Impact of Extreme Meteorological Phenomena on Soil Water Storage of Slovakia Typical Lowland Site

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Summary

Change of the hydrologic cycle on the Earth is closely connected to the climate change caused by global warming of the atmosphere. The conditions in natural ecosystem in agricultural areas are changing. Both surface water resources and the soil water store react to the prospective changes. Some areas in Slovakia witness extreme maximum, minimum or are lack of precipitation much more frequently. The maximum of precipitation result in flooding and the minimum in excessive soil drying. In this paper actual soil water storage measured by neutron probe in period 1999-2004 at lowland region, specifically in locality Bodiky, is shown. Amount of water in unsaturated soil zone for soil layers 0-30 cm and 30-60 are assessed with regard to precipitation totals and temperature. Furthermore, the impact of climate change to the soil water storage is solved. Numerical simulation was calculated using mathematical model GLOBAL. Calculation of soil water storage has been determined for daily time step for 30-years reference period (1955-84) and for the time horizons 2010, 2030 a 2075. Climate parameters for time horizons 2010, 2030 and 2075 were modified for climate scenarios CCCM2000 and GISS98.

Key words

soil water storage; climate change; mathematical modelling; unsaturated soil zone

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Introduction

Water regime which determines soil productive ability depends on water inflow and outflow into and out of unsaturated soil zone (Figure 1). The water supply in the unsaturated soil zone is directly influenced by water transfer through its upper and lower boundaries. The upper soil layer (the soil surface) is changing its basic physical and hydrophysical properties at extreme meteorological changes. Sometimes the water can flow off along prefered ways down to the ground water. Soil draining sustains preferred ways formation by forming cracks. The phenomena depend on a soil type. If water does not flow off at major floods, a water layer on the soil surface is produced. Water prevents the soil from air infiltration and changes the soil surface structure. If the soil is not cultivated the changes are irreversible. In this study, influence of these phenomena on a soil water regime or water store in an unsaturated soil zone will be quantified by monitoring of soil moisture in the whole profile of the unsaturated soil zone and also by using mathematical modelling for the water movement in soil. Determination of the soil water storage is commonly derived by empirical and semiempirical relationships that are based on the dependence among soil moisture, meteorological and hydrological components. An assessment method of these problems is developed in studies Tomlain (1997), Petrovic (2000), Takac (2003), Stehlova and Mikulec (2003).

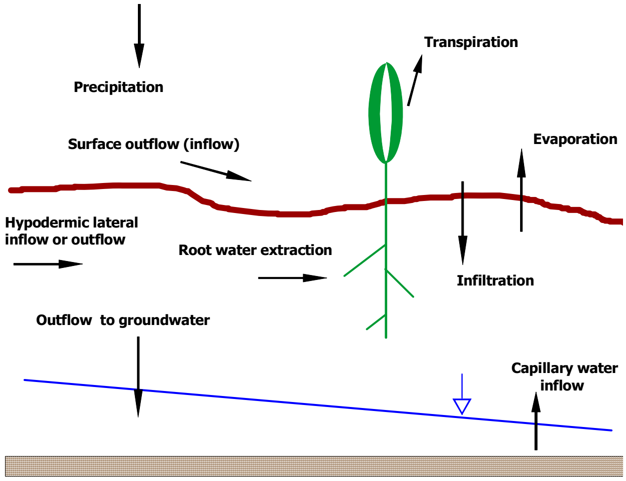

Figure 1.
Scheme of inflow and outflow into and out of unsaturated soil zone

Material and methods

Selected locality Bodiky lies on the of south Slovakia in the region named Zitny ostrov (Figure 2). It is situated on the inundating locality of the Danube River. On this locality is forest ecosystem with poplar vegetation (Novak et al., 1998). The soil is clay and clay – sand which in depth of 120 centimetres it is replased with only sand. In the depth of 150 cm is gravel subsoil.

