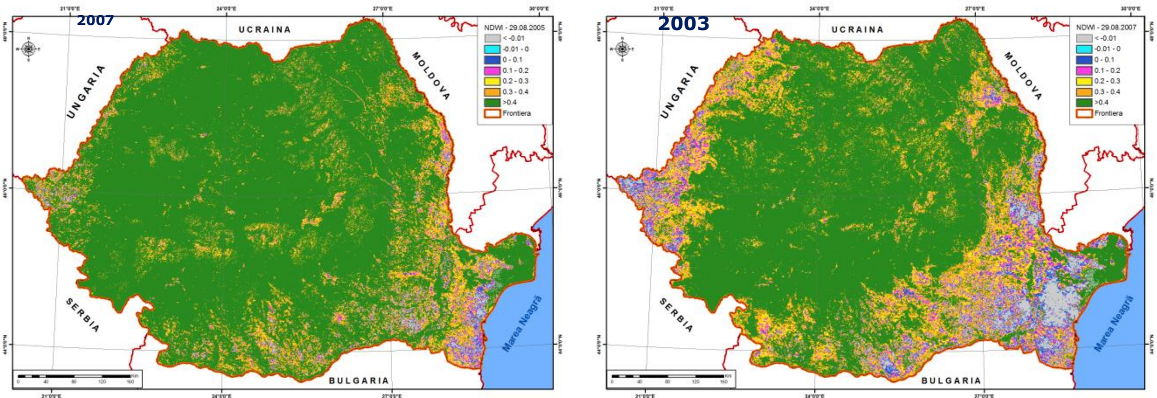


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Figure 51: NDWI maps over Romania, obtained from MOD09A1 products (8-day composite): for 10.06.2005 (left) and 10.06.2007 (right).

The *Normalized Difference Drought Index (NDDI)* combines information from both the NDWI and NDVI data derived from MODIS data. NDDI was found to be more responsive and have wider dynamic range values than a simple NDVI-NDWI differencing through drought periods.

The NDDI is characterized by its ease of calculation because it is based on normalized difference and it does not depend on time series data. This index can be an optimal complement to in-situ based indicators or for other indicators based on remote sensing data

The figure 53 shows the NDDI over Romania, obtained from MODIS MOD09A1 products (8-day composite) for 2005 (rainy year) and 2007 (droughty year).

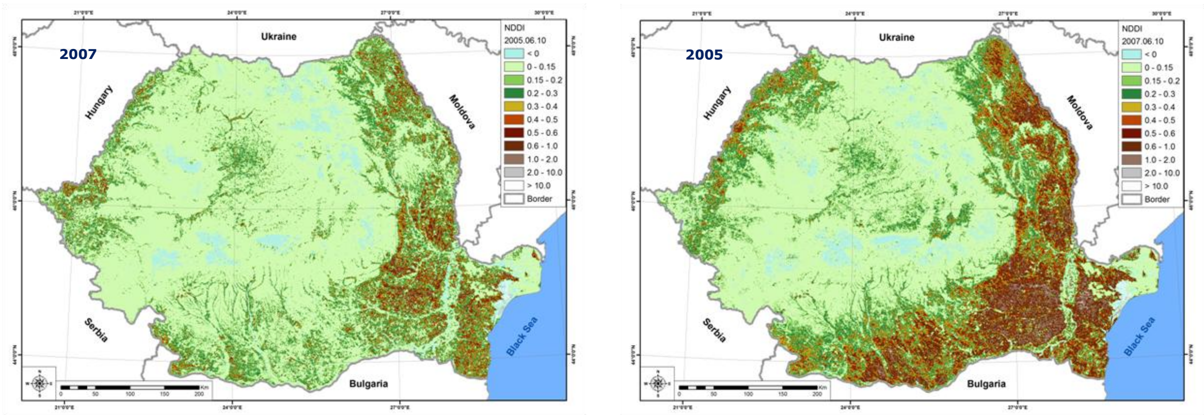


Figure 52: NDDI maps over Romania, obtained from MOD09A1 products (8-day composite): for 10.06.2005 (left) and 10.06.2007 (right).

The figure 53 also highlights the areas affected by drought in 2007, especially the Eastern, South-eastern and Southern agricultural regions of Romania.

Evapotranspiration (ET) estimation using remote sensing techniques have a significant role in the assessment of the Water Footprint (WF) being a key parameter of crop irrigation management, crop water demand assessment and for production modeling in dry land agriculture.

The figure 25 presents an example of the spatial evolution of the evapotranspiration for the years 2000, 2003, 2005 and 2010 in the Western part of Romania (Pecica agricultural area), expressed by averages values from the 6th of March to the 28th of August. The evapotranspiration was obtained from the MODIS MOD16 product (Global Evapotranspiration). The figure 54 clearly emphasized the doughy years 2000 and 2003.

