Drought as Stress for Plants, Irrigation and Climatic Changes

Ľ. Jurík and T. Kaletová

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Abstract Drought by itself cannot be considered a disaster. However, if its impacts on local people, economies and the environment are severe and their ability to cope with and recover from it is difficult, it should be considered as a disaster. Droughts and floods are a recognizable category of natural risk. Hydrological assessments of drought impacts require detailed characteristics. We propose a new conceptual framework for drought identification in landscape with agricultural use. We described hydrological drought characteristics with impacts at the agricultural landscape and food security and the issues related to drought water management. In the past, the Slovak Republic was not considered a country immediately threatened with drought. The situation had changed at the turn of the millennium, especially after the extreme weather conditions in 2014 and also in 2015, when, for example, the historical minima were recorded.

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1 Introduction

A settlement of countryside and population growth places emphasis on the increasing demands on exploitation of resources, including land, soil and water. On the first place, it is landscape—authentic forest vegetation was changed on an agriculture landscape with agriculture production. Authentic ecosystem with wide biodiversity was changed on the sort of plants which were selected in the aim of an increasing yields and resistance to diseases and pests by the millennium. A proper selection of crops, as has been found in archeologically excavations in China from 2000 years BC, helped several communities to survive impact of the extreme weather seasons—drought and floods (wheat, barley, millet, rice, sorghum, vegetables). They used to grow crops with high water demand and crops resistant to drought in the same time. Therefore, they always reach the needed minimum for human nutrition without the weather impact. High-performance crop varieties in order to achieve high yields require proper agrotechnics, nutrition, protection and optimum water regime. Landscape as itself is connected to the same water regime which ensures the safety for the people living in it. The extremes of water regime in the landscape are floods and drought. The drought in the landscape is a complicated and socially very important problem. We can relatively exactly determine and evaluate a beginning and end of flood. A beginning and end of the drought is hardly determined; therefore, it is important to know its progress and consequences.

Drought is one of the natural disasters. The area affected by drought increases from 6 to 18% in last 30 years according to data from European Commission [1].

1.1 Soil and Water

Soil is one of the most important non-renewable resources for the agriculture crop production. All of these basic components have undergone profound changes over the years as a result of anthropogenic activity that has adversely affected their state. The effects were mainly the destruction of the authentic ecosystems, the reduction of biodiversity and the creation of conditions for the intense growth of weed communities as accompanying vegetation of cultural plants, often with higher resistance than the cultural plants themselves. No lesser influence on potential plant production also has climatic conditions. Over the past 20 years, climate change has become increasingly apparent in Slovakia and surrounding countries. We are witnessing an increase in average temperatures and the impact of precipitation, both in terms of quantity and distribution over the year, and an increase in extreme phenomena (drought on one side and torrential rain on the other). Equally water consumption in different areas of economy needs optimization of its use. It is apart important accumulation capacity of natural landscape in Slovakia. Available water in the catchment during the whole year depends upon that accumulation capacity. Accumulation capacity is a function of the soil vegetation cover, soil properties and its subsoil and terrain configuration in the landscape.

The water balance draws the hydrological cycle quantitatively. The water balance looks at the balance between inputs and outputs. One can look at the water balance at a global level (hydrological cycle), at a local level (drainage basin cycle) or even just as an investigated site.

The general water balance equation is

$$P - R - G - E - T = \mathrm{DS} \qquad (1)$$

where P precipitation [mm] or [m^3 s^{-1}], R runoff, [mm] or [m^3 s^{-1}], $R = R_{\mathrm{out}} - R_{\mathrm{in}}$, R_{out} = runoff as outflow from the water body × hydrologic region, R_{in} = runoff as influx into the water body × hydrologic region, G groundwater flow, [mm] or [m^3 s^{-1}], $G = G_{\mathrm{out}} - G_{\mathrm{in}}$, G_{out} = groundwater as outflow from the water body ÷ hydrologic region, G_{in} = groundwater as influx into the water body ÷ hydrologic region, E evaporation [mm] or [m^3 s^{-1}], T transpiration [mm] or [m^3 s^{-1}], DS change in storage [mm] or [m^3 s^{-1}].

For water sustainability in the landscape, DS should be greater than zero. Storage may be in the form of the soil water, groundwater or surface resources in the reservoirs. The drought is when the change in storage is negative. Potentially evapotranspiration is usually higher than precipitation and cannot be achieved not only to ensure it but also to redistribute the water, e.g. to surface runoff or underground drains. The distribution of balance components is very different.

1.2 Water Resources and Drought

Water in the landscape is evaluated by resources and its division or consumption. It is expressed by the quantitative water management balance.

The evaluation of the drought in the landscape is by balance equation not only by the evaluation of actual and potential evapotranspiration but also the state of resources—local, regional or international—available in the area of evaluation. The sufficient available water may eliminate the local natural conditions during the evaluation of the drought.

The precipitation is the local parameter. Each square metre is covered by water from precipitation in particular time, and value significantly changes in the distance of 1 km; therefore, we are based on the data from meteorological stations. Also, data from different amateurs' stations of high quality are used, nowadays.

The soil moisture and the soil water content in depth of 1 m are also a local parameter, and the differences in the values may be in the distance of 100 m. We used data from the stations which network is minor. The Faculty of Horticulture and

Landscape Engineering operated a Centre of Excellence with its own network of stations for the Nitra river basin. The data are available from 2014. More information about the centre and monitoring network are available in Tárnik and Igaz [2].

The water resources in the landscape are also water in the streams or rivers and water in the reservoirs. The water runoff in the streams is the local parameter and is connected with the soil and groundwater and current precipitation. Its values vary a lot, and it is not possible to use as the water source during the drought because of low or zero discharge without a possible usage.

