QUANTIFICATION OF SOIL WATER BALANCE COMPONENTS DURING THE VEGETATION PERIOD IN 2018

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Hydrological processes in the atmosphere – plant cover – soil aeration zone – groundwater system are most affected by global climate changes, which influence the distribution and intensity of rainfall. These changes need to be monitored and forecasted for their future development, which is of great importance for human activities, especially agriculture and forestry. Data for the evaluation of soil water regime are obtained from field monitoring. Interpretation of temporal and spatial movement of water in the aeration zone is made by constantly improving computing techniques using various algorithms applied in mathematical simulation models. In our work we used the GLOBAL software, developed at the Institute of Hydrology of SAS, to simulate the individual components of the water balance in rigid soils in the locality Milhostov (Eastern Slovakia Lowland). The paper aims to quantify water balance components of a given soil system. Numerical simulation results were compared with data obtained from field monitoring during the vegetation period in 2018.

KEY WORDS: precipitation, soil aeration zone, groundwater level, evapotranspiration, numerical simulation

Introduction

The soil fertility is very important for agriculture. Its management is associated with nutrients, soil and water exchanges. Soil water regime depends on climate change. The major reason for global climatic changes in the last decades is increasing in solar irradiation, which contributes to the increase of global temperature and decrement in the global sea-ice extent (Bhargawa and Singh, 2019). Changes in water distribution, evaporation increasing and variation in intensity and amount of precipitation are also related to the temperature increasing. Deviations from normal soil water content necessary for the development of vegetation over some time as a result of changes in meteorological elements can cause complications (such as soil drought). Therefore it is necessary to deal with the prognosis that can serve to design adaptation measures to mitigate the adverse effects of climate change on the biosphere. Soil water regime forecasts can be simulated using various mathematical water balance models through input parameters characterizing soil hydrological processes, including precipitation, runoff, plant interception, evaporation, transpiration, infiltration, redistribution, and drainage or deep percolation (Ranatunga et al., 2008). The soil water movement is driven by the water potential, composed of the matrix potential and gravitational potential in the unsaturated zone (Mao et al., 2018). Simulation of the saturated-unsaturated soil water movement at various temporal and spatial scales was modeled using various numerical methods, developed since the 1970s (Bastiaansen et al., 2007; Ranatunga et al., 2008; Pan et al., 2015; Mao et al., 2018). Many commercial software, such as HYDRUS (Šimunek et al., 2008), SWIM (Huth et al., 2012), FEFLOW (Diersch, 2013), MIKE-SHE (Graham and Butts, 2005), and TOUGH (Xu et al., 2012; Gu and Riley, 2010) use Richards’ equation for description of unsaturated flows. Numerical solutions of the Richards’ equation have been widely applied in studies of groundwater resources assessment, groundwater pollution, seawater intrusion, land subsidence, soil water and salt transport, and agricultural water management (Yang et al., 2016). Software GLOBAL, developed at the Institute of Hydrology of SAS, belongs to the group of numerical methods based on the solution of the Richards’ equation (Majerčák and Novák, 1992). GLOBAL uses the finite element method. The basis of the software is the approximation of dependent variables, e.g. humidity potential, resp. soil moisture; finite series of base functions with time-dependent coefficients. The variables are substituted into the original equation describing the movement of water in a porous medium. Changes of various algorithms can describe water regime of plants, different schemes of water extraction by root system for individual plant species, as well as submodels using meteorological elements. Simulation using GLOBAL can also be performed with a one-day step, allowing the model to be used as an effective means of
monitoring the current soil moisture conditions at a given location. In our work, we aimed at the study of Milhostov station localized in the Eastern Slovakia Lowland (ESL) (Fig. 1). The main objective of this paper is to quantify soil water balance components in the soil profile of Milhostov locality using numerical simulation of GLOBAL software in the vegetation period of 2018.