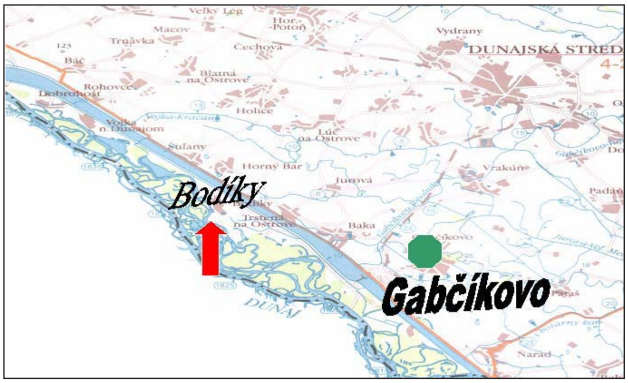

Figure 2.
Map of selected locality Bodiky (South -West Slovakia)

Hydro-physical parameters for this locality have been determined in the soil samples (their capacity was 100 cubic centimetres), which were taken on the place of monitoring (Table 1). Monograph (Sutor, Stekauerova, 2000) generalised these parameters. Drainage branches of moisture retention curve have been determined in the laboratory conditions by using the hyperbaric device (Soil Moisture Equipment, Santa Barbara, California). Laboratory method of variability hydraulic gradient was used to determine the Coefficient of saturated hydraulic conductivity. Parameters α and n were estimated by using retention curve fitting in accordance with the method van Genuchten method (1980) .

The locality was currently selected based on periodical monitoring for values of groundwater level and soil water storage since year 1999 by the workers from the Institute of Hydrology. Figure 3-4 shows time progresses of daily values of precipitation totals and temperature measured at meteorological gauge station Gabcikovo during period from 1999 to 2004. Their statistical characteristics are presented in Table 2 and 3. The maximum of annual precipitation amount from period from 1999 to 2004 was noticed in the year 1999 and the minimum of annual precipitation totals was observed in the year 2003. The highest average of annual temperature was recorded for the year 2000 and the lowest for the year 2003. These climatic differences influenced soil water storage in locality Bodiky, mainly for the top soil layer 0-30 cm and for the layer 30-60 cm (Figure 5-6). Lack of the soil water storage was measured for period 1999-2004 except for 1999. The most significant lack of the soil water was measured in layer 0-30 cm in the year 2003,

Table 1.
Hydro-physical parameter of the soil profile divided to five layers at locality Bodiky, where Θ_s is saturated moisture, Θ_{pk} is field water capacity, Θ_r is residual moisture, α, n are parameters and K is saturated hydraulic conductivity

Soil layer [cm]	Θ_s [cm^3.cm^{-3}]	Θ_{pk} [cm^3.cm^{-3}]	Θ_r [cm^3.cm^{-3}]	α [cm^{-1}]	N [-]	C [cm.deň$^{-1}$]
0–35	0.5474	0.3800	0.0684	0.04407	1.29706	193.27
36–90	0.5491	0.3500	0.0552	0.04920	1.35140	38.90
91–100	0.5425	0.3300	0.0265	0.09983	1.17602	39.73
101–150	0.5231	0.3700	0.0484	0.02314	1.38266	14.44
0–150	0.5396	0.3623	0.0541	0.04269	1.33745	66.82

Table 2.
Statistical characteristics of precipitation totals measured at meteorological gauge station Gabcikovo during period 1999-2004

Characteristics	1999	2000	2001	2002	2003	2004
Frequency	133	115	154	152	119	149
Total precipitation [mm]	592.9	437.8	488.9	538.6	327.8	560.6

Table 3.
Statistical characteristics of temperatures measured at meteorological gauge station Gabcikovo during period 1999-2004

Characteristics	1999	2000	2001	2002	2003	2004
Mean [°C]	10.69	11.83	10.47	11.27	10.95	10.60
Maximum [°C]	27.90	27.60	28.20	27.90	28.10	26.00
Minimum [°C]	-7.20	-9.50	-13.90	-10.40	-11.70	-11.40