River flow is a sum of outflows from subbasins and does not respond to local precipitation in a small part of the area. It is affected more by the stock of soil and groundwater in the area (base flow). Therefore, rivers can be used as a source of irrigation water even at the beginning of the dry season, as the base flow provides the resources from previous periods. Large transboundary rivers crossing the borders can bring water from areas with sufficient rainfall to drought areas and are thus an important source of water in dry periods.

The local water source for the dry season is the water in the reservoirs in which we create water reserves over a period with excess rainfall for a period with a lack of precipitation. The volume of water in the water reservoir creates the conditions for temporally bridging the current shortage of water resources for use for irrigation or production. The problem of water reservoirs is siltation and decreasing the capacity (volume) of reservoirs, nowadays [3].

The current processed water balance forecast considers irrigation water needs for the horizon of 2010 and also provides views of the years, 2030 and 2075. On the side for water sources are considered the natural average monthly flow rates with high security and on the other side are used minimum residual flows values MQ. The balance is processed by evaluating the discharge profiles of individual subbasins. The results only for 2010 are declared through the capacity of water sources (flows). A negative number means the shortage of water sources (Table 1) [4].

Table 1 Forecast of water balance in river basins in selected months for the year 2010 in $m^3 s^{-1}$ [4]

River subbasin	Month						
	4	5	6	7	8	9	10
Bodrog	26.85	18.71	9.801	0.383	0.196	3.604	6.140
Hron	6.461	6.042	3.072	1.165	**−1.554**[a]	0.961	**−0.111**
Ipeľ	0.763	0.110	**−0.686**	**−0.972**	**−0.792**	**−0.053**	0.311
Slaná	1.894	3.496	1.480	0.476	0.221	0.549	0.550
Nitra	2.456	0.575	**−0.833**	**−1.018**	**−1.453**	**−0.026**	0.567
Váh	47.42	17.95	13.64	4.707	**−2.042**	0.529	**−1.365**
Morava	30.99	22.93	9.396	3.022	2.013	5.314	3.219
Dunaj	888.5	828.4	824.1	890.8	437.5	276.7	13.6
Bodva	**−0.005**	0.339	0.306	**−0.249**	**−0.299**	**−0.318**	**−0.178**
Poprad	5.386	6.261	8.239	3.874	2.923	2.137	1.381
Hornád	2.047	3.396	2.024	1.745	1.035	0.126	0.604

[a]Bold cells mean a lack of resources in the balance sheet

The basis for water balance is the determination of the monthly potential evapotranspiration because we know the monthly rainfall.

Monthly totals have significant regional differences in Slovakia. As an example, we will show values from two stations on the lowland. Different are not only the sums of precipitation but also their distribution during the year (Fig. 1).

To create properly the local balance is the evapotranspiration basis for the real determination. The value of evapotranspiration is not usually measured but is determined from the measured meteorological and climatological parameters. There is a network of climatological stations with evaporation measurement in Slovakia (Fig. 2).

For direct measurement of soil vapour, equipment called lysimeter is used; in the case of soil with vegetation, they are called evapotranspirometer. These are containers filled with soil monolith and covered with a crop identical to the assessed environment. Lysimeters and evapotranspirometers are soil and plant water evaporation analysers that also allow the measurement of the amount or the chemical composition of water sprayed into the vessels that are part of the lysimeter.

The direct measurement of evaporation from plants is the most accurate determination of transpiration and, therefore, in the scientific institutions, is seeking new measuring devices. In the year 2017, Iowa State University researchers have developed new "plant tattoo sensors" (Fig. 3) to take real-time, direct measurements of water use in crops. "With a tool like this, we can begin to breed plants that are more efficient in using water," he said. "That is exciting. We could not do this before. However, once we can measure something, we can begin to understand it." [7]

1.3 *Soil and Drought*

The main factors determining agricultural production are landscape, soil and water. The landscape creates conditions for the distribution of precipitation water and provides space for the accumulation of that precipitation water and its outflow

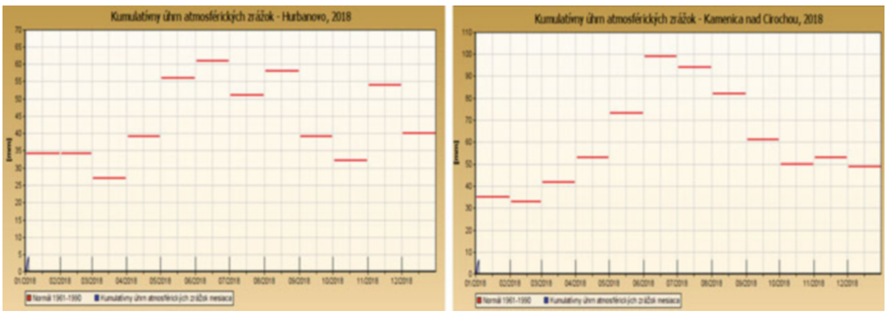

Fig. 1 Average monthly precipitation totals (red lines—normal 1961–1990) for Hurbanovo (left) and Kamenica nad Cirochou in mm month^{-1} [5]