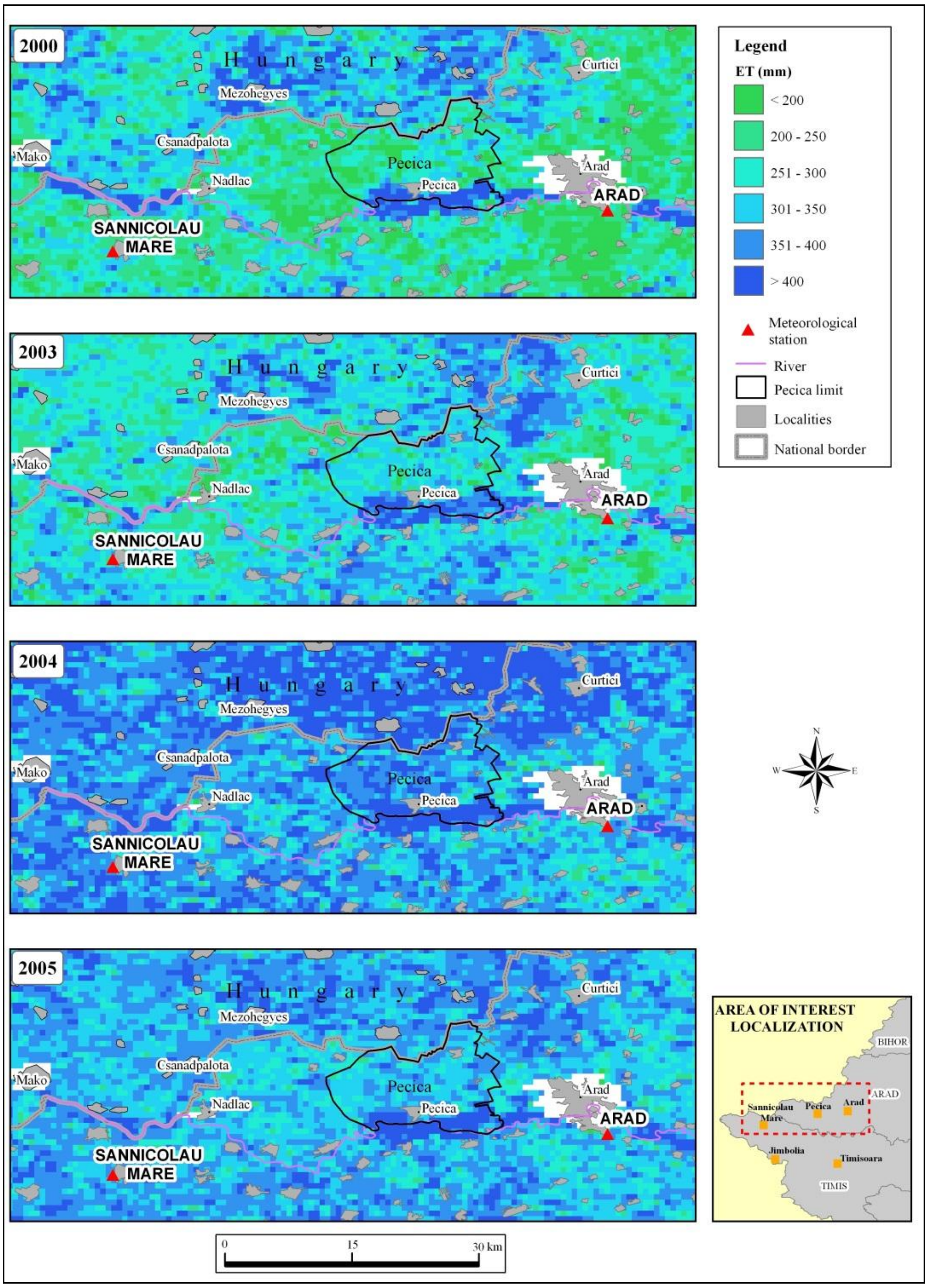


Figure 53: Spatial variation of ET values in the Western part of Romania (Pecica agricultural area). Averages values from the 6 March to 28 August

The satellite products can provide also, daily information on the soil moisture, in the superficial layer (0.5-2 cm), in relative units in the range 0% (very dry soil) to 100% (saturated soil), figure 55.

For the agrometeorological information to be as complex and accurate as possible, it is mandatory to improve the operational monitoring capabilities through the use of advanced remote sensing techniques.

By examining the spatial and temporal patterns of vegetation indices and comparing/correlating with the field conditions measured on site, it was determined that NDVI, EVI, NDWI and NDDI, are more suitable for agricultural drought characteristics monitoring.