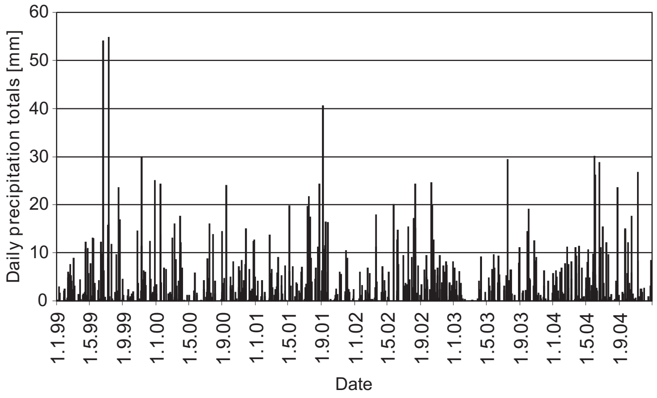

Figure 3.
Daily precipitation totals measured at meteorological gauge station Gabcikovo during period 1999-2004

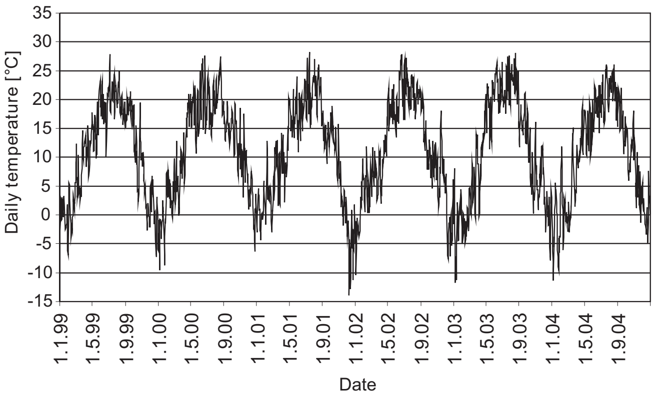

Figure 4.
Daily values of temperature measured at meteorological gauge station Gabcikovo during period 1999-2004

when the annual precipitation amount noticed was only about 330 mm. The soil water storage decreased about 20 mm under Wilting point in September. The sufficiency of soil water storage was shown for the layer 30-60cm. Growth trend of soil water has been decreased in both soil layers.

The long-term monitoring of soil water storage is not proceeding in Slovakia. The short-term observed periods are not representative for assessment of meteorological phenomena impact on the soil water regime. Based on this reason mathematical modelling was used for assessment of water storage in the soil.

The mathematical model GLOBAL created by workers from Institute of Hydrology, Bratislava (Majercak, Novak, 1994) is used for numerical simulation of climate change impact to the soil water storage. This model belongs to the group of one-dimensional vertical models which uses basic Richards's equation and it is simulating

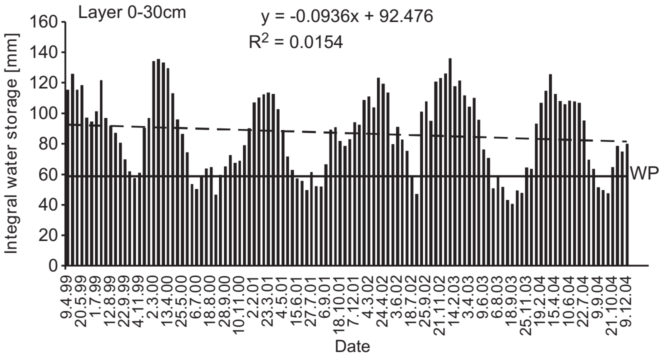

Figure 5.
Integral water storage in soil layer 0-30 cm measured at locality Bodiky in period 1999-2004 (WP – hydrolimit named wilting point)