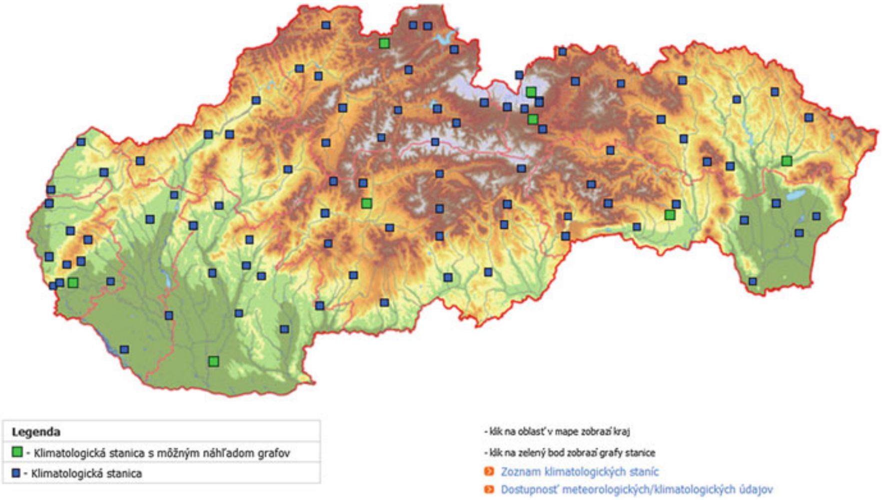

Fig. 2 Climatological stations measuring the evaporation in Slovakia [6]

Fig. 3 Plant sensors for direct measurements of water use in crops [7]

from the territory. The soil is a habitat for plants and creates for them the storage space for those substances necessary for plant growth, namely, nutrients, air and water. The main axis of the whole water dynamics in the landscape is the river network, which has to manage the regulation of all processes in the water. Agricultural production and plant biodiversity in the landscape are determined just by the basic constituents of the natural environment and their mutual interactions.

In many regions of the world, biomass production and water safety are at the risk level of overexploiting water resources and soil degradation. Climate change will increase this risk, especially in the environment with limited water sources and in the border regions.

The society can be gained from an improved understanding of the connection between soil, water and landscape. Improving the interconnection of soil management and land use requires regional specific management options that can help:

- To protect and develop land and water resources
- To enhance food and water security
- To improve the efficiency of water use and maintain and improve the soil and water associated with ecosystem services
- To enable the production of biomass in a variable climate and degrading and waning soil [8]

1.4 Drought Identification

There are hundreds of definitions, adding to the confusion about the existence of drought and its degree of severity. Drought may be defined as a period of a deficit with respect to the expected rain (normal), which occurs during the season [9]. Definitions of drought should be region and application specific or impact specifically. Drought is a natural disaster that is characterized by a lower-than-expected or lower than normal precipitation that, when the season is extended or a longer period, is insufficient to meet the demands of human activity and the environment. If we evaluate the effects of drought, problems can be combined into three common areas: economic, environmental and social problems [10]. Their effect and significance are usually different according to the location that we recognize. Expressions of drought are associated with looking at his assessment—we say about the drought meteorological, agronomical, hydrological, etc.

Drought is a regional phenomenon, and its characteristics differ from one climate regime to another. It is often difficult to know when a drought begins. Likewise, it is also difficult to determine when a drought is over and according to what criteria this determination should be made. Droughts have three distinguishing features: intensity, duration and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall [11].

The difficulty for a drought assessment and identifying are, for example, quantification of intensity and determining its length. Because normal precipitation and water use expectations vary, the specific definition of drought is more a matter of where the water comes from and how it is being used [12].

Drought may be defined as a period of a deficit with respect to the expected rain (normal), which occurs during the season [9]. Normal shows about the long-term balance between precipitation and evapotranspiration for a specific site (meteorological drought concept). About the agronomic drought, one can say if the amount of soil moisture does not meet the needs of the plants. Agronomic drought correlates to the water deficit in the soil. It occurs after meteorological drought but before the hydrological drought. Agriculture and forestry are the first sectors of the economy, which are significantly affected by the drought. Then it can follow in the water supply to the population and the industry. Therefore, definitions of drought are of a qualitative nature, and extent of drought is expressed by words such as "water scarcity", "less water" and "low amount of precipitation" [13]. Water deficits are the result of a multifaceted interaction between human inflows and outflows, meteorological anomalies, landscape processes at the surface and changes of total water storage (see Fig. 4) [14, 15].

In Slovakia, it is drought classification based on the water balance which consists of the difference between precipitation and evapotranspiration. The occurrence of drought in the country in recent years can be also connected with the methods of land use—surface changes, changing the classic crop rotation, regional changes in water abstraction, etc. [16]. In semiarid areas during the 3-year experiment, the vegetation strongly controlled water loss even when daily climatic evaporative demand was high, and soil water availability was expected to be non-limiting [17].

For the evaluation of drought, currently, not only many definitions but also a number of evaluation indexes are used. For agricultural landscape, Palmer Index (Palmer Hydrological Drought Index—PHDI, Table 2) is suitable to use, among others. It takes into account not only climatic characteristics of the area but also the basic soil hydro limits [19]. This means that the same value of Palmer's Index in the different areas in them should have approximately the same economic impact on

