The effect of spatial variability of soil hydraulic properties on surface runoff process

Ayodele Ebenzer Ajayi [1]
Ivana De Marco Fonseca Horta [1]

[1]Universidade Federal de Lavras – UFLA
Caixa Postal 3037 – 37200-000 – Lavras, MG, Brasil
ayodele.ajayi@yahoo.com; idmfh@hotmail.com

Abstract
The study report the evaluation in a two-dimensional hydrodynamic model of the effect of spatially varied hydraulic properties on runoff response. The model is written in a FORTRAN programme and the graphical interface on MATLAB. The investigations clearly show that spatial variability of hydraulic properties influence runoff response during a storm event particularly for low intensity events.

Key Words: surface runoff, hydrodynamic model, spatial variability.

1 INTRODUCTION

Spatial variability of soil hydraulic properties has been cited in a number of studies as the basis of the observed differences in runoff response using analytical or model-based evaluation (Dunne et. al., 1991; de Lima and Singh, 2002; de Lima et. al., 2003). But as noted by Woolhiser et al. (1996), the different processes of simplification of the routing models have limited the application of the results from most of these studies. Another limitation of most of the model used for such analysis is the failure to couple infiltration process with the surface runoff process. The model developed in this study have successfully taken care of most all the limitation observed in previous model study, thus it is imperative to investigate the effect of spatial variability of infiltration and other hydraulic properties on runoff discharge.

2 MATERIALS AND METHODS

Three possible scenarios of hydraulic conductivity distribution were simulated on a 2m X 6m size plot, using both a high and low rainfall intensity events data. The runoff plots are grided in 10cm interval along the slope. In the first experiment (**case A**), a linear increase in hydraulic conductivity (Ksat) downslope was simulated. In this scenario, the Ksat value is increased by 3% at every grid points along the flow direction (downslope), such that, at the end of the plot, where discharge is monitored, the final value of K sat is 171.6mmh^{-1}. Thus, the average hydraulic conductivity is 81.5mmh^{-1} while the standard deviation is 41mm/hr. An inverse of this linear variation was used for the second experiment (**case B**), such that, the Ksat reduces downslope from a maximum of 171.6mm/hr at the plot upslope. For the third scenario (**case C**), the measured hydraulic conductivity data for the 6m long plot during field studies is used to represent random variation in Ksat value within a plot. The contour map of the different distributions of Ksat is presented in Figure 1. The contour map shows that the upper and the lower limits of the hypothetical linear variations in the study could be observed within the plot. The three cases were used to study the dynamic effect of infiltration opportunity, as limited by a shrinking or expanding area from which infiltration can occur.

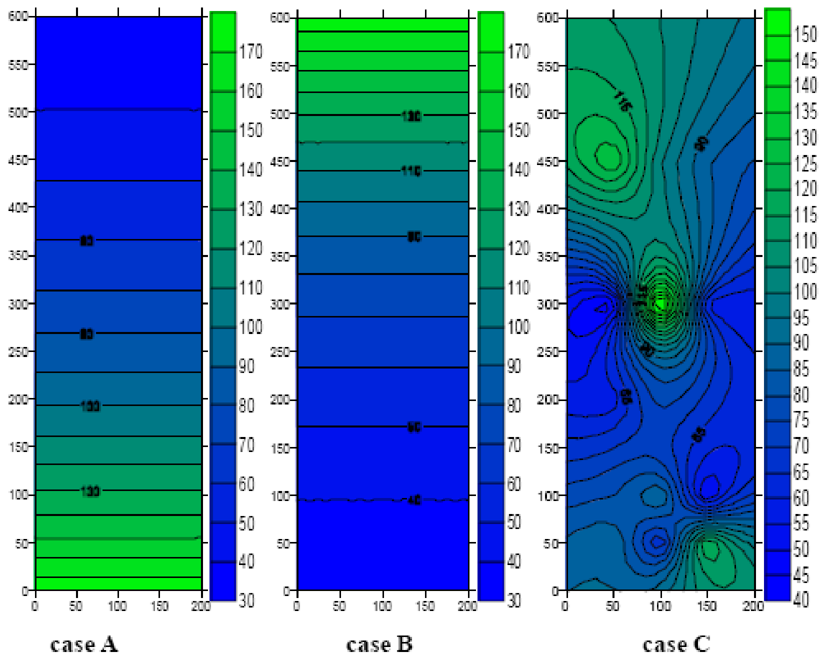
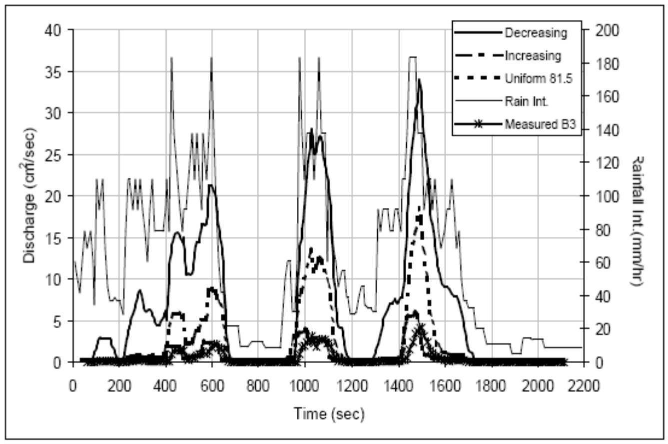