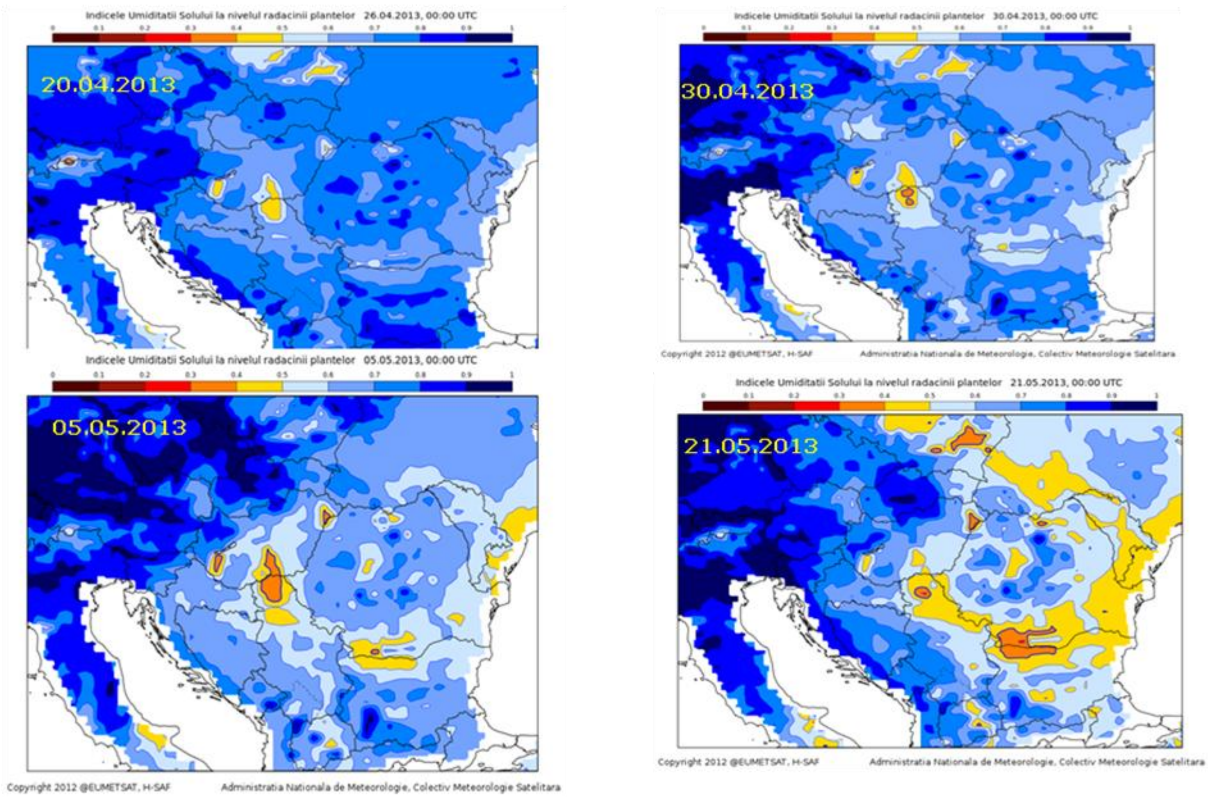


Figure 54: The soil moisture index in the soil superficial layer issue from satellite radar data MetOp - ASCAT

The use of remote sensing data in agrometeorology is a quickly developing and promising trend. The satellite remote sensing techniques play an important role in crop identification; disease and water stress detection, because they provide spatially explicit information and access to remote locations. The use of multispectral satellite data may ensure an improvement of the classical methods destined to determine the agrometeorological parameters of interest.

For a better operative surveillance of the agricultural areas and in order to work out new information products, starting with 2005, the Romanian National Meteorological Administration benefits by satellite - derived products, part of them being included and analyzed in the weekly Agrometeorological Bulletin.

The main sources of satellite data for crop vegetation state studies and monitoring are the TERRA/AQUA - MODIS, LANDSAT- TM/ETM+, ENVISAT - MERIS and SPOT-Vegetation archives.

The satellite-derived vegetation indices data and biophysical parameters proved to be good indicators of vegetation condition and relevant for the installation, duration and intensity of the agricultural drought.

The MODIS imagery still represents one of the most important type of satellite data available free of charge and can be successfully used in determining the vegetation status at one point or to predict the changes that may appear in plants activity.

The LANDSAT imagery proved to be a very useful tool in studying historical drought events of Romania; its high spatial resolution enables a detailed observation of the Earth's surface, while its broad spectral resolution allowed the development of numerous LANDSAT drought-oriented indexes.

4.3. ROIMPEL simulation model as instrument for drought assessment

ROIMPEL is an agro-climatic simulation model linked with the GIS based soil/terrain information and weather variables to evaluate the water-stress conditions.

Climate quality index

Climatic quality is assessed by using parameters that influence water availability to plants such as the amount of rainfall, slope aspect and aridity, as well as climate hazards, which might inhibit plant growth (Thornes, 1995). Table 2 shows the classification categories of climatic quality index according to Kosmas et all. (1999). Annual precipitation is classified in three classes considering the annual precipitation of 280 mm as a crucial value for soil erosion (Kosmas et al., 1997) and plant growth (Table 24). The most effective measure of soil water availability is the assessment of precipitation minus evapotranspiration and run-off. However, this calculation requires relatively many data such as soil moisture retention characteristics, vegetation growth characteristics etc., therefore, the simple Bagnouls-Gaussen aridity index (BGI) is used here. The concept of Bagnouls-Gaussen bioclimatic aridity index can be used for determining the aridity index from available meteorological data. The Bagnouls-Gaussen bioclimatic aridity index relates mean air temperature to precipitation on a monthly basis and provides a measure of water stress in the vegetation.
The Bagnouls-Gaussen aridity index (BGI) is defined as following:

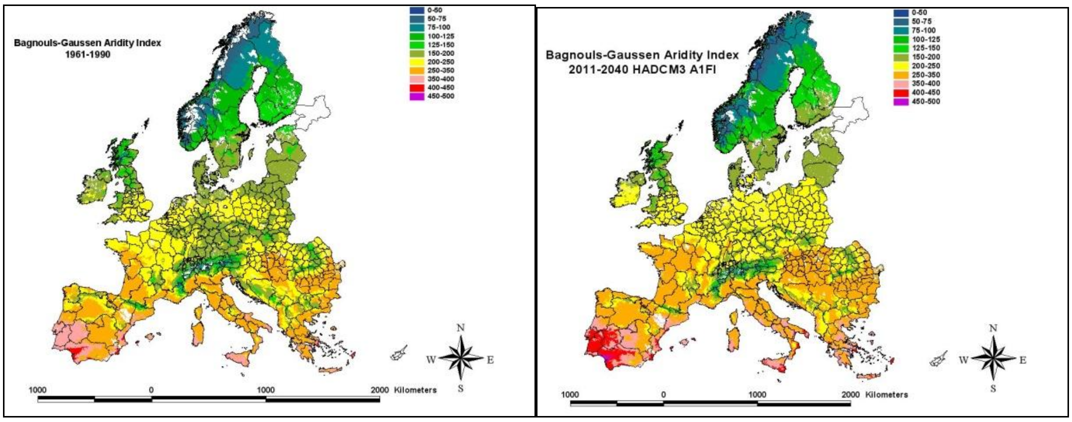
$$BGI = \sum_{i=1}^{n} (2t_i - Pi)\ k_i$$

where:
Ti is the mean air temperature for month i, in °C,
Pi is the total precipitation for month i, in mm;
k represents the proportion of month during which 2Ti - Pi >0.
The Bagnouls-Gaussen bioclimatic index is classified into six classes as in table 24.

Classes	Index	Description	Score
1	Rainfall (mm)	>650	1
2		280 to 650	1.5
3		<280	2
1	BGI Aridity index	<50	1
2		50 to 75	1.1
3		75 to 100	1.2
4		100 to 125	1.4
5		125 to 150	1.8
6		>150	2

Table 24: Classes and weighting indices for climate quality assessment

Figure 56 shows the values of Ombrothermic aridity index (Bagnouls-Gaussen) – BGI for the baseline (1961-2000) and climate change projections for 2011-2040 period (HADCM3-A1FI). It is estimated that in Central and Southern Europe will expand areas affected by drought.