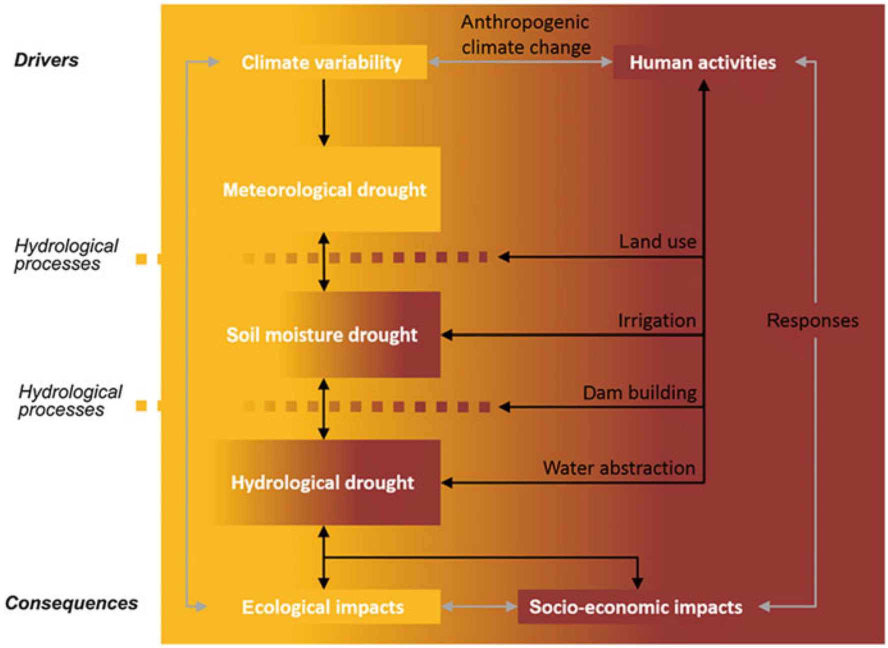

Fig. 4 Natural and human drivers and feedbacks (grey arrows) of drought; black arrows—direct influences [18]

Table 2 The Palmer drought severity index classifications for dry and wet periods

Value	Description	Value	Description
4.00 or more	Extremely wet	−0.50 to −0.99	Incipient dry spell
3.00 to 3.99	Very wet	−1.00 to −1.99	Mild drought
2.00 to 2.99	Moderately wet	−2.00 to −2.99	Moderate drought
1.00 to 1.99	Slightly wet	−3.00 to −3.99	Severe drought
0.50 to 0.99	Incipient wet spell	−4.00 or less	Extreme drought
0.49 to −0.49	Near normal		

crop production. The definition of drought in official documents is affecting reaction to drought. It is very important that the definition of drought allows the gradual implementation of the planned measures for its elimination. It is important to know and understand the diversity of drought definitions and the different needs of the perception of the drought phenomenon [20].

Drought impacts (Fig. 5) are most eye-catching in the agricultural sector. Dried crops, abandoned farmland and withered and yellow pastureland are the common signs of drought [12].

The sequence of drought occurrence has impacts for commonly accepted drought types. All droughts originate from a deficiency of precipitation or meteorological drought, but other types of drought and impacts cascade from this deficiency (Figs. 4, 5 and 6).

1.5 Water in the Landscape

Water in the Slovak landscape is the result of precipitation with a different character. We know the water balance equation in a landscape, where the water outflow from the territory is equal to rainfall, reduced by the amount of precipitation captured in the landscape, either through interception or infiltration into the soil profile.

The precipitation interaction in the soil profile creates two basic conditions. The first, the soil is with a partially saturated soil profile where the water content is smaller than the total porosity. The second, soil saturation is up to the porosity value, i.e. the state of saturation of the soil with water. These values have a significant impact on hydrological conditions in the area.

Tasks, given for the agricultural landscape, are currently:

- Create and maintain potential for crop harvesting.
- Create a place for social activities of the inhabitants of the given municipality, area, etc.
- Create conditions to maintain the optimal water cycle.
- Create conditions to maintain the optimal cycle of substances.
- Create conditions to maintain the optimal energy cycle.

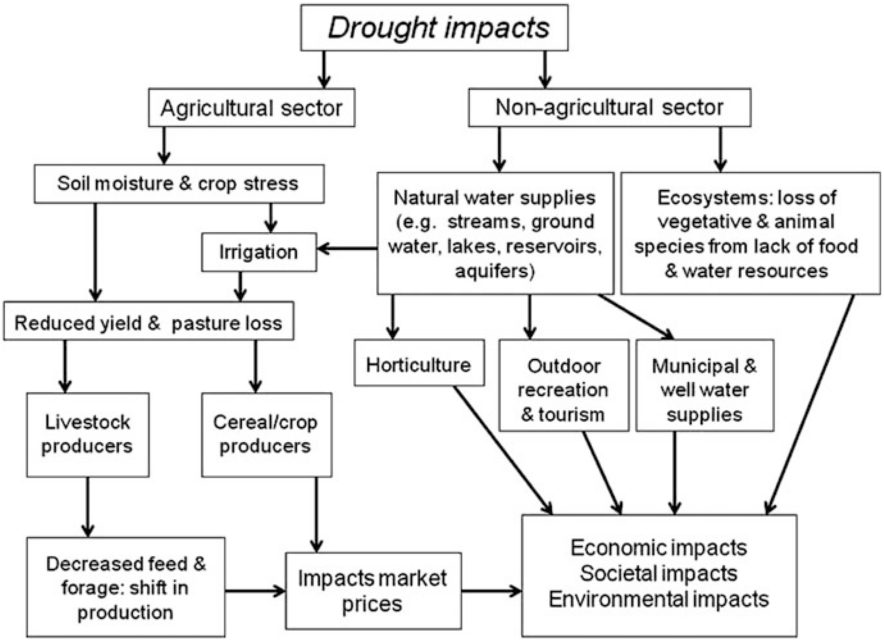

Fig. 5 Drought impacts on the economy, societies and the environment moving through time from the top to the bottom of the chart [21]

There is no clear and precise definition of the agricultural landscape in the literature. It is unclear whether or not only agricultural areas are concerned or the total cadastre of municipalities together with the parts of the residential area and, e.g. part of the forest fund. For its correct understanding, it is necessary to systematically analyse it. Water can significantly change soil properties—albedo, thermal conductivity and plant cover. Water has the largest thermal capacity of all known substances and can, therefore, influence the rate of change in the ambient temperature—soil and ground atmosphere [23].