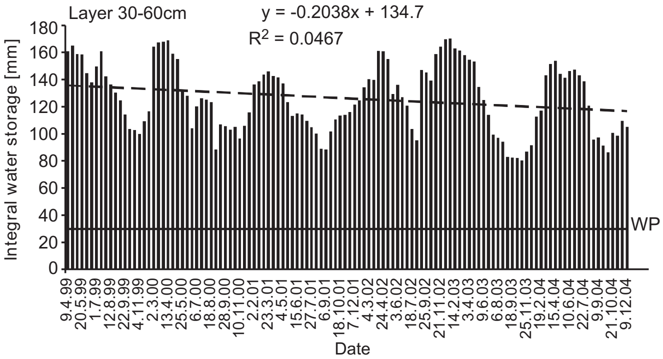

Figure 6.
Integral water storage in soil layer 30-60 cm measured at locality Bodiky in period 1999-2004 (WP – hydrolimit named wilting point)

the movement of water in the system soil – vegetation – atmospheres in isothermal conditions with especial regard to the root zone.

$$\frac{\partial h_W}{\partial t} = \frac{1}{c(h_W)} \cdot \frac{\partial}{\partial z}\left[k(h_W) \cdot \left(\frac{\partial h_W}{\partial z} + 1\right)\right] - \frac{S(z,t)}{c(h_W)} \qquad (1)$$

where
h_w - soil water pressure head [L],
$k(h_w)$ - unsaturated hydraulic conductivity [LT^{-1}],
$S(z,t)$ - intensity of water uptake by roots [T^{-1}],
$c(h_w)$ - specifically water capacity [LT^{-1}],

$$c(h_W) = \frac{\partial \theta}{\partial h_W} \qquad (2)$$

θ - volumetric soil water content [-]
z - vertical coordinate [L],
t - time [T].

Calculations of soil water storage are presented in daily time step for 30-years reference period (1955-84) and for the time horizons 2010, 2030 and 2075.

The following data sets were used as input for the simulation model GLOBAL:

- initial measurement of moisture profile in the beginning of vegetation period and time series of moisture capacity in the depth 150 cm (Stekauerova and Nagy, 2001; Stekauerova et al., 2001),
- values of crop parameters such as Leaf Area Index (LAI), roughness of evaporating surface, albedo of surface and root depth,
- climatic parameters from meteorological gauge station in Gabcikovo which belongs to observational networks of the Slovak Hydrometeorological Institute. The main variables were daily values of precipitation, average temperature, daily sunshine duration, average daily vapour pressure and average daily wind velocity.

Climate characteristics for time horizons 2010, 2030 and 2075 were modified by climate scenarios CCCM2000 and GISS98. These climate change scenarios were created based on results from general circulation models (GCMs)

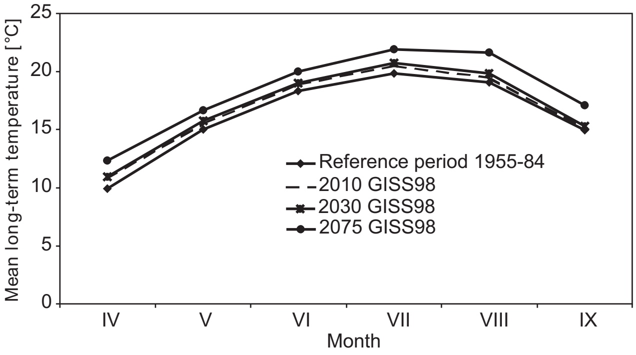

Figure 7.
Mean long-term temperature from April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (GISS98)

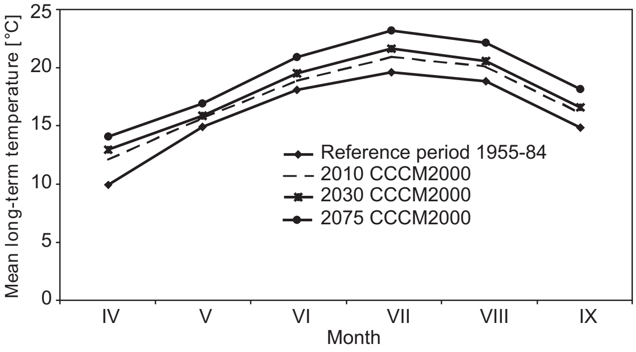

Figure 8.
Mean long-term temperature from April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (CCCM2000)

