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EXAMPLE OF THE ANALYSIS AND EVALUATION OF AGRICULTURAL SOIL MOISTURE CONDITIONS FROM THE LONG-TIME PERIOD POINT OF VIEW

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Abstract. The aim of paper is to i) present a method of evaluation of soil moisture conditions dynamics based on selected indicators in agricultural land of Slovakia; ii) describe how to create temporal and spatial model of agricultural soil moisture conditions in Slovakia at different spatial levels (points, polygons coverage) and iii) identify and describe basic characteristics of soil moisture dynamics at different time horizons (1970 – 1979; 1980 – 1989; 1990 – 1999; 2000 – 2009 and normal set for the period 1961 to 1990). Soil water deficit, water consumption, water surplus and soil water recharge were applied as indicators of the soil moisture dynamics at point level. Results were presented through line graphs. At polygon coverage spatial level, soil drought indicator (dry day) was defined as the day with soil water content which is equal or less to 50% of available soil water capacity. Another indicator was defined as a probability of dry day occurrence. Analysis results were displayed on maps. Increase in average monthly temperatures, potential evapotranspiration and soil water deficit were observed which resulted in negative changes in soil water balance of agricultural soils in comparison to normal. The significant changes were observed mainly in the period 2000 - 2009. Increase of area with higher number of dry days was observed from the soil moisture balance spatial patterns. Significant changes in dry days number pattern was observed also as being distributed over the year, particularly the increase of dry days number area was observed during vegetation season mainly in May, June and July.

Introduction

The soil moisture content represents a factor with crucial impact on soil formation processes and a key factor for agricultural sector (mainly for crop production). The temporal and spatial variability of soil moisture content is dependent on climatic, hydrological and soil conditions. Regarding to climate conditions, the relation between precipitation and evaporation seems to be most important; evaporation is dependent mainly on temperature, air humidity and air circulation. Distribution of the climatic elements during the year affects the character of water balance elements, which has a significant impact on the amount of soil water and its dynamics in time and space.

Besides the spatial variability of agricultural soil moisture content observable over the year, there is also variability in respect to long-term periods as well. The spatial and temporal variability of soil moisture content in soil profile and its changes for more consecutive (hydrological) years or vegetation seasons represents soil moisture regime (Fulajtár 2006). The variability of soil moisture conditions and regime has cyclic character; the soil water store changes between the states of soil full saturation in winter and early spring months and extreme low values near the wilting point in summer months.

There are several methods of soil water regime evaluation – hydrological, ecological and agronomic classifications (Bedrna et al 1989, Fulajtár 2006 or Kutílek 1978) and several papers which deal with classification of soil water regime in Slovakia (for example Bedrna et al. 1989, Fulajtár 2006, Takáč 1999, Takáč 2008).

As soil water regime is considered to be static view on general soil water conditions on individual localities, there is possibility to analyse the existence of some trends or changes between spatial variability of soil moisture conditions in ten-year periods in 1970 – 2009 period and normal set of soil moisture conditions specified for the period 1961 to 1990. The results of analyse can contribute to the study of impact of climate change on agricultural land of Slovakia.

The aim of paper is to i) present a method of evaluation of soil moisture conditions dynamics based on selected indicators in agricultural land of Slovakia; ii) describe how to create temporal and spatial model of agricultural soil moisture conditions in Slovakia at different spatial levels (points, polygons coverage) and iii) identify and describe basic characteristics of soil moisture dynamics at different time horizons (1970 – 1979; 1980 – 1989; 1990 – 1999; 2000 – 2009 and normal set for the period 1961 to 1990).

Material and methods

Theoretical experiment

In experiment, the spatial models of agricultural soil moisture dynamics were created and analyzed in several time horizons at different spatial levels in Slovakia. Different indicators of soil moisture dynamic were applied at different spatial levels.

At a point level, the *water deficit, water consumption, water surplus and water recharge* were expressed on the base of data on long-term averages of monthly potential evapotranspiration, monthly actual evapotranspiration and monthly rainfall. As well, the long-term average of monthly average temperature was applied to give an oversimplified picture of the moisture regime and to estimate basic outlines of soil water regimes changes for five weather stations (Hurbanovo, Beluša, Spišské Vlachy, Rimavská Sobota and Milhostov) in five time horizons (1970 – 1979, 1980 – 1989, 1990 – 1999, 2000 – 2009 and 1961 - 1990).