Mostly, the course and direction of the fulfilment of functions taking place in the landscape are ensured by the water cycle in nature. Landscape and agricultural hydrology is the most fundamental analysis of landscape creation and development processes. Names of the landscape forms have been stabilized primarily by sufficiency respectively lack of the water in the country. Current climate change redistributes the water cycle and the amount of water in the country, and as in history, even today, it will be necessary to reassess the names of the forms of the landscape. The speed of changes in natural hydrological processes is affecting by the economy interests of land use the economy. In the agricultural landscape, by changing cultures from economic interests, we can fundamentally change the water consumption in the country. Experiments in semiarid conditions in Australia show that total evaporation was less than rainfall, as would be expected, but there were periods when

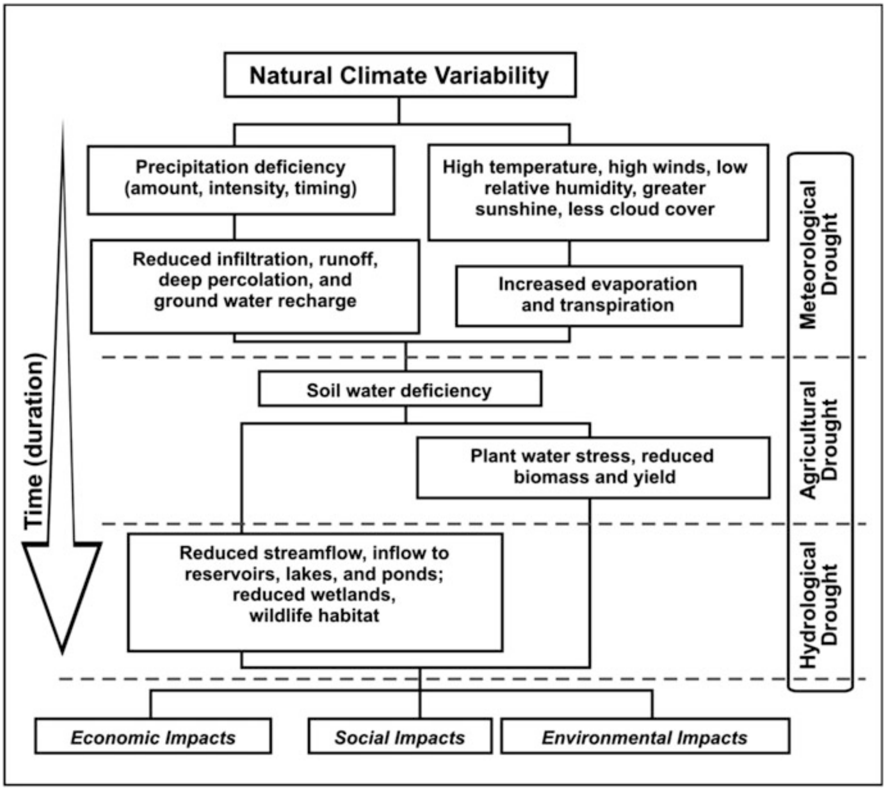

Fig. 6 Types of drought and their impacts [22]

evaporation exceeded rainfall for the period indicating that vegetation was using stored soil water from previous wetter periods [17].

For the classification of the landscape, its hydroclimatic regime is often used, balancing the ratio of evapotranspiration and precipitation (Table 3). With excess rainfall and small evapotranspiration, the landscape mode is wet and vice versa; when the evapotranspiration is greater than the rainfall, the mode is dry.

2 Drought in Agriculture in Slovakia

In Slovakia, more than one-third of the incident energy is used for evaporation, the part is heating the biosphere and part is radiated back into space. When the energy of the Earth is balanced over a period of 1 year, then there is a balance between the amount of energy received and the radiated energy [25]. From Slovak teritory on average about two-thirds of annual rainfall will evaporate, and one-third rainwater

Table 3 Review of evaluation of landscape hydroclimatic regimes [24]

ET/P	0–0.33	0.33–0.66	0.66–1.0	1.0–1.5	1.5–3.0	>3.0
Hydroclimatic regime	Very wet	Wet	Moderate wet	Moderate dry	Dry	Very dry

flows away. The average annual rainfall is 768 mm and layer of water that evaporates is 497 mm. Due to the varied morphological structure of our territory, the distribution of evapotranspiration also varied—up to 95% of the precipitations evaporate from southern Slovakia but only about 30% of the annual precipitation from mountain areas. Also, calculations in 2009 show that the increase in evapotranspiration for particular crops ranged from 9 to 57% in comparison with consumptive water usage calculated according to valid Slovak Technical Standard (STN no. 83 0635) [26]. Therefore, it is necessary to determine the exact value of the evaporation for a selected area.

Today there are several models to solve the soil-water-plant relationship. All of them are working with relatively different values for quantification of the surface condition of the land used by the territory. It is necessary to clarify these input data, in particular about the crop plants and their absolute or time-dependent water needs for the conditions of Slovakia. Models from other countries include data from other climate and soil databases. There are also different crops of the grown plants. Models from Belgium or the Netherlands are based on crops about 100% higher than in our country. Moreover, so it is clear that in Slovakia the absolute and time-divided need of the water is different.

The assessment ratio A for classification of soil humidity regime into types according to the agronomic classification for the vegetation period can be calculated in Slovakia according to the relationship [27]:

$$A = \frac{1}{n} \sum\nolimits_{i=1}^{n} \frac{\Theta_i - \Theta_\mathrm{w}}{\Theta_\mathrm{FC} - \Theta_\mathrm{w}} \tag{2}$$

where Θ_i the average moisture content of the active root zone of the i-th day of the balance sheet for period [$m^3\ m^{-3}$], Θ_w wilting point of the active root zone [$m^3\ m^{-3}$], Θ_FC field water capacity of the active root zone [$m^3\ m^{-3}$].

To evaluate the type of the groundwater regime, the ratio in Table 4 is used [28].

