Analysis of the Development of Available Soil Water Storage in the Nitra River Catchment

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Abstract. World is changing dramatically. Every sphere of our life is influenced by global climate changes, including agriculture sector. Rising air temperature and temporal variability of rainfall are crucial outcomes of climate changes for agricultural activities. Main impact of these outcomes on agriculture is the change of soil water amount. Soil water is an exclusive resource of water for plants. Changes of soil water storage are sensed very sensitively by farmers. Development of soil water storage was analysed in this paper. The Nitra River catchment is covered by nets of hydrological and meteorological stations of Department of Biometeorology and Hydrology, Slovak University of Agriculture in Nitra. Quantity of available soil water storage for plants was calculated every month in the years from 2013 to 2016. Calculations were done based on real measurements for soil horizon 0-30 cm. Ratio between a real available soil water storage and a potential available soil water storage was specified. Amount of potential available soil water storage was derived by retention curves of soil samples. Map of risk areas was created in GIS in pursuance of these calculations. We can see the negative trends of available soil water storage in years 2015 and 2016. Main addition of this paper is a selection of areas where soil moisture is a limiting factor of agriculture. In these areas, it is necessary to do the mitigation measures for sustainable development of agricultural activities.

1. Introduction

Water is one of the fundamental natural resources, life is not possible without water on the planet Earth. From agricultural point of view water has many functions. Soil water is significant mainly for agricultural and crop production because soil water is the main resource of water for plants, which receive water through their root system. Water supply in the aeration zone represents 3rd water source for biosphere alongside surface water (1st water source) and groundwater (2nd water source) in the system of water sources [1]. Serious attention is paid today to the problems of soil water storage and to its spatial pattern. Ecosystems are sensitive to soil water storage changes. These changes are driving forces of weather and climate also with heat fluxes between the Earth surface and the atmosphere. The quantification, spatial and temporal interpretation of soil water storage are considered crucial for a correct hydrological zonation of agricultural lands.

Soil water is bounded in soil, therefore not the whole soil water volume is available for plants. In practice, it is necessary to observe and maintain soil moisture in limits of its availability for field plants. Availability of soil water for plants is determined by hydrolimit field capacity as an upper boundary and hydrolimit wilting point as a lower boundary [1], [3].
\[ \theta_A = \theta_{FC} - \theta_{WP} \] 

where: $\Theta_A$ - plant available soil water [-]; $\Theta_{FC}$ - field capacity [-]; $\Theta_{WP}$ - wilting point [-].

2. Materials and methods

2.1. Area of interest

The area of interest is the Nitra river catchment (Figure 1). This catchment is a sub-catchment of the Váh river catchment. The whole catchment area belongs to the Slovak Republic and its area is 5 080 sq km. Northern and western neighbour of our catchment are the Váh river catchment and the Hron river catchment. The Nitra river is more than 170 km long. The river spring is situated in the southern slopes of Malá Fatra. It flows through Hornonitrianska hollow basin, between Strážovské hills and mountain chain Vtáčnik and Tribeč. Stream continues to Podunajska highland where it forms Nitrianska bottom land all the way to join the river Váh in Podunajská flat land.

Area of interest is mainly agricultural land (61 % of the area) and forest land (30 % of the area). There are Rendzic Leptosols in the northern part and Chernozems, Mollic Fluvisols and Brown soils in the southern part of our catchment [4] [5] [6].

![Figure 1. Location of Nitra River Catchment](image)

2.2. Collecting and processing of data

The Nitra river catchment is fully covered by a net of 6 meteorological and 25 hydrological observation stations. These stations were built up by the Department of Biometeorology and Hydrology SUA Nitra within the Centre of Excellence for Integrated Management of Catchment. Stations are able to continuously measure main meteorological and hydrological parameters and also to do an on-line data transfer.

Meteorological stations are set up to measure air temperature, air humidity, wind speed, wind direction, global radiation, precipitation, evapotranspiration and depth of soil freezing. Hydrological stations measure soil moisture in 10 various depth of soil profile (10, 20, 30, 40, 50, 75, 100, 150, 200 and 250 cm). Sensors 10HS developed by Decagon Devices are used. These sensors are based on
Frequency Domain Reflectometry method. Accuracy of 10HS sensors in mineral soils is ± 0.03 m$^3$/m$^3$ if standard calibration equation is used [7].

Soil samples were taken from 112 localities in the catchment for determination of soil properties. Samples were analysed to obtain retention curves of soil (Figure 2). Porousness, field capacity and wilting point was calculated from curves. Value for the field capacity was estimated to be 2.3 (200 cm w.c.) and for the wilting point 4.18 (15 000 cm w.c.). Samples from 20 cm depth were taken for horizon 0-30 cm properties.