The area between the lines which represent the long-term average of monthly rainfall and potential evapotranspiration indicates the status of soil moisture (Figure 1). The difference between long-term average of monthly potential and actual evapotranspiration on graph (potential evapotranspiration is higher than actual evapotranspiration) refers to soil water deficit. The area between the lines of long-term average of monthly actual evapotranspiration and rainfall (actual evapotranspiration exceeds rainfall), represents soil water utilization. The area between the lines of long-term average of monthly rainfall and actual evapotranspiration (rainfall exceeds potential and actual evapotraspiration) is water recharge; if recharge exceeds the soil water capacity, the area is assumed as water surplus. The relations between indicators are usually applied the soil water regime to be estimated (according to *Soil Taxonomy;* Soil Survey staff 1999).

At polygon coverage spatial level which cover the area of agricultural land in Slovakia, *the number of dry days and probability of dry days occurrence* were applied as indicators of agricultural soil moisture dynamic in the same time horizons (1970 – 1979, 1980 – 1989, 1990 – 1999, 2000 – 2009 and 1961 - 1990). Dry day was defined as a day with soil moisture under 50% of available soil water capacity, while this value is convenient with a presence of soil water held at a tension of 1500 kPa and more.

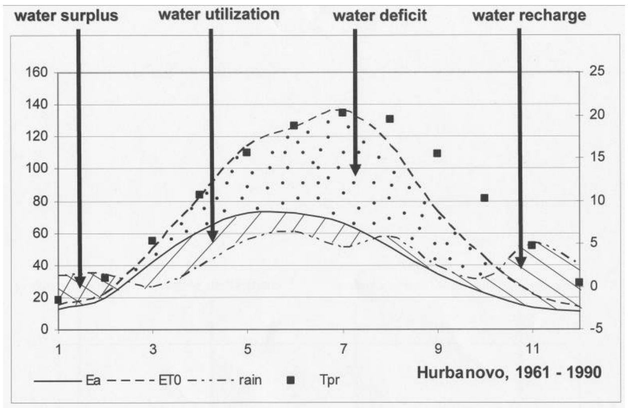

Figure 1. The example of graphical processing of soil water deficit, utilization, recharge and surplus

Data

In experiment following data were applied:

- weather data, namely daily data on minimum, maximum and average temperature (°C), sunshine duration (hours), vapour pressure (hPA), average wind speed ($m.s^{-1}$) and rainfall (mm) in 1961 – 2009 coming from 71 weather stations localized approximately regularly across the whole areas of agricultural land in Slovakia; weather data were obtained from Slovak Hydrometeorological Institute (SHI);
- experimental soil data on available water capacity (%) for selected weather stations (Hurbanovo, Beluša, Spišské Vlachy, Rimavská Sobota and Milhostov), data were obtained from Slovak Hydrometeorological Institute (SHI);
- soil data from soil profile database (a content of individual texture fractions in soil profile horizons) and from database of pedo-ecological units (spatial variability of soils with different texture), both under the maintenance of Soil Science and Conservation Research Institute (SSCRI).

Methods

In experiment following methods were applied:

- the calculations of evapotranspiration; potential evapotranspiration was calculated in the daily time horizons on the base of Penmen formula (Micale and Genovese 2004), actual evapotranspiration was specified on the base of application of simplified soil water balance equation (see lower);
- spatial interpolation of weather data into regular grid with spatial resolution of 10 km; the applied method of spatial interpolation followed the method implemented in European Crop Growth Monitoring system (CGMS) which has been developed in JRC (Micale and Genovese 2004) and which has been modified to national conditions of Slovakia (SK_CGMS; Nováková 2007, Nováková and Skalský 2008, Nováková et al. 2010);
- application of set of pedotransfer rules aimed to specify available soil water capacity (%) for 1 m deep soil layer, calculated data were spatially interpreted to 1 km spatial resolution grid covering agricultural soils of Slovakia via soil map data on land evaluation units and soil-ecological regions (Nováková et al. 2010);
- application of simplified soil water balance equation that was used to calculate soil moisture status including the relative soil moisture and number of dry days for 1 km spatial resolution grid covering agricultural soils of Slovakia:

$$W_1 + Z + K_p + q_1 + q_2 = ET + O_1 + O_2 + W_2,$$

where W_1 is soil water store at the beginning of balanced period (mm), Z is rainfall in balanced period - except of the interception (mm), K_p is the increase of the soil water from ground water (mm), q_1 is surface influx (mm), q_2 is undersurface influx (mm), ET is evapotranspiration (mm), O_1 is surface runoff (mm), O_2 is undersurface horizontal and vertical runoff (mm) a W_2 is soil water store at the end of balanced period (mm) (Kutílek, 1978); in this equation K_p, q_1, q_2 and O_2 were ignored;
- graphical representation of the results: a) line graphs through which outputs for selected weather station were expressed and interpreted and b) maps which enabled the results for agricultural land to be expressed and interpreted.