Material and methods

Once a week, the water storage was monitored to a depth of 0.8 m and at the same time, the groundwater level is measured. The soil type is characterized by a heavy, clay-loamy to clay-like fluvial glaze, which is specific for its two-layer composition. For numerical simulation of the water storage in a given soil, a wide database used by the model in the form of input files is needed. The first group of inputs consisted of daily courses of meteorological elements obtained from the Slovak Hydro-meteorological Institute (SHMI), Slovakia. The next part, phenological characteristics, was based on real grown crops on the experimental field no. 9 (for 2018 it was spring barley). The vegetation cover forms an important part of the atmosphere – plant cover – soil aeration zone – groundwater level system (Štekauerová et al., 2001). There are complex interactions between these subsystems within the hydrological cycle, resulting in the temporal and spatial distribution of water in the soil (Tall, 2007). The different crops have their individual physiological and agrotechnical specifics, the investigation of which is well-founded for a better understanding of the processes taking place between soil and plant. This fact is also taken into account by GLOBAL simulating the water regime of soils through input parameters of the stand (e.g. leaf area index, the roughness of evaporating stand surface, root system depth, etc.). The lower boundary condition consisted of a weekly GWL (groundwater level) course measured in the hydrological well and the initial condition included hydrophysical characteristics of the soil. Soil water storages calculated in a one-day step to the depth of 0.8 m were evaluated for the vegetation period 2018. Since monitoring was performed once a week, the same model days were selected for comparison. The model verification included calculation of the linear regression coefficient and deviations, which expresses the degree of dependence of measured and calculated values.

Quantification of soil water balance components during the vegetation period in 2018 was investigated in the locality Milhostov, which is located in the central part of the ESL. The daily course of soil water storage and water balance elements during the vegetation period in 2018 were analyzed. The daily courses of the water balance elements and the soil water storage were obtained by numerical simulation using GLOBAL software.

The results of the numerical simulation were verified on the results of the field monitoring carried out in 2018. After successful verification of the model, the water regime was simulated to a depth of 3 m. The top layer of the soil profile with a thickness of 0.8 m was analyzed. Also, the daily courses of potential (ET0) and actual evapotranspiration (ETa) were calculated using the model simulation (Penman, 1948; Monteith, 1965). The base-line database for the analysis consists of daily precipitation totals (P), daily maximum (Tmax), minimum (Tmin) and average (Tavg) temperatures, wind speed, relative air humidity, and sunshine duration. The GLOBAL software is based on the balance equation (1), which expresses the change in water volume (Vw) over a given soil volume over a given period (t):

\[ V_w = V_i + P_d - (I + E_e + E_t) \]  

where

- \( P_d \) – capillary inflow from groundwater,
- \( I \) – downflow,
- \( E_e \) – evaporation,
- \( E_t \) – transpiration,
- \( V_i \) – soil infiltration.

The model simulation is based on the numerical solution of the nonlinear partial differential equation (2) of water movement in the soil aeration zone in the form:

![Area of interest situated in the Milhostov station in the Eastern Slovakia Lowland.](image)
\[
\frac{\partial h_w}{\partial t} = \frac{1}{c(h_w)} \frac{\partial}{\partial z} \left[ k(h) \left( \frac{\partial h_w}{\partial z} + 1 \right) \right] - \frac{S(z, t)}{c(h_w)}
\]

where

- \( h_w \) – soil moisture potential,
- \( z \) – vertical coordinate,
- \( k(h_w) \) – unsaturated hydraulic conductivity of soil,
- \( S(z, t) \) – intensity of water uptake by plant roots from unit soil volume per unit of time [cm\(^3\) cm\(^{-3}\) d\(^{-1}\)],
- \( c(h_w) = \frac{\partial \theta}{\partial h_w} \).

Results and discussion

As a first step, the GLOBAL model was verified in selected vegetation periods (2000–2008 and 2014–2018) (Fig. 2). Figure 2 shows the course of the measured and calculated soil water storage (WS) to a depth of 0.8 m during the verification period i.e. 197 days. It is clear from the figure that the model reliably follows the trend and changes in the soil water storage. However, it tends to underestimate the real state, as seen in the course of the water supply and their absolute error (AE).

The values of absolute errors between the measured and calculated water storages in the soil in the individual vegetation periods of the verification series are collected in Table 1. The mean absolute error (MAE) was in the range between 27.60 mm (2001) and 96.48 mm (2015). The maximum absolute error (MAXAE) during the verification period varies from 44.32 mm (2005) to 126.18 mm (2015) and the minimum absolute error (MINAE) vary from 0.92 mm (2001) to 74.89 mm (2008). Linear dependence showed a high degree of correlation between measurement and model. Except for some growing seasons, high values of the linear regression coefficient \( R^2 \) indicate this correlation.