Table 4.
30-years averages of mean temperature (T), mean vapor pressure (WP), mean wind velocity (WV), amount of sunshine duration (SD) and precipitation totals (R) in summer period (IV-IX) for reference period 1955-84 and for time horizons 2010, 2030, 2075

	Period	T [°C]	WP [hPa]	WV [m.s^{-1}]	SD [h]	R [mm]
	1955-1984	16.2	10.4	2.4	1329.8	305.6
GISS98	1996-2025	16.7	11.4	2.4	1314.2	321.0
	2016-2045	16.9	11.6	2.4	1312.2	320.4
	2061-2090	18.3	12.5	2.4	1308.8	310.3
CCCM2000	1996-2025	17.5	11.5	2.4	1422.7	294.4
	2016-2045	18.0	11.8	2.4	1440.5	284.5
	2061-2090	19.5	12.9	2.4	1436.2	291.6

and were modified for Slovakia by Prof. Milan Lapin from FMFI UK, Bratislava (Lapin et al., 2001). GCM model CCCM2000 were introduced by the Canadian Centre for Climate Modelling and Analysis, Victoria, British Columbia in 2000 (Flato, Boer, 2001; Lapin et al., 2001). GCM model GISS98 was introduced by Goddard Institute for Space Studies, New York, U.S.A. in 1998 (Russell, 1998; Lapin et al., 2000).

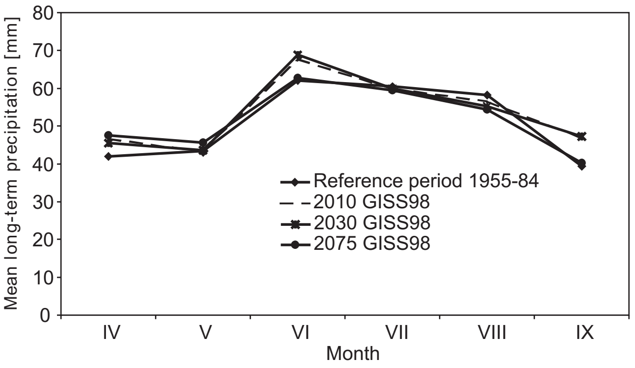

Figure 9.
Mean long-term precipitation totals from April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (GISS98)

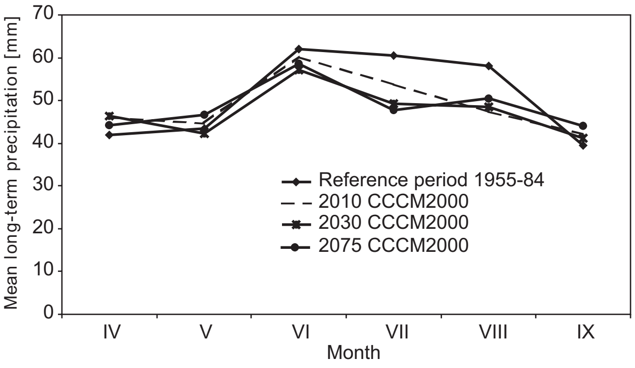

Figure 10.
Mean long-term precipitation totals from April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (CCCM2000)

Measurment work done for 30 years (period from 1955 to 1984) at locality Gabcikovo was used for climate reference. The corrections of climatic scenarios by correcting quotients and deviations were necessary for this period. New developed scenarios of climatic change were used for creation of daily data sets of selected meteorological parameters. Results of calculated 30-years of average temperature, average vapour pressure, average wind velocity, amount of sunshine duration and precipitation totals in summer period (IV-IX) for reference period 1955-84 and for time horizons 2010, 2030 and 2075 are presented in Table 4. Figures 7 and 10 show average long-term values of temperature and precipitation totals from April to September calculated for reference period 1955-84 and for horizons 2010, 2030 and 2075 (GISS98 and CCCM2000).

Results and discussion

Time series of soil water storage were calculated for two soil profiles (0-30 cm and 30-60 cm). The soil profile was considered homogenous. Figures 11-14 show average long-term soil water storage in layer 0-30 cm from April to September calculated for reference period from 1955-84 and for horizons 2010, 2030, 2075 (adjusted by climate scenarios GISS98 and CCCM2000).