Results and disscussion

Dynamics of soil moisture at the level of weather stations

Weather stations applied in analyze of soil moisture dynamic were selected on the base of criteria of their location in different agroclimatical regions in Slovakia (Figure 2).

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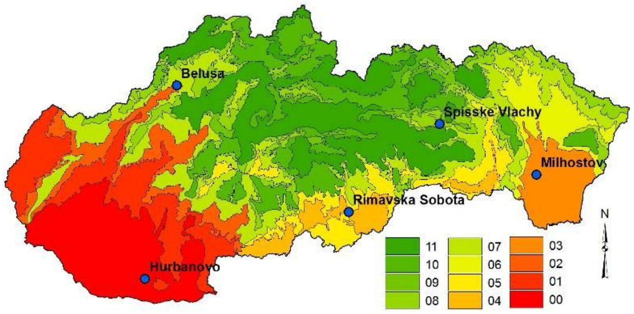


Figure 2. Weather stations localities in agroclimatic regions according to database of pedo-ecological units (Linkeš et al. 1996)

Several general trends in soil water dynamic were observed at analyzed weather stations:

- the significant changes mainly between the period 2000 – 2009 and period 1961 – 1990 (normal set), that is why there is paid attention to mentioned ten year periods in paper;
- the increase in average monthly temperatures, the increase in potential evapotranspiration, and the increase in soil water deficit;
- progressive movement of dryness up of agricultural soils in spring from March to April;
- and for that reasons negative changes in soil water balance of agricultural soils in vegetation season in comparison to normal.

In comparison of soil moisture conditions in periods 2000 – 2009 and 1961 – 1990 at Hurbanovo weather station were observed: a) moderate increase in average monthly temperatures (maximum temperature differs in 2°C), b) significant increase of potential evapotranspiration (about 20 mm), c) almost no change in rainfall amount but significant change in rainfall distribution over the year (two maximums of rainfall in summer – in June and August and dry period in March versus one rainfall maximum – in August and dry period in April) and consecutively d) increase of water deficit (Figure 3).

At weather station Beluša, the comparison of soil moisture status in ten years period 2000 – 2009 and in period 1961 - 1990 showed a) increase in average monthly temperatures (maximum temperature differs in 2 - 3°C), b) significant increase of potential evapotranspiration (about 30 mm), c) change in rainfall distribution over the year (two maximums of rainfall in summer – in June and August and without dry period in spring versus one rainfall maximum – in August and dry period in April) and consecutively d) significant increase of water deficit (Figure 4).

a) b)

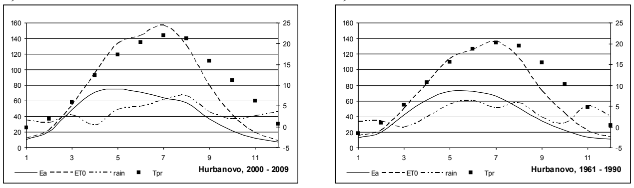


Figure 3. Comparison of average monthly data on potential and actual evapotranspiration, rainfall and average temperature in the periods of a) 2000 – 2009 and b) 1961 – 1990 in Hurbanovo

a) b)

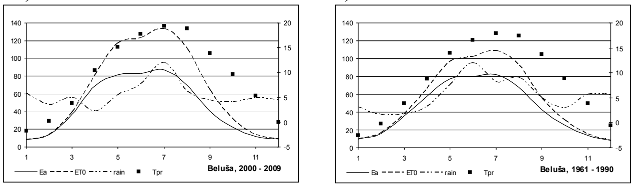


Figure 4. Comparison of average monthly data on potential and actual evapotranspiration, rainfall and average temperature in the periods of a) 2000 – 2009 and b) 1961 – 1990 in Beluša

At weather station Spišské Vlachy, the comparison of soil moisture status in ten years period 2000 – 2009 and in period 1961 - 1990 resulted in a) un-considerable increase in average monthly temperatures (maximum temperature differs in 1°C over the year), b) increase of potential evapotranspiration (about 10 mm), c) change in rainfall distribution over the year (two maximum of rainfall in summer – in June and August versus noticeable rainfall maximum in August which exceeds the values of potential and actual evapotranspiration) (Figure 5).

