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Impact of the loess’ hydraulic characteristics on its degree of saturation for the purpose of radon index measurements (Northeast Bulgaria case study)

Влияние на хидравличните параметри на льоса върху степента му на водонасищане за целите на измерванията на радоновия индекс (пилотно изследване за Североизточна България)

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Abstract. Radon gas has high mobility and is driven by advection and diffusion with the soil gas throughout connected and water-unsaturated pores and/or cracks in permeable rocks and soils. Therefore, there is a need for quantitative assessment of the saturation state, even on a daily-base in order to estimate the radon potential correctly. The more so as, the permeability is one of the key factors in the radon risk assessment. For the purpose of such investigation, a vertical profile model was elaborated for a study site in Northeast Bulgaria. On the base of pedotransfer function analyses, the hydraulic parameters describing the retention function and the hydraulic conductivity function were determined for each case study. The results show that even in a month with high amount of rainfall precipitation (13% of the total amount per year), the loess profile at certain depths remains unsaturated, regardless the difference in the hydraulic characteristics.

Keywords: vadose zone, hydraulic parameters, HYDRUS-1D.

Introduction

Radon is a naturally occurring radioactive heavy noble gas, decay product of ^{226}Ra, which is a member of ^{238}U chain. The main source of radon in a building is soil and rocks on which the buildings were situated on. Radon exposure is responsible for approximately half of the total annual background radiation exposure (UNCEAR, 2000). For many people, ^{222}Rn is an important source of exposure which, in principle, can be controlled to some extent (Ivanova et al., 2019). Radon gas has high mobility and is driven by advection and diffusion with the soil gas throughout connected and water-unsaturated pores and/or cracks in permeable rocks and soils. Hence the radon potential of the area could be dependent on not only geology as a constant source of radon but also from the changes of the saturation state of the ground. In Bulgaria, studies for the evaluation of the radon geogenic potential, applying the different approaches over the whole territory are carried on nowadays at relatively general geological spatial schemes (Ivanova et al., 2019; Antonov et al., 2020).

Worldwide, loess soils are distinguished by their permeability and usually are in unsaturated condition. In Bulgaria, they cover about 10 % of the country (Evlogiev, 2019). Therefore, there is a need for quantitative assessment of the saturation state, even on a daily-base in order to estimate the radon potential correctly. The more so as, the permeability is one of the key factors in the radon risk assessment (Neznal, Neznal, 2005; Benavente et al., 2019). One modern approach for such assessment is computer modeling based on the convective-dispersion equation with the addition of evapotranspiration models (*e.g.* Šimůnek, Bradford, 2008; Šimůnek et al., 2013; Šimůnek, 2015). In Bulgaria, there are

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some attempts for investigation and evaluation of the unsaturated state of the (near)surface sediment deposits and especially that one of the loess complex based on either modelling approach or field observations (Mallants et al., 2007; Benderev et al., 2015; Antonov et al., 2018; Gerginov at al., 2018, 2020; Tsvetkova et al., 2019). In addition, in the recent years there are few models concerning particular parts of the hydraulic characteristics (parameters) of the loess in the vadose zone and the moisture dynamics due to precipitation rates in Northeastern Bulgaria (Gerginov, Antonov, 2019; Kolev, 2021). The current study is an attempt to evaluate the degree of saturation based on one-dimensional model and four different sets of hydraulic parameters.

Materials and methods

Investigated site

The study site is located in Northeastern Bulgaria close to the Danube River and west of Ruse, at the high riverbank. The climate is temperate, and in the particular year of this case study (2016), in March the total amount of the rainfall was a kind of abundant 65.6 mm, which is 13% of the amount for this area. The terrain is flat, and the loess deposits are approximately 30 m thick. The exact specifications of the devices recorder the meteorological dataset and the dataset itself are described in details in Gerginov (2019) and in Gerginov and Antonov (2019). At the site, in area approximately 12 sq. m four loess samples were taken for grain-size distribution analysis, namely case study A, B, C, and D, respectively (Tabl. 1).

Code and model description

The program HYDRUS-1D numerically resolves the advection-dispersion equation on the basis of the solution of the partial differential equation of Richards and incorporates several modules for solute transport, CO_2 transport, root-water uptake, etc. (Šimůnek et al., 2013). Resolving this equation requires the knowledge of two nonlinear functions, namely *the soil-water retention function* and the *hydraulic conductivity function*. The hydraulic parameters describing *the retention function* and the *hydraulic conductivity function* (van Genuchten, 1980) were determined for each *case study* (*A, B, C, and D*) on the base of pedotransfer function analyses (Schaap, Leij, 1998; Schaap et al., 1998) using the ROSETTA program (Schaap et al., 2001) incorporated in the HYDRUS-1D (Tabl. 1). For the evaluation of a potential evapotranspiration Penman-Monteith Method incorporated in HYDRUS-1D (Allen et al., 1998; Leterme et al., 2012; Šimůnek et al., 2013) is used.