Percentage differences of long-term averages of soil water storage calculated between values modified by scenarios GISS98 and CCCM2000 and values calculated for reference period in soil layer 30-60 cm are presented in Tables 5 and 8.

By comparison of time progresses of soil water storage in time horizons 2010, 2030 and 2075 (scenario CCCM2000) obtained by simulation using the model GLOBAL to calculated values for reference period we have found, that the soil water storage will decrease as a result of climatic changes. The lowest differences are between simulated values for reference period and prognoses values calculated for horizon 2010. For period

Table 5.
Percentage differences of long-term averages of soil water storage calculated between values adapted by scenario GISS98 and values calculated for reference period in soil layer 0-30 cm

Time horizon	April	May	June	July	August	September
2010	0.6	1.5	3.4	3.3	2.9	5.1
2030	0.3	0.1	-0.3	3.0	2.2	4.2
2075	0.2	0.2	-1.9	0.3	-0.5	-0.8

Table 6.
Percentage differences of long-term averages of soil water storage calculated between values adapted by scenario GISS98 and values calculated for reference period in soil layer 30-60 cm

Time horizon	April	May	June	July	August	September
2010	0.4	0.9	2.7	4.5	3.9	4.4
2030	0.2	0.2	-1.6	3.6	2.8	2.9
2075	0.1	0.1	-2.7	0.4	-0.7	-2.5

Table 7.
Percentage differences of long-term averages of soil water storage calculated between values adapted by scenario CCCM2000 and values calculated for reference period in soil layer 0-30 cm

Time horizon	April	May	June	July	August	September
2010	0.0	0.6	-0.3	-3.4	-8.3	-7.8
2030	-0.2	0.8	-2.9	-6.0	-9.6	-8.2
2075	-1.0	-0.6	-4.2	-7.8	-10.5	-7.3

Table 8.
Percentage differences of long-term averages of soil water storage calculated between values adapted by scenario CCCM2000 and values calculated for reference period in soil layer 30-60 cm

Time horizon	April	May	June	July	August	September
2010	0.0	0.5	0.2	-2.1	-5.8	-10.2
2030	-0.1	0.3	-3.3	-4.0	-8.2	-12.2
2075	-0.5	-0.8	-4.7	-5.8	-10.3	-13.4

from April to June only low differences are noticed. The more significant decrease of soil water is predicted for period from August to September (6-10%). The horizons 2030 and 2075 are similar to horizon 2010, but changes of soil water are more significant compared to reference period. The drop of soil water from August to September in horizon 2030 is about 8-12% and in horizon 2075 is about 7-13%.

Scenarios GISS98 predicte slight increase of soil water storage compared to reference period (1955-84). Increase of soil water in horizon 2010 is about 4-8% in the end of vegetation period. It is similar in horizon 2030 when differences are about 3-6%. In horizon 2075 it is different then in horizons 2010 and 2030. Soil water storage is decreased compared to values of reference period for about 1-3%.

Conclusion

The first part of this paper shows actual soil water storage measured by neutron probe for period 1999-2004 at lowland region, specifically in locality Bodiky (Figures 5 and 6, Tables 5-8) and the second part of this study shows analyses and comparison of long-term average values of soil water storage during vegetation period (IV-IX). Modelling water amount in the unsaturated soil zone were assessed in the soil layer 0-30 cm and 30-60 cm for time horizons 2010, 2030 and 2075 and for reference period from 1955-84 (Figures 11-14). For numerical simulation of climate change impact on the soil water storage mathematical model GLOBALwas used. Inputs of meteorological characteristics were modified using