At weather station Rimavská Sobota, in comparison of soil moisture status in ten years period 2000 – 2009 and in period 1961 - 1990 following trends were observed a) increase in average monthly temperatures (maximum temperature differs approximately in 1°C), b) significant increase of potential evapotranspiration (about 20 mm), c) change in rainfall distribution over the year (maximum of rainfall in June and without dry period in spring versus one maximum – in July and dry period in April) and consecutively d) significant increase of water deficit (Figure 6).

a) b)

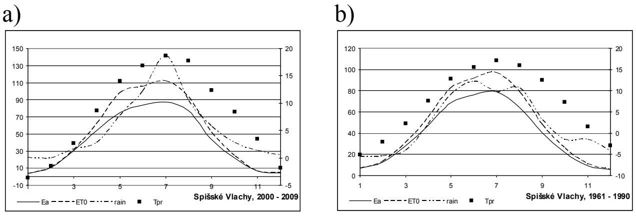


Figure 5. Comparison of average monthly data on potential and actual evapotranspiration, rainfall and average temperature in the periods of a) 2000 – 2009 and b) 1961 – 1990 in Spišské Vlachy

a) b)

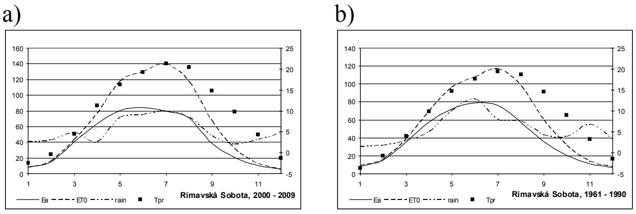


Figure 6. Comparison of average monthly data on potential and actual evapotranspiration, rainfall and average temperature in the periods of a) 2000 – 2009 and b) 1961 – 1990 in Rimavská Sobota

And finally, the comparison of soil moisture status in ten years period 2000 – 2009 and in period 1961 - 1990 at Milhostov weather station pointed out a) moderate increase in average monthly temperatures (maximum temperature differs in 2°C), b) increase of potential evapotranspiration (about 10 mm), c) change in value of rainfall maximum (increase in about 10 mm), without change in rainfall distribution over the year (maximum in July) and d) occurrence of dry period in April (Figure 7).

a) b)

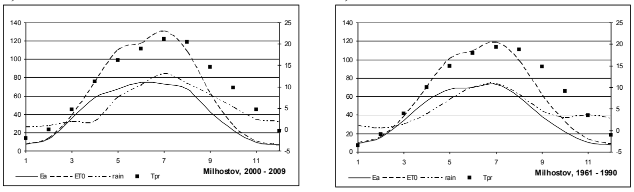


Figure 7. Comparison of average monthly data on potential and actual evapotranspiration, rainfall and average temperature in the periods of a) 2000 – 2009 and b) 1961 – 1990 in Milhostov

As we assume weather stations to be representative for the regions of their occurrence, it will be possible to find regional differences in trends of soil moisture dynamic and in relations between water deficit, consumption, recharge and surplus. This task requires additional weather stations to be analyzed. As well, the condition of sufficient number of representative weather stations is needed to be fulfilled.

Dynamics of soil moisture at the level of agricultural land of Slovakia

In experiment, spatial variability of number of dry days in individual months in ten-year periods (example of May), individual years (example of extreme years), ten-year periods and normal was confirmed (Figure 8 - 12).

In May during ten-year periods in 1970 – 2009 (Figure 8), there was noticed similar spatial variability of average number of dry days with relatively low frequency in periods 1970 – 1979 and 1990 – 1999. The difference between maximum and minimum of average number of dry days over the area of agricultural land is not too high. On the other hand, the May in periods 1980 – 1989 and 2000 – 2009 was evaluated as dry and both periods were characterised with more noticeable spatial variability of average number of dry days. In period 1980 – 1989, the high average number of dry days (15 – 20 days) was achieved in Podunajská nížina lowland (maily in Trnavská tabuľa region) and Juhoslovenská kotlina basin; higher average number of dry days (above 20 days) occurred only locally. In period 2000 – 2009, localities with 15-20 and above 20 dry days in May were noticed mainly in Záhorská nížina lowland, in the east part of Podunajská nížina lowland and in the south part of Východoslovenská nížina lowland.