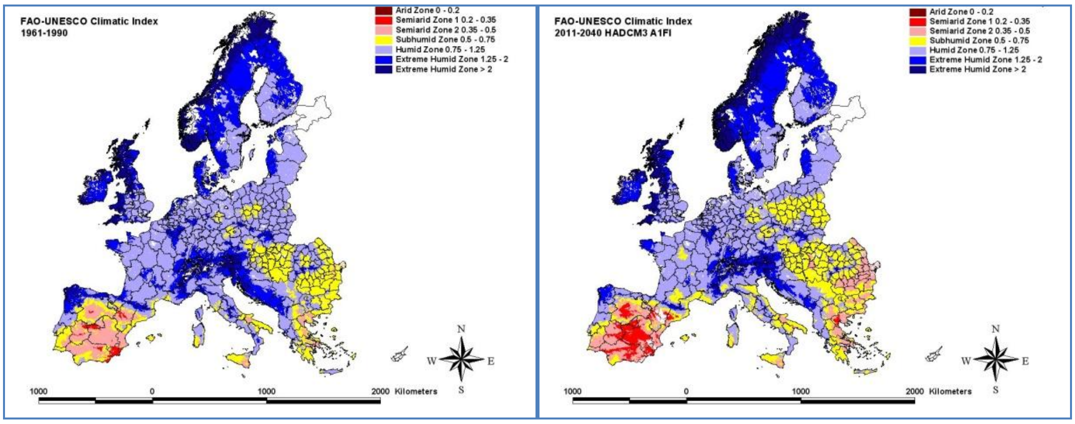
1961-1990 2011-2040 HADCM3-A1FI

Figure 55: Ombrothermic aridity index (Bagnouls-Gaussen) calculated for two time ranges (1961-1990 and 2011-2040, based on HADCM3-A1FI scenario)

The FAO-UNESCO Climatic index (1989) is defined by the ratio between precipitation (P) and Potential Evapotranspiration (ET_0):

I) Arid zone $0.03 < P/ET_0 \leq 0.20$
II) Semi-arid zone $0.20 < P/ET_0 \leq 0.50$
III) Dry subhumid $0.50 < P/ET_0 \leq 0.65$
IV) Humid zone $0.65 < P/ET_0 \leq 1.00$
V) Extreme humid zone $P/ET_0 > 1.00$

In the context of future climatic scenarios (2011-2049 period) in the South and South-East Europe the availability of water for crops will decrease in comparison with current conditions (1961-1990), figure 57.

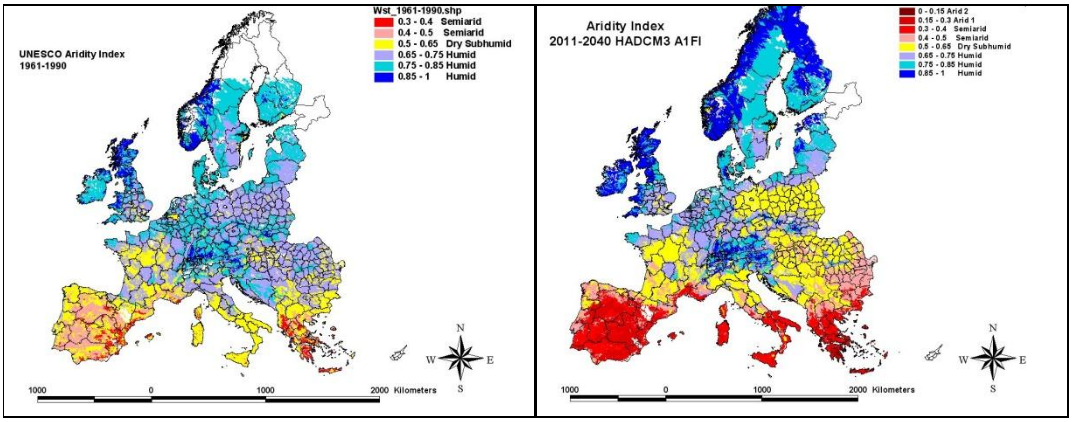


HADCM3-A1FI

Figure 56: FAO-UNESCO Climatic Index (1961-1990 and 2011-2040 based on HADCM3-A1FI scenario)

UNESCO Aridity Index (1979) is defined by the ratio between actual evapotranspiration (ETactual) and potential evapotranspiration (ET_0):

I) Arid zone $ET_{actual}/ET_0 \leq 0.3$
II) Semi-arid zone $0.3 < ET_{actual}/ET_0 \leq 0.5$
III) Dry subhumid $0.5 < ET_{actual}/ET_0 \leq 0.65$
IV) Humid zone $ET_{actual}/ET_0 > 0.65$



1961-1990 2011-20140 /HADCM3-A1FI

Figure 57: UNESCO Aridity Index (1961-1990 and 2011-2040 based on HADCM3-A1FI scenario)

The results shows a strong trend of aridity over 2011-2040 period especially in the South and Soutt-East of Europe according with the HADCM3-A1FI scenario (figure 58).

Indicators used for evaluating conventional vs. minimum tillage are: number of days with water stress below the 0.75 threshold and average daily water stress over various periods defined as: days with average temperature over 4, 8 or 10°C or average daily water stress over April-September period. Water stress is defined as the ratio between actual and potential evapotranspiration, i.e. no water stress correspond to 1 and maximum stress to 0 value.

Figure 59. shows that for the baseline scenario 1961-1990 the number of days with significant water stress is higher in conventional tillage than in minimum tillage practices mainly on light and medium textured soils.