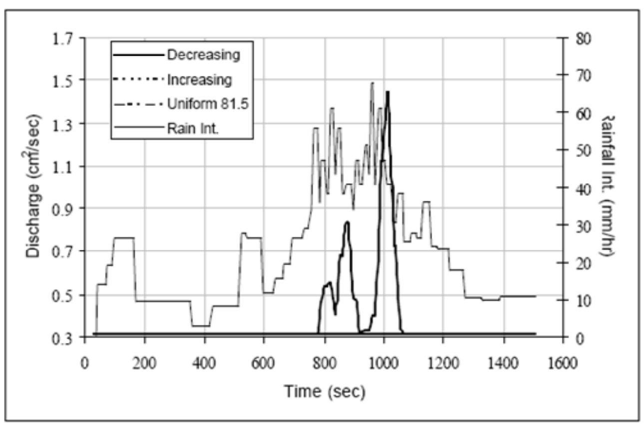
Figure 1: Contour Map of Hydraulic Conductivity for the different distribution used in the simulation experiment.

3 RESULTS AND DISCUSSIONS

Figures 2a and b showed that the magnitude and spatial pattern of Ksat within a plot or on a hillslope could significantly affect the observed discharge in a runoff event. Increasing saturated conductivity downslope allow more of the overland flow traveling towards the gutter to be lost due to increasing infiltration opportunity. This results in a significant reduction in discharge and peak rates. The high value of saturated hydraulic conductivity also induces a substantial reduction in flow depth and this is clearly displayed in the asymmetric pattern of the flow depths at about 500 sec into the event. When the conductivity decreases in the downslope direction, flow depth, discharge, and peak rate increases. Overland flow apparently emanating from the downslope regions with low saturated conductivity values, and, which only has a short distance from the gutter to overcome results in the sharp increase in discharge, in this scenario. With the low intensity events (figure 3), the downslope increase, the random variation and uniform conductivity of 81.5mmh^{-1} produce no surface runoff. This apparently results from the high infiltration rate compared with the rainfall intensity in the two cases. Case B produces small quantity of surface runoff and this explains why the effect of scales in runoff response is often more pronounced with low rainfall intensity events. In those cases, the differences in runoff appear to be attributable to increased opportunity for infiltration with increasing slope length. In all the three different cases, and in both high and low intensity events, the flow pattern is considerably influenced by the microtopography (Figure 3). The magnitude of the difference between the hydrograph for the downslope-decreasing trend also shows that most of the runoff that arrives at the gutter emanates from regions not too far from the point of discharge. There is a marked similarity in the outflow hydrographs of random variation (measured values) and an average of the Ksat in the varied scenarios. This indicates that, appropriately selected average Ksat value could be used for investigation without too much loss of accuracy. At 1750 sec, which corresponds to the tailing part of the rain for event A, flow pattern and all other parameters are uniform in the three cases.