The histogram in Fig. 3 shows the frequency distribution
of absolute errors between the measured and calculated water storages in the soil. The absolute errors are divided into 7 intervals. In the evaluated time series there are 54 days with an absolute error value in the interval 0–30 mm, 92 days in the interval 50–70 mm and 51 days in the interval 90–130 mm. The average absolute errors (MAE) over the entire verification period is 51.34 mm. Based on the verification, the highest linear dependence rate between soil water storage in the vegetation period of 2018 was shown. Through the 1:1 line it can be seen that the model underestimates the measurement by 27.73 mm in the average (Fig. 4).

The daily courses of the individual components of the balance equation in the vegetation period of 2018 are plotted in Fig. 5. Here, the interaction between individual subsystems within the atmosphere – vegetation cover – unsaturated soil zone – groundwater level system is visible. Optimum soil moisture conditions in the soil were observed at the beginning of the vegetation period in April and some days of May. In these sections of the growing season, the sums of $ET_a$ were equal to $ET_0$. The water storage in the analyzed soil profile and the groundwater level was the highest in this period. A significant capillary inflow ($P_d$) from the groundwater

Table 1. Values of maximum, minimum and mean absolute errors with linear regression coefficient between the measured and calculated water storages in the soil during the verification period

| Growing season | MAXAE [mm] | MINAE [mm] | MAE [mm] | $R^2$ |
|----------------|------------|------------|----------|------|
| 2000           | 85.72      | 28.31      | 54.17    | 0.0663 |
| 2001           | 73.21      | 0.92       | 27.60    | 0.5072 |
| 2002           | 117.54     | 4.84       | 56.57    | 0.3011 |
| 2003           | 113.72     | 7.29       | 32.78    | 0.6694 |
| 2004           | 56.47      | 2.73       | 31.45    | 0.7837 |
| 2005           | 44.32      | 7.93       | 29.63    | 0.4680 |
| 2006           | 66.63      | 8.38       | 42.85    | 0.7814 |
| 2007           | 107.62     | 37.03      | 82.97    | 0.7496 |
| 2008           | 97.23      | 74.89      | 82.62    | 0.7510 |
| 2014           | 71.92      | 31.55      | 51.26    | 0.7284 |
| 2015           | 126.18     | 49.47      | 96.48    | 0.8370 |
| 2016           | 78.83      | 22.36      | 54.78    | 0.7529 |
| 2017           | 79.27      | 28.39      | 46.64    | 0.7831 |
| 2018           | 56.99      | 4.21       | 27.73    | 0.8513 |

Fig. 4. Linear dependence between measured and calculated soil water storage in the vegetation period of 2018.
level into the unsaturated soil zone was found. The water storage in the soil also increased significantly due to the high amount of rainfall in May. From July to the end of the growing season, the water storage gradually decreased as the groundwater level decreased. The capillary inflow of water into the unsaturated soil zone was replaced by the predominant outflow of water from the saturated soil zone to the groundwater level. The precipitation during this period caused a slight increase in the soil water storage, but they were not sufficient to cover the need for water for optimal soil water storage and groundwater level. The result was the evapotranspiration deficit at the end of June, which lasted until the end of the growing season.

**Conclusion**

Our study was aimed to verify the results of the numerical simulation with the results obtained by field monitoring of the selected locality Milhostov in the investigated period of 2018.

*Fig. 5. Modeled daily courses of balance equation components in the vegetation period of 2018.*
vegetation period of 2018. Under these conditions, using the GLOBAL software, the water storage in the soil aeration zone was simulated to a depth of 0.8 m with a one-day time calculation step. The verification was based on the model’s ability to follow the actual trend of water storage development over time, obtained by field monitoring. If the groundwater level interfered with the balance zone, it was supplied with a water capillary inflow. This situation occurred in April and May. At that time, the soil had optimal moisture conditions and the actual evapotranspiration was equal to the potential evapotranspiration. In May, the significant increase in soil water storage was also due to the high amount of precipitation. From July to the end of the growing season, soil water storage and groundwater levels had a decreasing trend. Water outflow from unsaturated soil zone to groundwater prevailed. This was reflected in the evapotranspiration deficit in early July and its duration until the end of the growing season. Based on our results of the verification, it was shown that the mathematical software GLOBAL represents a suitable tool for the quantification of individual components of the water regime of soils in Milhostov conditions. The model simulation reliably follows the trend and changes in the water storage in the soil. However, it tends to underestimate the real state.

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