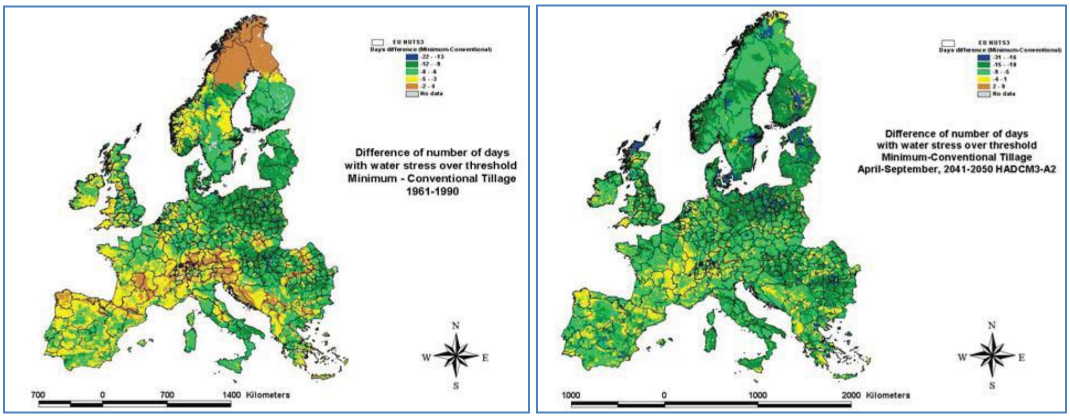


Figure 58: Difference in number of days with water stress over the threshold between minimum and conventional tillage practices (Baseline 1961-1990 and 2041-2050 HADCM3-A2 scenario)

The same trend show the daily average water deficit calculated for April-September time period: the minimum tillage is better for water conservation mainly on light and medium textured soils; the water conservation is more efficient for future climate change scenario (figure 60).

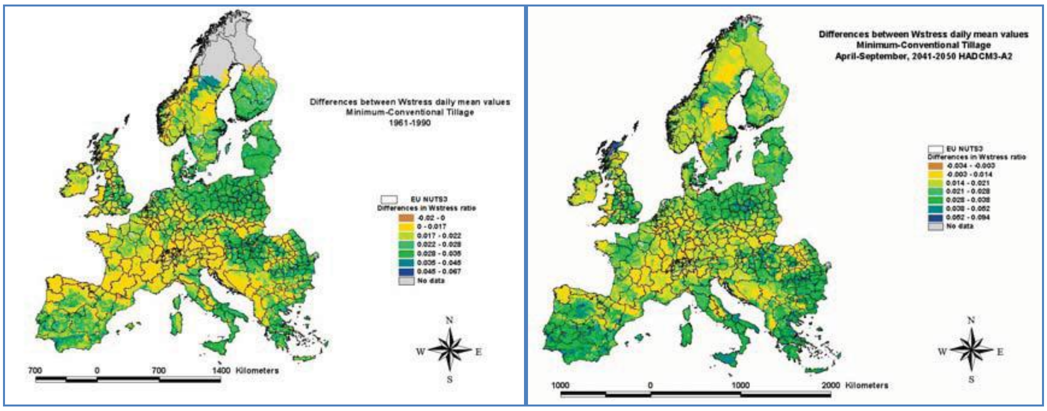


Figure 59: Average water stress difference between minimum and conventional tillage for baseline (1961-1990) and climate change scenario (2041-2050 HADCM3-A2) (1: no water stress, 0: maximum water stress)

The effect of water saving using minimum tillage on crop yields is significant in South and South-East Europe. Figure 61 presents the percentage of spring wheat yield increase/decrease if minimum tillage is used instead conventional tillage.

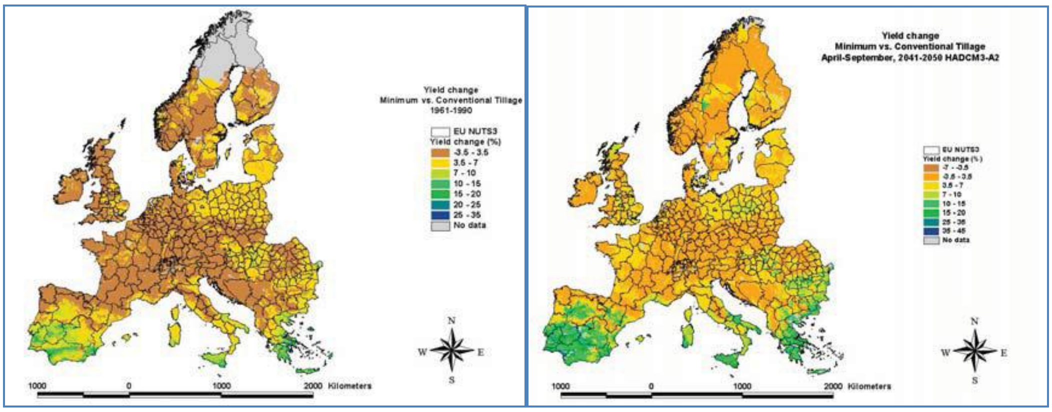
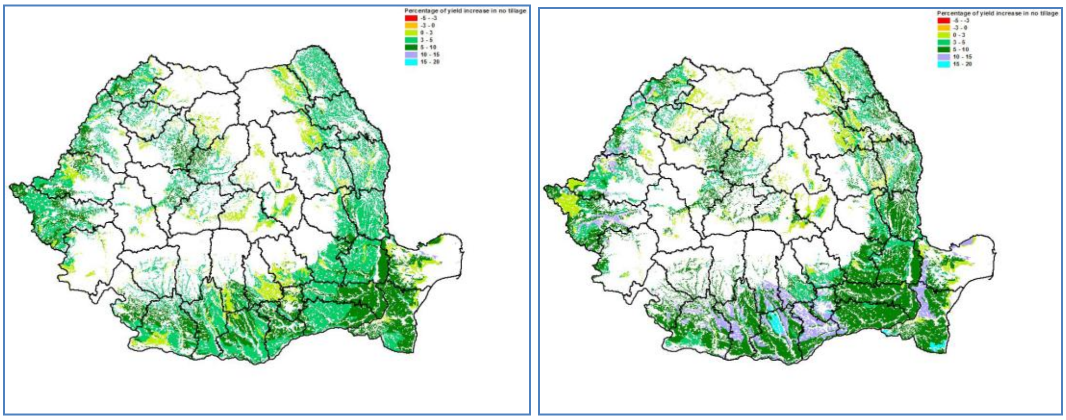