The calculation and evaluation are seemingly simple. However, the problem is that current soil moisture is measured only on a few research grounds. We do not know such a simple relationship to count for specific locations in Slovakia. Therefore, there are projects focused on the spatial modelling of soil moisture, soil water availability or water storage capacity of agricultural soils within the catchment [29, 30].

The calculation comes from the time when the soil moisture values were solved on the soil sample. There was no distinction between soil layering and different moisture ratios at different depths of soil. The water is naturally moved by gravity in

Table 4 Types of moisture regime according to agronomic classification of soil moisture regime [28]

Part of soil water content	Type of soil moisture regime in the balance period
<0.10	Completely dry, lack of soil water for plants
0.11–0.20	Very dry
0.21–0.30	Substantially dry
0.31–0.40	Dry
0.41–0.50	Alternately dry
0.51–060	Alternately wet, optimum water content for plants
0.61–0.75	Wet
0.76–0.90	Very wet
0.91–1.00	Wet, surplus of soil water
>1.00	Waterlogged

the soil profile, and we know a lot of the works, reporting on the redistribution in the soil profile after irrigation or collision (Fig. 7).

2.1 Drought Monitoring

The drought and soil water content calculation and evaluation are often simple. In practice, however, it looks different. Problem is data measurement for larger regions. The Faculty of Horticulture and Landscape Engineering has the group of automatic soil moisture measurement stations available [2]. Soil moisture is continuously measured at depths of 10, 20, 30, 40, 50, 75, 100, 150 and 200 cm. Changes in soil moisture are usually not the same at all measured depths. Using measurement devices, we recorded drought in previous years. The significant drought was in 2014 and 2015. Soil moisture fell to a wilting point in both years.

From the records for the Mužla village, it is possible to evaluate the actual humidity and its deficit and the likely development in the coming days without precipitation or after the expected rain. In Figs. 8 and 9, it is possible to see the fundamental difference in the soil moisture development at individual depths (10, 40 and 50 cm) of the soil profile in 2014 and 2015. In 2014, the soil had been with plenty of winter moisture and gradually was replenished with new rainfalls. The 2015 growing season began with a lack of moisture and period without rains; this condition deteriorated critically at all depths.

2.2 Drought Evaluation

More interesting is the evaluation of the changes of soil moisture after a long drought (Fig. 10) and subsequent precipitation at the end of May 2015 and June 2015. Even

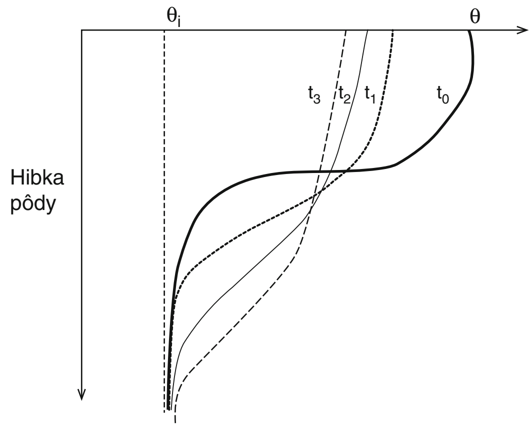

Fig. 7 Change of soil moisture after the redistribution of applied irrigation water

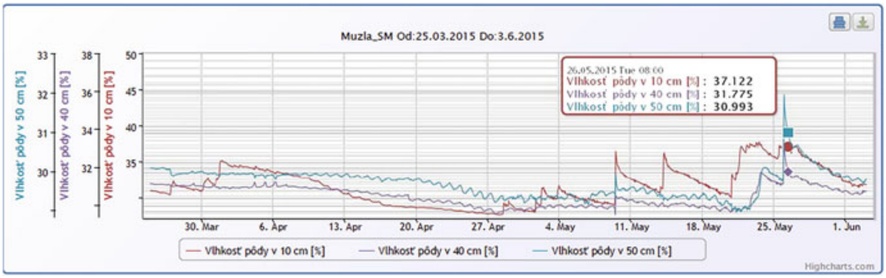

Fig. 8 Graph of soil moisture in March and June 2015

Fig. 9 Graph of soil moisture in March and June 2014

with significant water infiltration after precipitation is moisture descending on the value after the long dry period very quickly.

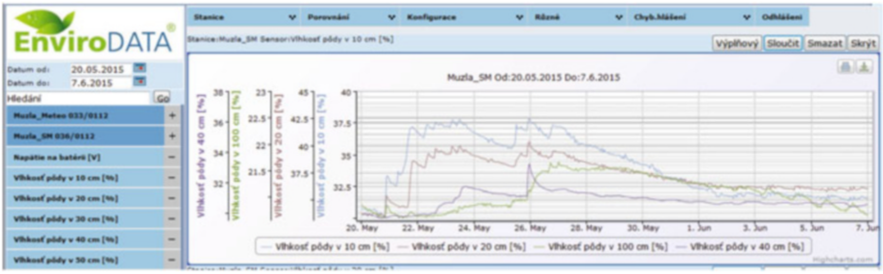

Fig. 10 Evaluation of soil moisture progress after the long-term drought in 2015

For Hurbanovo station Palmer index was calculated [31] for the entire measurement period, and the results are in the following Fig. 11. Palmer index in the last two decades was moved into the negative values and often below −4, which are already extremely dry years. Therefore, the use of long-term series for evaluation is important because the comparison data for the period since 2000 is then drought rated moderately [27]. These values are related to changes in temperature in the northern hemisphere (see Fig. 12).

In the recent times, SHMU introduced freely available output from modelling drought—integrated system for drought monitoring ("Monitor sucha"). This output is focused on meteorological and agricultural drought, with a view to their more frequent occurrence and that of the economic consequences for Slovakia.