Besides, several trends were observed in comparison of spatial variability of dry day average number in May during ten-year periods and spatial variability of dry days average number in May specified for period 1961 - 1990 (normal set, Figure 9):

- considerable difference between normal spatial variability in May and spatial variability in May in ten-year periods 1980 – 1989 and 2000 – 2009 and similar spatial variability between normal in May and May in ten-year periods 1970 – 1979 and 1990 – 1999;
- significant changes in spatial pattern of dry days number mainly in lowlands and basins localized in south part of Slovakia;
- and the increase of impacted area with higher number of dry days in lowlands and basins localized in south part of Slovakia.

a) b)

c) d)

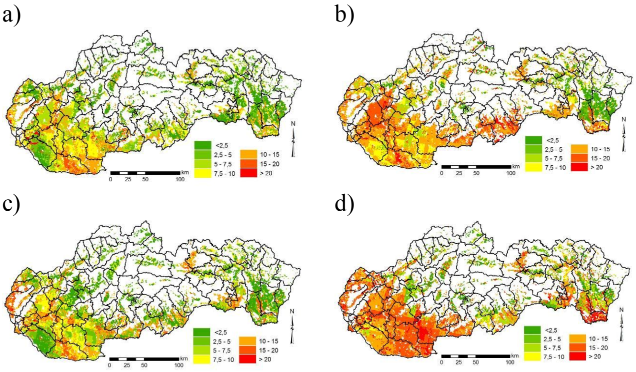


Figure 8. Comparison of spatial variability of average number of dry days in May in different periods: a) 1970 – 1979; b) 1980 – 1989; c) 1990 – 1999 and d) 2000 – 2009

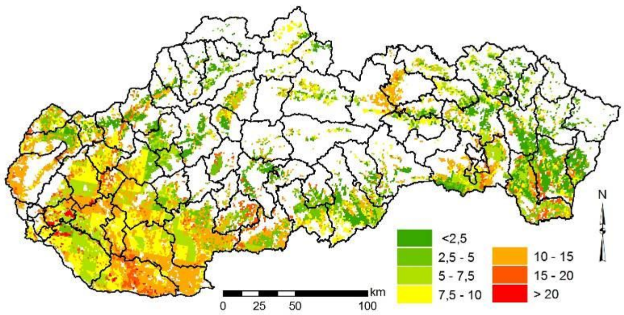
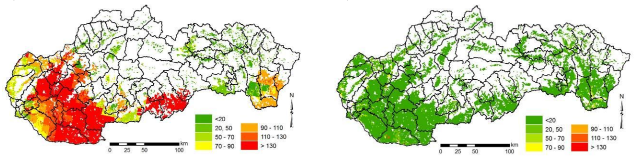


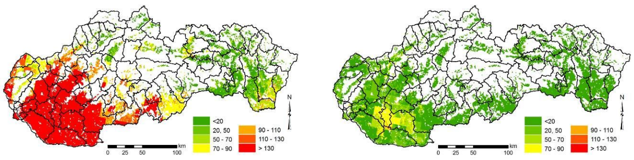
Figure 9. Spatial variability of average number of dry days in May in 1961 – 1990 (normal set)

Relating to spatial variability of number of dry days in individual years of ten-year periods, there is considerable dynamic and temporal variability of soil moisture conditions which is observable in comparison of extreme years (figure 10). In moist years (for example 1972 - figure 10b, 1980 - 10d, 1996 - 10f and 2005 - 10h), the spatial variability of number of dry days is weak, the area is relatively homogenous and the differences between individual regions are inconsiderable. In dry years (for example 1971 - figure 10a, 1983 - 10c, 1992 - 10e and 2003 - 10g), there is more significant spatial variability of number of dry days than in moist years, the area is heterogeneous and the differences between individual regions are considerable from the number of dry days point of view. Maximum number of dry days reaches 130 days per year and more (in lowlands and basins), minimum number of dry days reaches 20 days per year and less (mountainous regions).

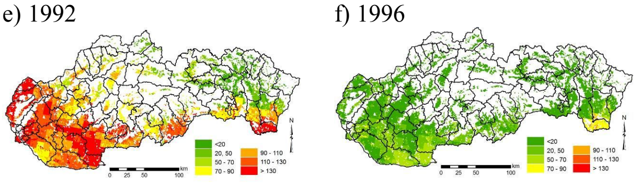
a) 1971 b) 1972



c) 1983 d) 1980



e) 1992 f) 1996



g) 2003 h) 2005

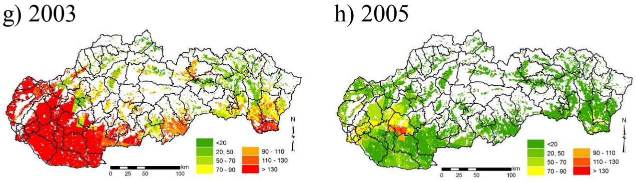
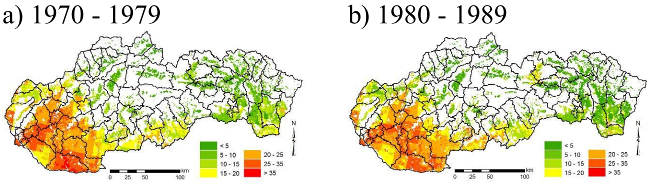