Figure 60: Yield change (%) between minimum and conventional tillage for baseline (1961-1990) and climate change scenario (2041-2050, HADCM3-A2)

The analysis based on ROIMPEL and SIDASS model linked with soil, climate and terrain databases shows various adaptation options for mitigating climate change effects on Romanian agriculture systems such as: minimum tillage, change of cultivars and irrigation.

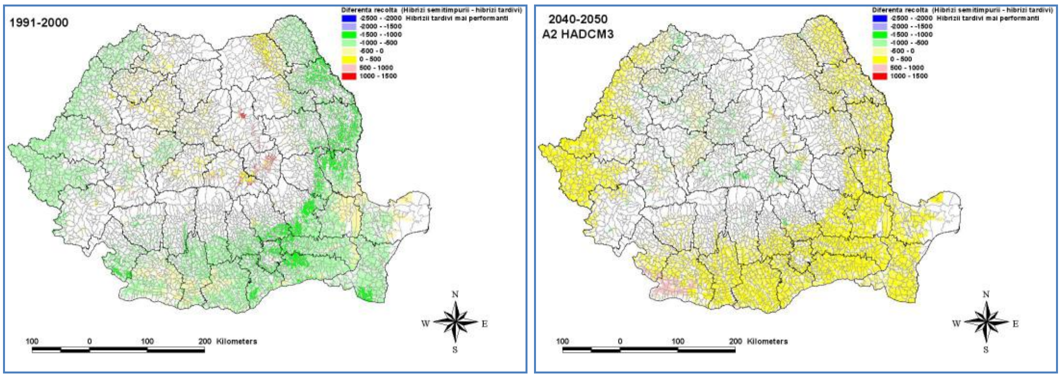
Minimum tillage will increase spring crop yields in South Romania up to 20% by the conservation of water (figure 62). The main limitations are related to the costs of tillage implements and the needs of trainings for farmers. This problem could be solved in the process of aggregation of small farms and the creation of large agriculture entreprises.



1961-1990 | 2041-2050 /HADCM3 – A2

Figure 61: Yield change (%) of spring crops for minimum tillage management practice comparison with conventional system

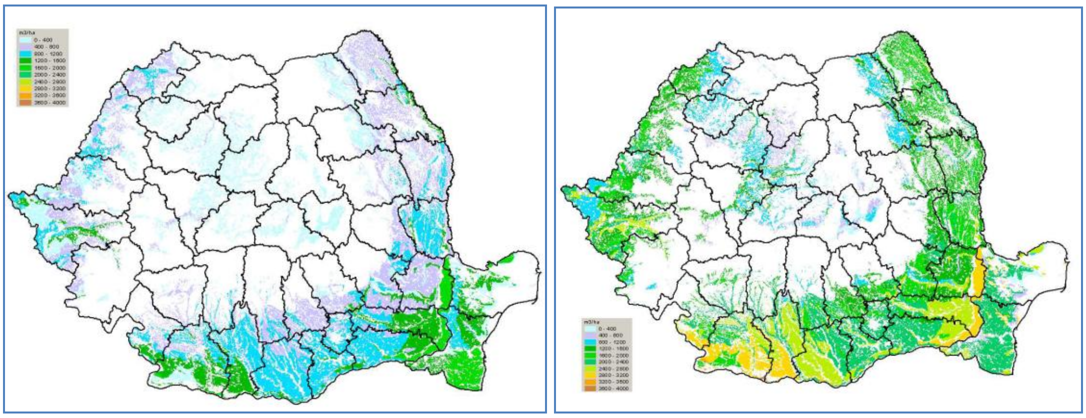
In the figure 63 is showed the difference of maize yields between early and late cultivars. If for the baseline the late cultivars are more productive (up to 1 t ha-1) in the future climate change scenario (2041-2050) in South Romania the two types of cultivars gives similar yields (in Dolj county the early cultivars will give higher yields up to 1000 kg ha-1. Therefore, will be more profitable to use early cultivars due to low costs of their technology of production.



1961-1990 | 2041-2050 /A2 HADCM3

Figure 62: The difference of maize yields by changing the cultivars structure

In terms of water needs, the results shows a sustantial increase in water demand for irrigation on large areas in the future (figure 64: e.g. in Dolj from 1200-1600 m3 ha-1 to 2800-3200 m3 ha-1; Calarasi from 800 – 1600 m3 ha-1 to 3200 m3 ha-1 linked with the need of fertilisers with higher proces estimated for future scenarios).



1961-1990 **2041-2050 /A2 HADCM3**

Figure 63: Needs for irrigation water (m3 ha-1) for baseline (1961-1990) and 2041-2050 time horizon

Today's interest in extreme weather phenomena and their impact upon human and economic activity is stronger than ever. Agriculture, in every branch of it, is directly affected by such phenomena, whose effects, be them positive or negative, cannot be minimized or ignored.. All information on the current and future condition of agro-climatic resources and the development of models to simulate and forecast the global/regional change of the environment are particularly useful to decision takers in their efforts to elaborate realistic and sustainable environmental policies. Assessing the climate change influences upon crop yields makes it possible to elaborate several methodologies that lay the agricultural planning and sustained development process on a scientific basis.