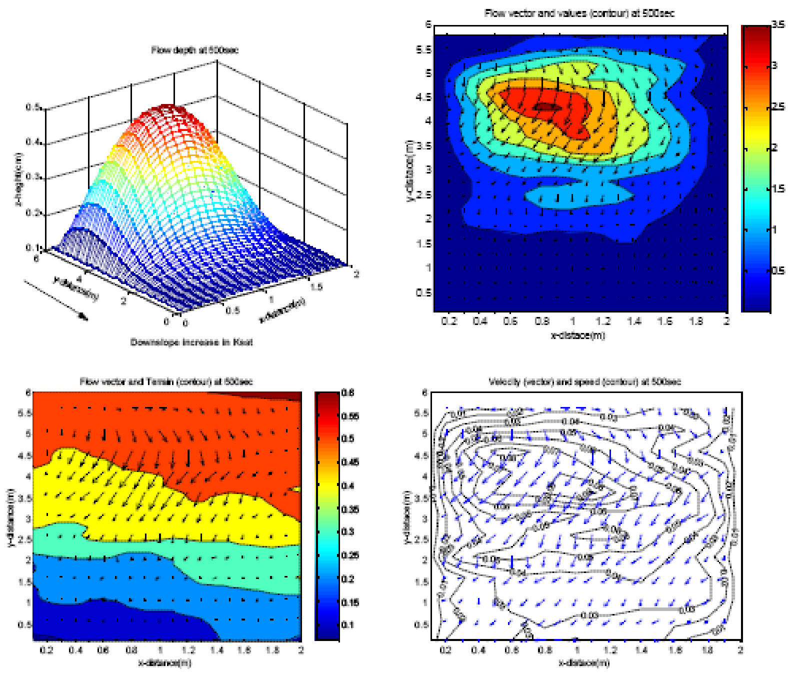


a. high intensity event

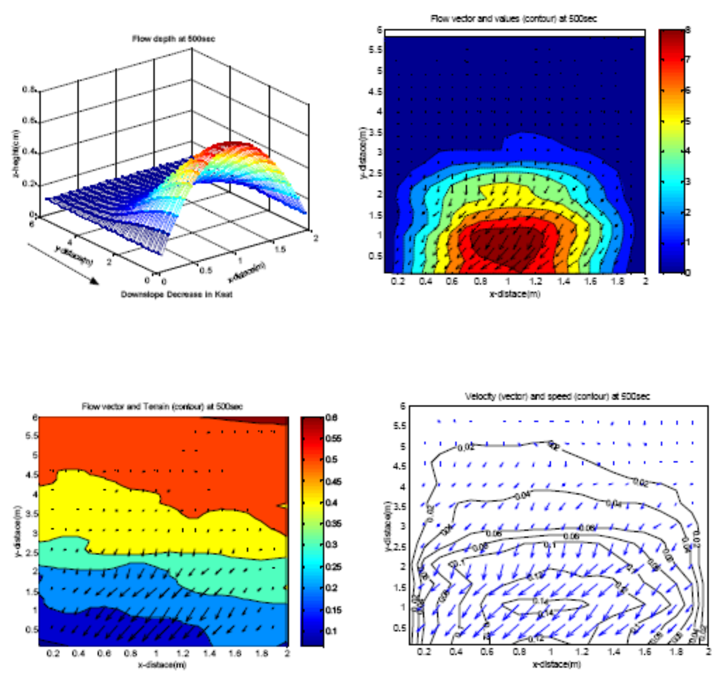


b. low intensity event

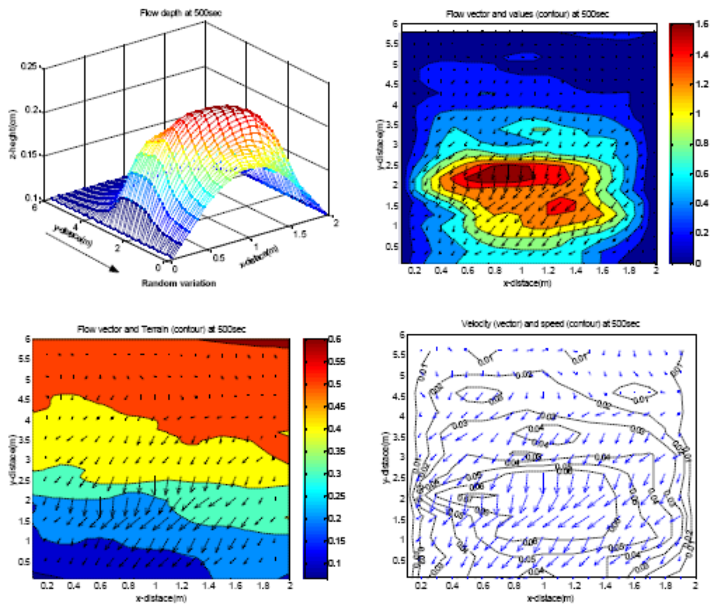
Figure 2: Comparison of simulated outflow hydrograph showing the effect of variation in distribution of Ksat for High and Low Intensity rainfall events