Figure 10. Spatial variability of number of dry days in individual years: a, c, e, g - dry years; b, d, f, h - moist years

Spatial variability of probability of dry day occurrence in ten-year periods and in normal set refers to identification of the driest regions in Slovakia (Figure 11). There was observed not very significant differences between spatial variability of probability of dry day occurrence in individual ten-year periods and in normal set. There was observed differences related to "spatial movement" of areas with relatively high probability of dry day occurrence only with regional importance (maily in Podunajská nížina and Záhorská nížina lowlands). As well, the increase of impacted area with higher probability of dry day occurrence in Podunajská nížina lowland was noticed in comparison of ten-year period 2000 - 2009 with period 1961 – 1990.

a) 1970 - 1979 b) 1980 - 1989



c) 1990 – 1999 d) 2000 - 2009

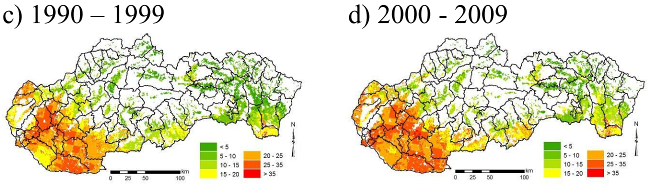


Figure 11. Spatial variability of probability of dry day occurrence in ten-year periods

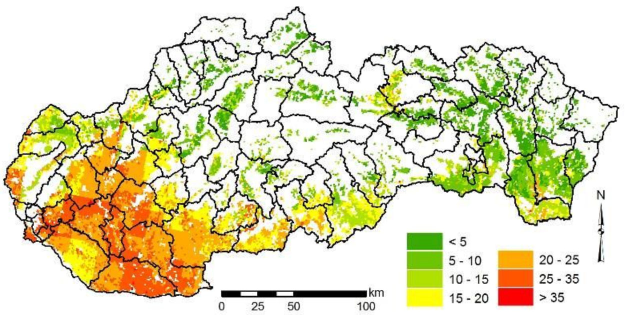


Figure 12. Spatial variability of probability of dry day occurrence in 1961 - 1990 periods (normal set)

Conclusions

In paper, the method of assessment of dynamics of soil moisture conditions based on selected indicators is presented; temporal and spatial models of agricultural soil moisture conditions in Slovakia at different spatial levels were created and basic characteristics (trend lines) of soil moisture dynamics at different time horizons were identified as well.

Simplified assessment of trends in moisture conditions at individual weather stations was realized through the processes of water deficit, water consumption, water recharge and water surplus indicators. The indicators were expressed on the base of relations between potential evapotranspiration, actual evapotranspiration, rainfall and average air temperature. The changes in relations between indicators refer to negative trends in soil moisture conditions on analyzed weather stations – the increase of average monthly temperature, increase of average monthly potential evapotranspiration and increase of soil water deficit. The most significant changes (in comparison to normal set) are linked to period 2000 – 2009.

The analysis of dynamic of soil moisture at the level of agricultural land of Slovakia in ten-year periods in 1970 – 2009 and in 1961 – 1990 (reference period) was realized through indicators as number of dry days and probability of dry day occurrence. The analysis confirmed significant spatial and temporal variability of indicators at the level of month periods (example of May), at the level of individual years (example of extreme years) and at the level of ten year periods.

Several "general" trends were identified at all time horizons: a) significant changes in spatial pattern of dry days number mainly in lowlands and basins; b) the increase of impacted area with higher number of dry days in lowlands and basins localized in south part of Slovakia; c) the significant changes were noticed in comparison of period 2000 – 2009 and normal period – 1961 – 1990 and d) not very significant relating to spatial variability of probability of dry days occurrence in all analyzed time horizons.

In compliance with present - day trends in dynamic of agricultural soil water, analysed indicators can be considered as dryness indicators of conditions of Slovakia.

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