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How capillary forces promote colloid mobilization in macroporous soils: an alternative model

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Summary

Soil colloids are known to facilitate the transport of adsorbed pollutants through the vadose zone. This communication proposes a conceptual model that computes particle mobilization in macroporous soils during extended series of successive rainfall events. Model outputs are qualitatively compared with mobilization recorded during series of up to 38 rainfall event simulated onto undisturbed soil cores.

Introduction

Colloidal sized soil particles have been known for over 20 years to act as vectors of adsorbed pollutants from the soil surface towards the groundwater. Model used to predict pollutant fate in the soil must thus take into account this phenomenon in order to make accurate predictions. To date, the understanding of processes and factors leading to natural particle mobilization in soils is still incomplete and models of colloid mobilization are far from being predictive models. Furthermore, although throughout the year, in situ soils are submitted to successive rainfall events, most of the experimental and modelling efforts focused on single events (with a few exceptions: e.g. Schelde et al. 2002).

However, recently, a conceptual model based on the concepts of porous media drying and differential capillary stresses occurring in the macropore walls was proposed (Michel, 2010). The model provides a framework to understand the mobilization variations observed at the column scale, during series of successive rainfall events, when the rain interruption duration (RID) separating two successive events changes from a few hours to a few month; and, when the number of successive rainfall events is sufficiently short (a few tens of events).

In this paper, we modified the model in such a way that it now allows modelling long term leaching of soil particles, when several tens of successive rainfall events are performed onto a soil core. This was achieved introducing into the model the concept of “regeneration of the stock of mobilizable particles”. In the following, we summarize the main features of the model presented in Michel (2010) as well as the proposed regeneration mechanism. We compare qualitatively the model outputs with mobilization recorded during series of up to 38 successive rainfall events performed onto a single soil core, and finally discuss how the model gives a framework that helps

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understanding mobilization fluctuations occurring during extended series of rainfall events.

Model

The model describes particle mobilization in macroporous soils at the beginning of a rainfall event when the mobilization reaches a maximum. The walls of active macropores are modelled as a set of cylindrical smaller pores arranged in a single transect, with radiuses randomly chosen in a normal distribution. During a rainfall, all the active macropore walls are filled with water. At the end of a rainfall, water is lost from the walls, either by gravitational drainage, evaporation or redistribution towards the inner matrix. This loss occurs in the pores making up the macropore wall according to their size: widest pore first. The model uses a set of parameterized equations to compute the menisci depth in each pore of the macropore walls as a function of the time elapsed since the end the previous rainfall. When after a rain interruption of duration T_{pause} a new rainfall event starts, the model compares the menisci depth Δh in all neighbouring pores. If Δh is higher then a threshold value Δh_{thr}, it is assumed that the wall separating the neighbouring pores has been weakened by the differential capillary stresses occurring between a water filled and an empty pore, and that this wall is removed by the incoming infiltration front. Accordingly, the number of “mobilized particles” is incremented by one, and the number and radiuses of the pore distribution are updated. With this mobilization mechanism, the “stock of dispersible particles” i.e. of intact pore walls is an ever decreasing function of the number of rainfall event already performed. To get around this pitfall we introduce into the model the following “regeneration mechanism”. We consider that as particles are mobilized the walls of the preferential flow path flatten out, uncovering new pore underneath the previously mobilized pore walls. We model this process replacing each pore that became wider than a threshold radius r_{regen} with N new pores picked up randomly into the same normal distribution as the initial set of pores. In addition we impose the total surface area of the N new pores to be equal to that of the replaced pore.

Materials and methods

Two soil (calcisol) cores (i.d. 14.7 cm, height 25 cm) were submitted to series of successive rainfall events at fixed rainfall intensity and rainwater ionic strength. The amount of mobilized particle in the first 120 ml of effluents was determined by light extinction. The first core was submitted to 19 identical rainfall events, the RID between each rainfall was constant and set to 47 hours. The second core underwent 38 rainfall events. The 38 events were split up into three series of 12, 15 and 11 events. During each series the RID between the rainfall events increased from 1 to about 2500 hours.

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Results and discussion.

Fig. 1a displays the mobilization recorded during the 19 events performed on core 1 at fixed RID as a function of the rainfall event number. Mobilization decreases sharply from 55 to about 10 mg during the first seven events, and from event 8 on fluctuates around a mean value of 10.5 ±3.4 mg. Fig. 1b., and 1c. display the mobilization recorded during the three series of rainfall performed at increasing RID as a function of RID (Fig. 1b.) or rainfall event number (Fig. 1c.). For each series, the mobilization increases with RID, reaches a maximum and decreases, although the amplitude of the maximum in series 2 and 3 is slightly lower compared to series 1.