The climate data recorded over the last decades have therefore shown a progressive warming of the atmosphere as well as a higher frequency of extreme events. As it can be seen, the climate change effects in Central and Eastern European countries have been clearly mirrored by modifications in the temperature and precipitation regimes, with significant influences upon plant growth and development. In this context, water scarcity and pedological droughts in Romania can cause drastic yields decreases, particularly during the excessively droughty agricultural years (such as recent years 2006-2007 and 2011-2012), and the higher/lower than optimum temperatures are reflected by metabolically reactions in plants, causing thermal stress especially in summer and winter, while every modification in the trend of their lows can easily aggravate frost injury in sensitive plants. For this reason the adaptation of crop species to climate change can be mainly based on the experience obtained from their reactions to extreme climate events by implementing climate change risk adaptation and drought management plans as well as on the new researches approaching the regional and local effects related to the behaviour of genotypes in current and predictable climate change conditions. Basically, every solution and recommendation aimed to support the actions and procedures for climate risk prevention and mitigation in agriculture should include the complete range of known measures (agro-technical, cultural, irrigation etc.) as well as actual interventions to locate and confine every extreme weather phenomenon in order to avoid aggravated consequences.

5. End-users and dissemination products

Lithuania

The agriculture is the most vulnerable sector to drought in Lithuania. Consequently the drought identification and warning system are best adapted for agricultural droughts. Lithuanian Hydrometeorological Service under the Ministry of Environment is responsible for identification of droughts. In case of drought the Lithuanian Hydrometeorological Service warns the Ministry of Agriculture. The Ministry of Agriculture makes the list of municipalities affected by drought and informs the insurance companies.

The Ministry of Agriculture is also responsible for the coordination of actions of all institution involved in drought management.

Institution	**Responsibility**
Ministry of Agriculture	Organize and coordinate the measures for livestock, agriculture, and food sources protection. Establish special protective measures for managing of disaster consequences. These measures are mandatory for all land managers, owners and users. Give recommendations to farmers about protection of livestock, plants and forage. Make proposals for organization of compensation for the loss.
Ministry of Environment	Provides meteorological and hydrological information and forecasts to institutions involved in the management of emergency.
Ministry of Health	Coordinates the individual and public health care.
Ministry of Economy	Coordinates the state monetary reserve and plans the usage of material resources.
Ministry of interior	Coordinates firefighting, people and property rescue, and other rescue operations.
State food and veterinary service	Organize drinking water, food and forage laboratory tests and risk assessment.
Administration of municipalities	Ensure the implementation of State Emergency Operations Center instructions and measures imposed by the municipal emergency plan. Warn and inform the public, state and local authorities and institutions about the state of emergency, possible consequences and measures to eliminate and prevent the spread of emergency situation. Integrate all measures of civil protection located in the municipality to organize the aid for the victims, if necessary, organize evacuation of population.

Table 25: The institutions involved in coordination and actions during droughts and their responsibility.

The drought information and forecasts are available for public in the official site of Lithuanian Hydrometeorological Service. Service provides the droughts warnings and the relevant meteorological and hydrological information. In case of droughts the information is widely distributed by media.

Poland

The drought hazard assessment should be directed to particular end-users and fulfil their needs. The offered information should mainly concern two elements of risk management – planning and monitoring/prediction. The planning information (risk assessment above all) let take proper mitigation action in long-term perspective and the prediction of the following drought lets to start effective crisis management. The examples of possible dissemination products for particular end-users are presented in table 26.

<table>
<tr><th></th><th>Dissemination products</th><th>End-user</th></tr>
<tr><td colspan="3">PLANNING</td></tr>
<tr><td colspan="3">General products</td></tr>
<tr><td>1</td><td>general drought risk assessment for river basins and administrative units for meteorological, hydrological and groundwater drought</td><td>administration – planning insurance companies</td></tr>
<tr><td rowspan="8">2</td><td>detailed drought risk assessment for river basins and administrative units for economic drought, for particular water uses:</td><td>administration – planning insurance companies</td></tr>
<tr><td>drinking water supply</td><td>water plants users of private wells</td></tr>
<tr><td>agriculture</td><td>farmers</td></tr>
<tr><td>forestry</td><td>foresters</td></tr>
<tr><td>industry</td><td>mainly water consumed industry (paper-making, chemistry)</td></tr>
<tr><td>hydropower</td><td>power plants - so-called small hydropower stations</td></tr>
<tr><td>fisheries</td><td>fish ponds</td></tr>
<tr><td>inland navigation</td><td>goods navigation (very rarely in Poland) public transport navigation (very rarely in Poland, in some cities only, not primary) users of tourist water routes (small ships, yachts, canoeing)</td></tr>
<tr><td colspan="3">Detailed information of the above mentioned products</td></tr>
<tr><td>3</td><td colspan="2">the analysis of historical droughts and their effects</td></tr>
<tr><td>4</td><td colspan="2">estimation of potential drought trends corresponding to climate changes</td></tr>
<tr><td>5</td><td colspan="2">identification of drought vulnerable regions</td></tr>
<tr><td>6</td><td colspan="2">identification of water scarcity vulnerable regions</td></tr>
<tr><td>7</td><td colspan="2">identification of drought vulnerable sectors</td></tr>
<tr><td>8</td><td colspan="2">identification of water scarcity vulnerable sectors</td></tr>
</table>

9	primary guidelines to implementation of water management rules in the context of drought risk (the rules of water distribution, water users hierarchy establishment, determination of possible water intake/use restriction implemented in the case of drought occurrence/to drought mitigation)	
FORECAST		
10	meteorological drought forecast	agriculture insurance companies
11	low flow/water table forecast in the context of water intake	administration - water management drinking water supply, agriculture forestry industry fisheries
12	low flow forecast in the context of hydroenergy production	hydropower
13	low flow forecast in the context of navigation posibility	inland navigation

Table 26: The examples of possible dissemination products for particular end-users

The end-users with quite different character constitute the large part of economy so it shows the large importance and need of drought protection and drought information exchange system development. Besides it's important that both public administration and the private sector or even society itself should participate the system.