3 Conclusion

Slovakia wants to achieve greater protection from drought in the landscape, also for the reason of the security by the self-sufficiency in agricultural production. A supply of crops will be critical with sufficient soil moisture. Current climate change and state of the irrigation structures in Slovakia show that this goal can not be achieved if we do not provide better soil and water management and we do not have enough sources of the information.

The measuring stations measure tens and hundreds of surface water parameters, but the soil water information network is not yet planned in Slovakia. Current weather developments and changes in cultivated crops, however, indicate the importance of this water source for the future.

A basic conceptual document for addressing drought and water scarcity issues will be the river basin plans, in particular, plans for subbasins where this issue is dealt with at the most detailed level.

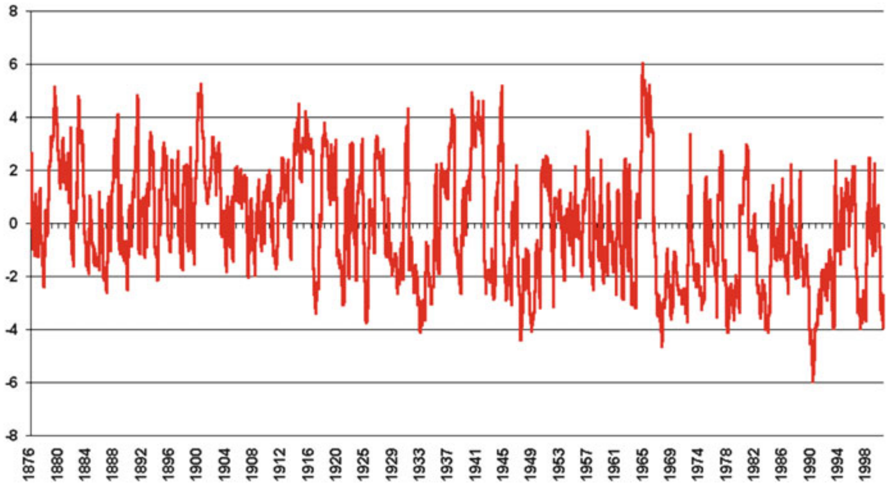

Fig. 11 Palmer index of monthly values for station Hurbanovo (1876–2000) [32]

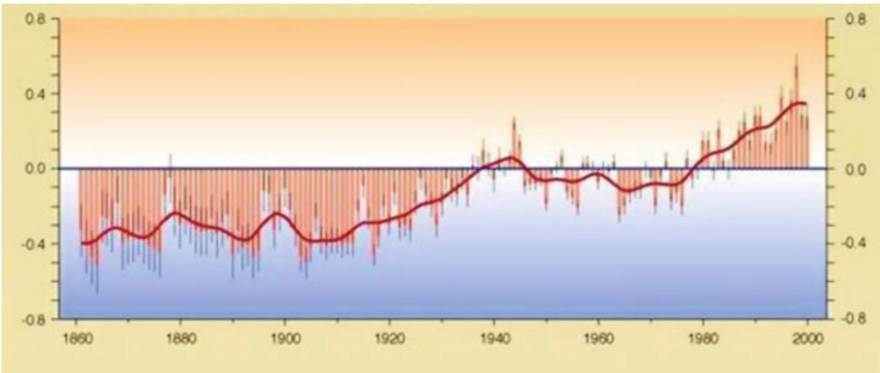

Fig. 12 Average annual temperatures in the period 1861–2004 in the northern hemisphere. The red line is the 5-year moving average for temperature [33]

It is not yet determined how the surplus water can be estimated in the landscape, and, conversely, we cannot estimate water consumption from other areas. It is not even determined what could be the maximum water consumption in the smallest basins or what maximum deficiency can be acceptable from the point of view of the water cycle in nature and its sustainability. The occurrence of drought leads to a fundamental influence on the outflow from the river basin and causes changes in the flow regime to be discontinuous, characterized by a reduction in flow often to zero.

4 Recommendations

To mitigate the impact of drought, which will occur more often in the future, it is necessary to re-examine the theoretical and practical approaches that are being used today. It should seek to respond to the basic challenges of protecting the country and its users from droughts in the future:

- Development of methods to forecast droughts using existing resources
- Ensuring quality drought monitoring and related phenomena (state of the agricultural land, water quality, state of aquatic ecosystems, state of forest stands)
- Determining the distribution of the precipitation (water resource creation) in a country that can be described as sustainable
- Creating the methodology for quantifying the production and non-production functions of the landscape (including water resources) as a basis for optimizing measures
- Addressing the assessment of the excessive water resource creation in the small river basin and excessive water consumption in another neighbouring river basin—the relation between the upper and lower part of the basin
- The interaction between human economic activities and natural processes and possibilities of using this interaction in designing effective measures especially in the field of agricultural and forestry management
- Evaluating the effectiveness of the measures that influence the energy and water balance at a local, regional and supra-regional level under normal and extreme conditions
- Real reallocation of the precipitation in the soil and quantification of the contribution of groundwater to the creation of groundwater reserves and to increase its level

Prioritizing the above tasks and their mutual relations is important.