![Figure 2. Soil samples and determination of retention curves](image)

2.3. HYDRUS model
Spatial compactness of hydrological data was not suitable for spatial interpolation of soil moisture for the whole catchment. HYDRUS model was used to compute soil moisture data for many other localities. The HYDRUS 1D numerical model is widely used for simulating water flow and solute transport in variably saturated soils and groundwater. HYDRUS 1D software can be used to simulate such processes as precipitation, irrigation, infiltration, evaporation, transpiration, soil water storage, capillary rise, deep drainage and groundwater recharge [8]. This model is widely used for task like this by many authors all around the world [9] [10] [11] [12].

New 38 modelled localities were added to get a more compact net of point’s data. For evaluation of the model validity, correlation coefficient and divergence with the variance of 15 % for several localities were computed. Correlation coefficients of measured and simulated data were between 0.67 and 0.95. Coefficient $r = 0.60$ to 0.79 is considered as a strong and $r = 0.80$ to 1.0 as a very strong relationship [13]. Divergence with variance of 15 % between measured and simulated data was between 79 to 100 %.

Simulations can be declared as valid due to the values of correlation coefficient like this. Many authors have research outputs about HYDRUS 1D model validity like ours. For example, [14] said that the soil water content predicted with HYDRUS was found to be in good agreement with the experimental measured data.
2.4. GIS modelling

Geographic information system (GIS) was used to interpolate measured and modelled point data to reach spatial information. Kriging tool was used for spatial interpolation. This tool is often used by many authors, for example [15] or [16]. [17] said, that kriging method has a better precision for spatial interpolation in areas with distant point data. Resolution of output raster data is 200 m. Hydrolimits point’s values were estimated to be the same as the soil moisture point values by using a kriging method for its spatial interpretation of the agricultural land of the Nitra river catchment. Cell size 200x200m for output raster was used. Average plants available soil water storage for the catchment from this spatial information was calculated.

Plant available soil water storage was calculated by determining the difference among actual soil moisture and hydrolimit moisture determining available soil water, and considering the soil depth.

\[ W_A = (\theta_M - \theta_{WP}) * h_p \]

where: \( W_A \) - amount of available soil water [mm]; \( \theta_M \) - soil moisture [-]; \( \theta_{WP} \) - wilting point [-]; \( h_p \) - soil depth [mm]

Maps of the available soil water storage were created by this spatial interpolation for every month of years 2013-2016. Area of catchment was divided into six groups by percentage filling quantity of potential available soil water storage (Table 1).

| Table 1. Category by percentage filling quantity of potential available soil water storage |
|---------------------------------------------|---|---|---|---|---|---|
| Category | 1 | 2 | 3 | 4 | 5 | 6 |
| Percentage filling quantity | < 0 | 0 - 20 | 20 - 40 | 40 - 60 | 60 - 80 | 80 - 100 |

Maps were counted to obtain one map of categories of soil water storage availability safeness. This map was analysed to obtain statistical data about our catchment. Dimension of potential risky areas were also calculated.

3. Results and discussions

Aim of this study was to create soil water storage availability risk map. Map should show areas where amount of soil water is potentially under the level of wilting point.

Map was successfully elaborated. Map (Figure 3) shows areas of risk of soil water availability. There are areas where the available storage is filled very low (red colour) and areas where the storage is filled high (blue colour) during time period of years 2013 - 2016. We can see how a big part is under the risk. There are areas where risk of non-availability of soil water for plants is very high. In this area, it is necessary to do some mitigation measures. Other areas are out of potential of available soil water shortage. This map should form a base for decision-making processes of landscape engineering. Map provides a unique view to soil moisture development in the Nitra River Catchment for relatively long and continuous period. Figure 4 better illustrates the distribution of risk level in the Nitra river catchment.

For better representation of the water storage temporal variability, an average catchment area category was calculated by percentage filling quantity of potential available soil water storage (Table 2).
Figure 3. Areas of risk of soil water availability
Figure 4. Area with low and high risk of non-availability of soil water

| Years | Category 1 | Category 2 | Category 3 | Category 4 | Category 5 | Category 6 |
|-------|------------|------------|------------|------------|------------|------------|
| 2013  | 0,00       | 0,00       | 0,18       | 6,00       | 43,67      | 50,16      |
| 2014  | 0,00       | 0,00       | 0,01       | 10,91      | 37,45      | 51,63      |
| 2015  | 34,03      | 22,73      | 25,59      | 11,80      | 5,85       | 0,00       |
| 2016  | 8,49       | 30,95      | 26,55      | 19,81      | 12,41      | 1,80       |

Years 2013 and 2014 were very well supplied by soil water. In year 2015 and 2016, an area of the catchment in category 1-3 grew, which means that there was a deficit of the available soil water storage. This could be caused by many reasons. Main reason is the climate change and the decreasing of annual precipitation in these years [18].

4. Conclusions

On basis of our data we can observe impact of climate change on amount of soil water. It is necessary to pay attention to this topic because climate is changing dramatically. Changes of amount of soil water could cause many other changes. We have to be prepared to face them.

Practical use of this paper could be a basis for the decision making during the landscape planning, land consolidation or irrigation planning. Created map (Figure 3) is a unique basis for other activities in the Nitra river catchment. No more data with better spatial resolutions have been created so far.

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