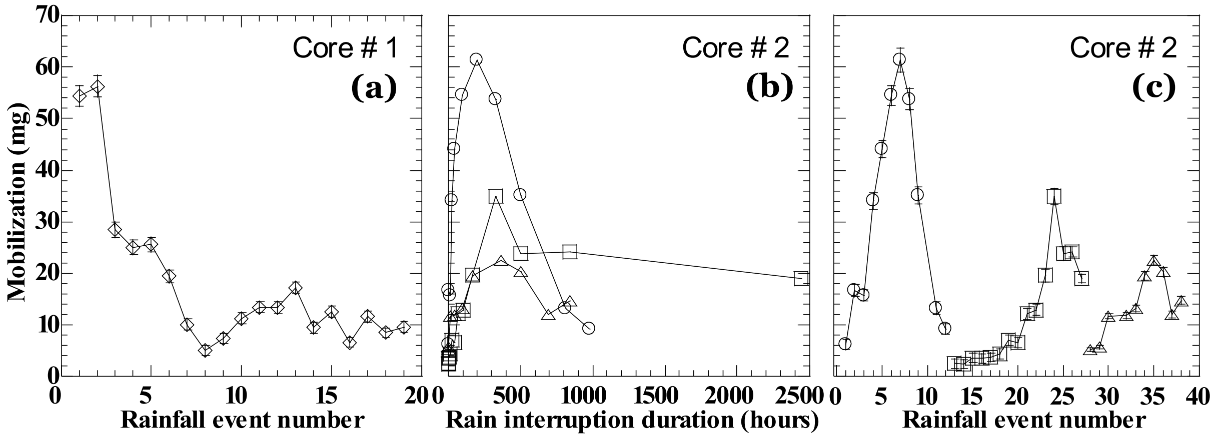

Fig. 1. (a) Core 1. Mobilization (mg) in the first 120 ml of effluent for 19 rainfall events separated by RIDs of 47 hours. **(b and c)** Core 2. Mobilization in the first 120 ml of effluent for 38 events separated by increasing RIDs as a function of RID (middle panel) and rainfall event number (right panel). Series 1 (circles), Series 2 (squares), Series 3 (triangles).

We mimicked with the model the experiments performed on column 1 and 2. The threshold for pore mobilization was set to 0.06m, and the initial distribution was made of 2000 pores randomly picked in a normal distribution with mean radius 3.5 µm and standard deviation 1 µm. “Regenerated” pores were randomly chosen from the same distribution. Three values of r_{regen} are represented in Fig. 2: 100, 20 and 10 µm. Fig. 2a. shows the model outputs for 19 rainfalls performed at fixed RID. Regardless of the r_{regen} value, mobilization decreased from one rainfall to another and after a few rainfall events started to fluctuate about a constant mean value. In Fig.2b. mobilization pattern observed for the three series of rainfall separated by increasing RID are reproduced qualitatively. The agreement (relative height and position of the mobilization maxima) is better for the intermediate value of r_{regen}.

By construction modelled mobilization depends on the number of pores in the distribution at the beginning of each rainfall. After a few rainfall events, mobilization reaches a dynamic equilibrium (Fig. 2a.). Its value depends on T_{pause} and r_{regen} : the lower r_{regen}, the higher the equilibrium value. The initial mobilization decrease results from the difference between the number of pores in the distribution before the first event and the equilibrium value. Similarly the initial experimental mobilization

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decrease observed during the first events (Fig. 1a.) may reflect the transition between an initial state characterized by a set of parameters (number of pore (or size of the stock of dispersible particles), mean radius and standard deviation) towards a final state characterised by a new set of parameters.

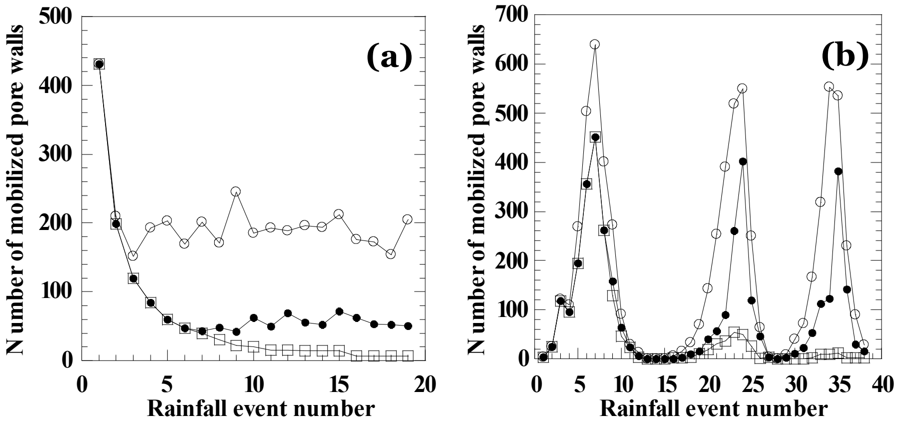

Fig. 2. (a) Modelled mobilization as a function of rainfall event number for 19 events spaced by even RIDs of 47 hours, and **(b)** for three series of rainfall events spaced by RIDs of increasing durations. r_{regen} was set to 100 µm (squares), 20 µm (filled circles) and 10 µm (opened circles). Δh_{thr} was set to 0.06m. Initial distribution had 2000 pores with a mean radius of 3.5±1 µm.

Conclusions.

The goal of this study was twofold: 1) to collect particle mobilization data during extended series of successive rainfall events at fixed and variable RID; and 2) to introduce into the conceptual model proposed in (Michel 2010) a mechanism opening up the possibility to model mobilization for these extended series of rainfalls. The model makes several strong hypothesise (existence, and modification from one rainfall to the other, of a distribution of pores making up the macropore walls, differential capillary stresses as the driving mobilization mechanism, absence of particle transport, pores arranged in transects). Nevertheless, it was able to qualitatively reproduce –and gave a framework to understand- the mobilization patterns observed experimentally.

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