For the purpose of the investigation, a vertical profile model is elaborated for the study site. One-dimensional model is proposed in accordance to Kolev (2021). It has been found suitable because of the observed downward water percolation of the alluvial deposits (Rahaman, 2016). The schematization is in accordance with the field observation data using the information on the loess layers' depth with the respective five hydraulic parameters for the first 0.50 to 1.00 m loess layer determined by pedotransfer function analysis of the grain-size distribution curve. The initial condition is set equal to the examined in situ pressure head (Antonov et al., 2018). The bottom boundary condition is set to free drainage condition and the

Table 1. Particle-size distribution percentages of loess samples at a site in Northeastern Bulgaria, and respective hydraulic parameters determined by a pedotransfer function analysis based on texture percentages of the soil

Case	Depth	Particle size distribution ranges, %			Residual water content**, θ_r	Saturated water content**, θ_s	Empirical constant, α	Empirical constant, n	Hydraulic conductivity, K_{sat}
–	*[m]*	*sand** 2.0–0.05 mm*	*silt** 0.05–0.002 mm*	*clay** <0.002 mm*	*[cm³/cm³]*	*[cm³/cm³]*	*[cm⁻¹]*	*[–]*	*[cm/d]*
A	0.50	30	62	8	0.0454	0.4299	0.0045	1.7013	50.32
B	1.00	30	63	7	0.0435	0.4344	0.0046	1.7047	56.65
C	0.30 – 0.60	25	63	12	0.0547	0.4282	0.0043	1.7012	30.27
D	0.60 – 1.00	37	52	11	0.0478	0.4074	0.0058	1.6184	34.31

* US Department of Agronomy Classification for texture percentages (%sand, %silt, %clay)
** Volumetric content

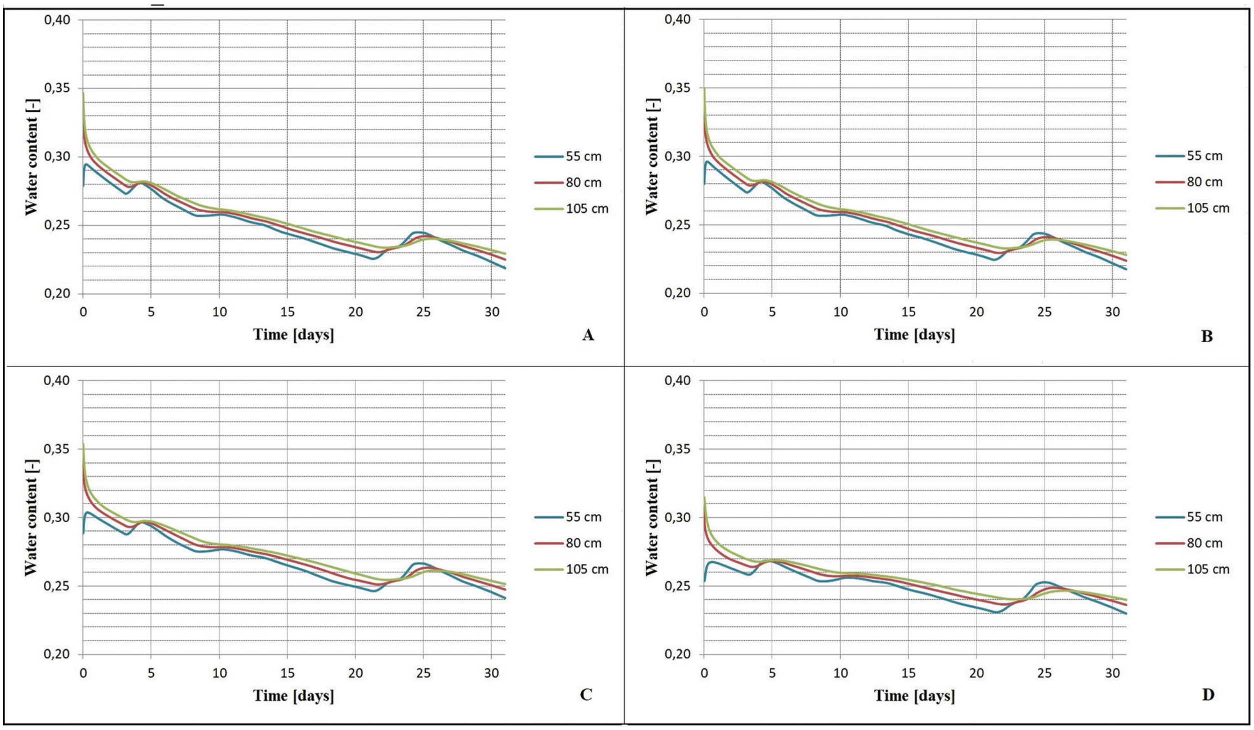

Fig. 1. The obtained moisture content at three depths in the March 2016 period for the investigated case studies

upper boundary condition represents the number of time-variable boundary records, *i.e.* the precipitation records for March (Gerginov, Antonov, 2019). Three *observation points* (OP) were set at 55 cm, 80 cm and 105 cm depths in the models due to the field measurement of gas permeability of soils in connection with the radon index determination.

Results and discussion

The results of simulations with the different hydraulic parameters' sets are shown on Figure 1. As it can be seen, although the initial values of the water content differ (due to the different hydraulic characteristics) the trends of all four models are similar. At 55 cm, the initial water content (at 1st of March) is always less than those at 80 cm and 105 cm, *i.e.* between 0.25 (case study D) and 0.30 (case study C) vs OP 105 cm's 0.31 (case study D) and 0.35 (case study C) but on 25th of March it is always above both of them (Fig. 1). In any case, at the end of simulations the water content at all three observed depths is always less than those at the beginning. That means, despite the relatively abundant rainfall events in March 2016, the amount of the rain`s water penetration into the loess profile is not sufficient to lead to saturation at the observed depths. The results of the simulations are quite alike, despite the differences in the hydraulic parameter sets.

Conclusion

Based on the one-dimensional profile model, four case study simulations using different sets of hydraulic parameters were performed. The results show that even in a month with high amount of rainfall precipitation (13% of the amount for this area per year), the loess profile at certain depths remains unsaturated, regardless the difference in the hydraulic characteristics. This conclusion will be useful during the further determination of the radon index in North Bulgaria.

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