Probabilistic methods of soil erosion evaluation

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Soil erosion is determined by the interaction between water flow and structured soil. This interaction has a strong stochastic component due to both great variability of the geomecanical structural and electro-chemical forces in real soil at the micro scale and overland flow turbulence. This suggests that the use of the probability density functions (PDF) and the spectral density functions (SDF) for the key (or for most) variables in the soil erosion models instead of their mean (or typical) values should provide a better description of real erosion processes. Although such an approach requires larger amount of initial information for modeling, the output results and predictions should be more general and accurate. The original idea of the process-based stochastic approach in erosion modelling was proposed and used by H.A. Einstein who applied it for prediction of non-cohesive sediment erosion in rivers. Recent achievements in hydrodynamics of shallow rough-bed flows and in soil science make the development of a similar approach for cohesive soils also attainable.

The detachment rate *DER* of soil aggregates within this approach can be parameterised using several approaches. One of them defines the detachment rate as the product of the mean concentration (C_Δ) of unstable soil aggregates in the bed surface layer with the thickness Δ and the vertical velocity of soil aggregates ($U_\uparrow$):

$$DER = C_\Delta U_\uparrow \qquad (1)$$

Both parameters in (1), the mean concentration C_Δ of unstable soil aggregates and their vertical velocity $U_\uparrow$, can be defined using the probabilistic field of driving and resisting forces, described by PDFs of flow parameters and soil characteristics.

Another approach in modelling the upward sediment flux considers it as the product of the volume V_u of unstable aggregates in the bed surface layer and the frequency of its detachment f_d per unit area S:

$$DER = \frac{V_u f_d}{S} \quad (2),$$

which relates to the frequency spectrum of the detached aggregate volume per unit area. This spectrum may be defined considering the soil aggregate instability in the near-bed layer and probabilistic properties of turbulent flow and soil structure.

The first approach requires some spatial averaging of flow and soil properties to include their spatial variability, though the period for time averaging can be relatively small. The second approach needs sufficient time averaging to include low frequency fluctuations of the velocity field, though the spatial averaging "window" can be relatively small, compared to that for the first approach.

The variables in (1) and (2) are stochastic by nature and require the same equation of soil aggregate instability for their definition and parameterisation. Thus, the stochastic methodology in soil erosion requires defining probabilistic fields of driving and resistance forces and deriving theoretical and/or phenomenological relationships for the soil aggregates detachment rate with the use of both approaches, (1) and (2).

To study probabilistic fields of driving and resistant forces in soil erosion, these variables can be associated with stochastic components of evolution laws in dynamic cellular models. Further, these cellular models can be coupled with a cell-based hydrodynamic model such as the Lattice Boltzmann (LB) model. The LB model involves the evolution of the momentum distribution at each point on a spatial grid, and is capable of generating the flow field past the complex granular boundary, from which the relevant pressure forces may be derived. A unifying dynamic computational model such as this may be utilised in conjunction with the analytic approaches mentioned above, in order to formulate a broad representation of the stochastic components of soil erosion and its spatially varying characteristics.