In Poland no one uniform system of drought dissemination products exists. There are some smaller systems (like *POSUCH@* by IMGW, *Monitoring and forecasting water deficit and surplus in agriculture* by ITP and *Agricultural Drought Monitoring System (ADMS)* by IUNG) but they directed to some specific drought analyses. The above mentioned systems give information for the whole country in the same way but for some regions there are some more detailed programmes too (like *Monitoring meteorological and agricultural drought in Kujawy region* by ITP or *Drought Analysis* by RZGW in Cracow) – so information can be often dissipated. It's worth to emphasize the growing need of complex and uniform system fulfilling the needs of particular users.

Romania

National Meteorological Administration (NMA) forms a necessary component of any strategy to mitigate weather and climate related risks including droughts.

NMA's Romanian agrometeorological observation network provides weekly in-situ monitoring on soil moisture and information is collected, analyzed and compiled in an Agrometeorological Specialized Bulletin (diagnosis/forecasts and warnings) that is disseminated currently to decision factors (Ministry of Environment and Climate Change, Ministry of Agriculture and Rural Development) in electronic format. During extremely droughty years this service enables monitoring of drought dynamics and assessing the spatial extent and intensity of drought phenomenon.

The process of elaborating the agrometeorological warnings/wheater alert is particularly complex and represents the support system for the identification of the agricultural areas potentially affected by extreme weather phenomena (e.g. drought, scorching heat, precipitation deficit etc.), the rounding off stages being function of the anticipation interval (very short range, from 0 to 12 hours, or short and mean range, with anticipation intervals of 12 hours and 10 days respectively).

The operational weather forecasting activity takes place following four main stages:

a) monitoring the state of the weather and achieving the agrometeorological diagnosis at national and regional levels;
b) interpreting the diagnostic and prognostic materials, a stage that implicitly represents finalizing a stage and the elaboration of the forecast;
c) issuing the warnings about the occurrence of extreme weather phenomena, if such phenomena are forecasted;
d) disseminating the agrometeorological products for early warning using mobile phone systems as new application at regional/local levels (Figure 65).

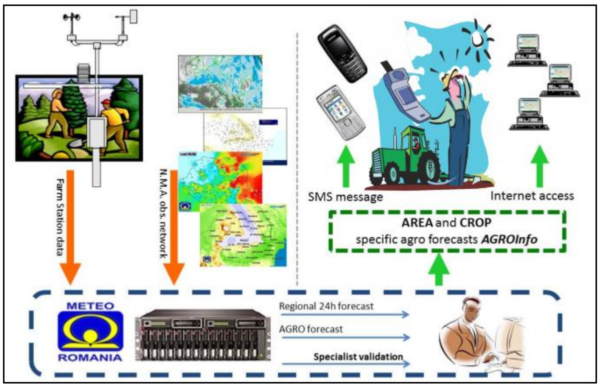


Figure 65. Mobile phone application for early warning in agriculture

The agrometeorological message includes meteorological data about the air temperature, precipitation, wind etc. as well as agrometeorological data: the thermal and moisture regime of the soil, data on the outlook for the phenological evolution of the crops undergoing vegetation and the phyto-sanitary state. Function of this specialized information, the user in agriculture can adapt the calendar of the agricultural works to the forecast meteorological and agrometeorological conditions.

This approach aims to test specially designed technologies, techniques or practices in order to decrease the drought effect. In this context, increasing use of agrometeorological forecasting by different ways (mobile phone, bulletin, etc) can help the farmers to improve the water management practices especially on drought conditions. Thus, the access by via mobile phone for farmers to agrometeorological warnings help the farmers to monitor the evolution and the intensity of drought and to choose the best options to the adverse effects of water scarcity and drought followed by technological solution (e.g. minimum tillage system, irrigation, etc). The farmers where the warnings have been received confirmed that the drought effects were minimized as much as possible.

The Agrometeoorlogical Laboratory of NMA also develops specialized products such as:

- Basic products:
  - ➢ weekly, monthly and seasonal agrometeorological diagnoses/forecasts
  - ➢ agrometeorological dedicated reports
- Specialized products (i.e. maps):

✓ parameters and maps of thermal vulnerability and risks at sub-regional level (temperature, sunstroke, tropical nights, hot days, etc);

✓ parameters of water stress at regional and sub-regional level (rainfall, ETP, atmospheric relative humidity, soil water shortage, precipitation deficit, etc);

✓ aridity indices (standardized at full network level);

The weekly Agrometeorological Bulletin includes the specific information (air temperature, rainfall, ETP, soil moisture, crop water requirement) needed for assessment of drought occurrence.

This data collected from the National Observation Network is analyzed and compared with the critical thresholds in order to evaluate the threat and make recommendations to decision-makers and farmers.

Also, the soil moisture maps, weekly agrometeorological informations and seasonal forecasts which are updated daily according with the flow operational activity are free on the NMA web-page (www.meteoromania.ro) for informational and decisional purpose in terms of technological measures that can be applied in drought conditions (Fig. 66).

Fig. 66. The Romanian NMA web-page

For the general public the information is disseminated through also the mass-media. Periodical broadcasts (i.e. “Village Life”) are made at the public radio and television having nationwide coverage, and targeting rural audience. Articles for specialized publications and magazines are disseminated bi-monthly and monthly in electronic format (www.lumeasatului.ro; www.revista-ferma.ro) and paper format (i.e. “Village World”).

The vegetation indices based on satellite products at national/regional and local levels are produced by the Remote Sensing and GIS Laboratory of NMA.

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