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References

1. Čimo J, Igaz D, Bárek V (2008) Hodnotenie sucha na základe agroklimatických a pôdnych faktorov. In: Rožnovský J, Litschmann T (eds) Bioklimatologické aspekty hodnocení procesů v krajině, Mikulov 9. 11.9.2008, ISBN 978-80-86690-55-1
2. Húska D, Jurík Ľ, Tátošová L, Šinka K, Jakabovičová J (2017) Cultural landscape, floods and remote sensing. J Ecol Eng 18(3):31–36

3. Jurík Ľ, Húska D, Halászová K, Bandlerová A (2015) Small water reservoirs—sources of water or problems? J Ecol Eng 16(4):22–28
4. Fekete V (2013) Výhľadová VHB množstva a kvality povrchovej vody k časovému horizontu 2021 vrátane prehodnotenia výhľadových vodných nádrží. VÚVH Bratislava
5. SHMU (2018) http://www.shmu.sk/sk/?page=1784&id=
6. SHMU (2018) http://www.shmu.sk/sk/?page=1604
7. https://www.news.iastate.edu/news/2018/01/03/planttattoosensors
8. Hettiarachchi H, Reza A (eds) (2016) Safe use of wastewater in agriculture: good practice examples cUNU-FLORES
9. Wilhite DA (1991) Drought planning: a process for state government. Water Resour Bull 27 (1):29–38
10. Freire-González J, Decker C, Hall JW (2017) The economic impacts of droughts: a framework for analysis. Ecol Econ 132:196–204. https://doi.org/10.1016
11. WMO (2006) Drought monitoring and early warning: concepts, progress and future challenges. http://www.wmo.int/pages/publications/showcase/documents/1006_E.pdf
12. Ding Y, Hayes MJ, Widhalm M (2010) Measuring economic impacts of drought: a review and discussion. Papers in Natural Resources 196:1–23
13. Novák V (2012) Evapotranspiration in the soil–plant–atmosphere system. Springer Science + Business Media, Dordrecht. 253 p
14. Van Loon AF (2015) Hydrological drought explained. WIREs Water 2:359–392. https://doi.org/10.1002/wat2.1085
15. Wanders N, Wada Y (2015) Human and climate impacts on the 21st-century hydrological drought. J Hydrol 526:208–220
16. Ondráček P (2014) Vyhodnocení trendů k vysychavosti vodních toků: Projekt TA ČR BIOSUCHO a databáze SALAMANDER—Hydrogeologické hodnocení povodí. Zpráva. Brno, 2014, 16 s
17. Meyer WS, Kondrlová E, Koerber GR (2015) Evaporation of perennial semi-arid woodland in southeastern Australia is adapted for irregular but common dry periods. Hydrol Process 29:3714–3726
18. Van Loon AF, Stahl K, Di Baldassarre G, Clark J, Rangecroft S, Wanders N, Gleeson T, Van Dijk AIJM, Tallaksen LM, Hannaford J, Uijlenhoet R, Teuling AJ, Hannah DM, Sheffield J, Svoboda M, Verbeiren B, Wagener T, Van Lanen HAJ (2016) Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches. Hydrol Earth Syst Sci 20:3631–3650. https://www.hydrol-earth-syst-sci.net/20/3631/2016/hess-20-3631-2016.pdf
19. Newman JE, Oliver JE (2005) Palmer index/Palmer drought severity index. In: Oliver JE (ed) Encyclopedia of world climatology. Springer, Dordrecht, The Netherlands, pp 571–573
20. Urquijo J, Pereira D, Dias S, De Stefano L (2016) A methodology to assess drought management as applied to six European case studies. Int J Water Resour Dev. https://doi.org/10.1080/07900627.2016.1174106
21. Kellner O, Niyogi D (2014) Forages and Pastures symposium: assessing drought vulnerability of agricultural production systems in context of the 2012 drought. J Anim Sci 92(7):2811–2822. https://doi.org/10.2527/jas.2013-7496. https://www.animalsciencepublications.org/publications/jas/articles/92/7/2811
22. National Drought Mitigation Center, University of Nebraska-Lincoln, USA. http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx
23. Lapin M, Melo M (2004) Methods of climate change scenarios projection in Slovakia and selected results. J Hydrol Hydromechan 52(4):224–238
24. Weiskel PK, Vogel RM, Steeves PA, Desimone LA, Zarriello PJ, Ries KG (2007) Water-use regimes: characterizing direct human interaction with hydrologic systems. Water Resour Res 43. https://doi.org/10.1029/2006WR005062
25. Novák V (1995) Evapotranspiration and its estimation. Veda, Bratislava. 260 p

26. Bárek V, Halaj P, Igaz D (2009) The influence of climate change on water demands for irrigation of special plants and vegetables in Slovakia. In: Bioclimatology and natural hazards. Springer, Dordrecht, pp 271–282
27. Benetin J, Šoltész A (1988) Hydrologické charakteristiky vodného režimu pôd a ich výpočet. In: Agromelio. ČSVTS, Nitra, pp 12–20
28. Gomboš MJ, Ivančo R, Mati D, Pavelková D (1999) Výsledky meraní pôdnej vlhkosti v ťažkých pôdach na Východoslovenskej nížine. In: III. Zborník z konferencie "Vplyv antropogénnej činnosti na vodný režim nížinného územia". ÚH SAV Bratislava, Michalovce, s. 258–261
29. Tárník A, Tárníková M (2017) Analysis of the development of available soil water storage in the Nitra river catchment. IOP Conf Ser Mater Sci Eng 245:9
30. Orfánus T (2005) Spatial Assessment of Soil Drought Indicators at Regional Scale: Hydrolimits andSoil Water Storage Capacity in Záhorská nížina Lowland. J Hydrol Hydromechan 53 (3):164–176
31. Tate EL, Gustard A (2000) Drought definition: a hydrological perspective. In: Vogt JV, Somma F (eds) Drought and drought mitigation in Europe. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 23–48
32. Lapin M, Faško P, Kveták Š (1988) Metodický predpis 3-09-1/1. Klimatické normály. SHMÚ, Bratislava, 25 pp
33. European Environmental Agency (2012) Climate change, impacts and vulnerability in Europe 2012. An Indicator Based Report. EEA Report No. 12/2012. EEA, Copenhagen, 300 pp