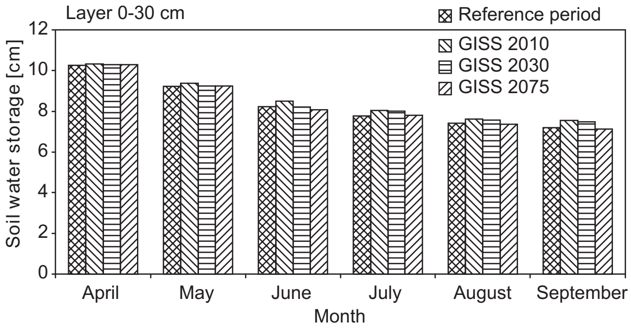

Figure 11.
Mean long-term soil water storage in layer 0-30 cm from April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (GISS98)

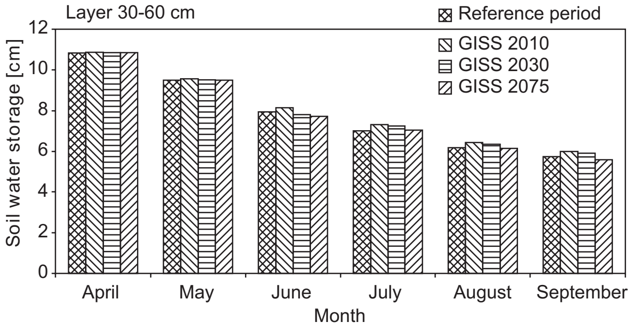

Figure 12.
Mean long-term soil water storage in layer 30-60 cm from April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (GISS98)

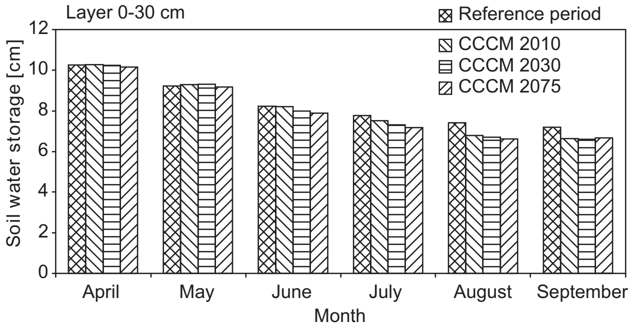

Figure 13.
Mean long-term soil water storage in layer 0-30 cm from April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (CCCM2000)

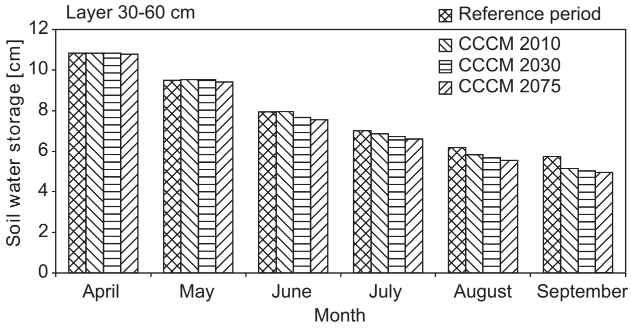

Figure 14.
Average long-term soil water storage in layer 30-60 cm in month April to September calculated for reference period 1955-84 and for horizons 2010, 2030, 2075 (CCCM2000)

climatic scenarios GISS98 and CCCM2000 (Figures 7-10, Table 4).

Time progresses of soil water storage measured at selected locality indicate the top soil layer sensitivity to the meteorological phenomena. Six-years trends in both investigated layers are decreased.

Results calculated by mathematical model GLOBAL indicate, that scenario GISS98 prognoses slight increase of long-term values of soil water storage, especially in horizons 2010 and 2030. In horizon 2075 decrease of long-term values of soil water storage is calculated in comparison with values of reference period, and it is about 1-3% in the end of vegetation period.

Values of soil water storage for scenario CCCM2000 prognoses decrease of long-term values in comparison with reference period. The highest differences are indicated in horizon 2075. There is decrease of water of about 4-13% in the second half of vegetation period.

Climate change scenarios are only possible prognoses named alternative scenarios because the modelling has many uncertainties. Based on our results we concluded that observation of the extreme meteorological phenomena, future climatic changes and their impacts on social-economic sphere and the natural environment is necessary in order to use the knowledge for the preparation for adaptation steps in order to reduce negative influence of above mentioned events.

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