Downslope increase



Downslope decrease



Measured value

Figure 3: Overland flow characteristics with linear increase, decrease and random variation in Ksat

This also explains why the difference in scale effect is reduced in rainfall event with extended recession phase or with prolonged pulse moments. The differences in the outflow hydrograph in the various cases considered provide an avenue to evaluate the importance of spatial variability of soil hydraulic properties in the Hortonian runoff process. The trend of spatial variation of infiltration properties influences the discharge from runoff plots or hillslope. However the effect can only be explained in the context of the temporal related changes that occur during the time required for the overland flow to move from the point of initiations, to the point of collection. The required time depends on the rainfall intensity, which determines the available kinetic energy, the microtopographic forms which moderate depression storage and slope of the field. All the three factors affect the velocity of flow. This observation explains why Wainwright and Parson (2002) advocated for the use of variable intensity rainfall data in appropriate resolution (preferably tipping bucket) in better understanding of scale effect.

The study also showed that the infiltration opportunities vary with slope length and the pattern of the distribution of hydraulic conductivity. The difference in infiltration opportunities result in differences in transmission losses potential, during surface runoff routing downslope. It can also be concluded that the vegetated and surface microtopography, which become more varied with increase in slope length determined surface depression storage shape and network, consequently influencing runoff initiation and flow rate. However, the effect of the two factor of spatial variability is influenced by the time required to move from point of runoff initiation to the trough, which also depend on the rainfall intensity and field slope (Estevees et. al, 2000; Wainwright and Parsons, 2002). Thus, the temporal pattern of rainfall can influence runoff response. Temporal patterns of rainfall intensity; particularly the distribution in terms of numbers of peaks in the event, the duration of the pulses, the length of time for recession, and magnitude of rainfall intensity coupled with temporal variation in travel largely determine the response to high intensity events while, soil related effect in terms of spatial variability in hydraulic properties mainly influences low intensity event. The dominance of temporally induced factors in the basin could be related to the high intensity events synonymous with tropical storm, which often do not allow the spatial factors to manifest. The other factor of soil that could significantly influence runoff response is the initial moisture status of the soil. However, the high intensity rainfall predominant in the Volta basin limits its influence. In low intensity events, high initial moisture content increases runoff volume.

4 CONCLUSION

The study has gone further to enhance the understanding of rainfall runoff dynamics in the face spatially variable infiltration opportunities, which Woolhiser et al., (1996), admitted was not possible in their study because of the inability of their model to accommodate heterogeneity in rainfall intensity as well as incomplete knowledge of field conditions.

REFERENCES

DE LIMA J.L.M.P. AND SINGH V.P. 2002. The influence of the pattern of moving rainstorms on overland flow **Adv. in Water Resou**. 25 (7): 817-828.

DE LIMA J.L.M.P. SINGH V.P. AND DE LIMA M.I.P. 2003. The influence of storm movement on water erosion: storm direction and velocity effects **Catena** 52 (1): 39-56

DUNNE T., ZHANG W. AND AUBRY B.F. 1991. Effects of rainfall, vegetation and microtopography on infiltration and runoff. **Water Resour. Res**. 27, 2271–2285

ESTEVES M FAUCHER X GALLE S AND VAUCLIN M 2000 Overland flow and infiltration modelling for small plots during unsteady rain: numerical results versus observed values. **J. Hydrology**, 228: 265–282

WAINWRIGHT J. AND PARSONS A.J. 2002. The effect of temporal variations in rainfall on scale dependency in runoff coefficients. **Water Resou. Res**. 38 (12): 1271 10.1029/2000WR000188

WOOLHISER D.A., SMITH R.E. AND GIRALDEZ J.V. 1996. Effect of spatial variability of saturated hydraulic conductivity on Hortonian overland flow**. Water Resou. Re**s. 32(3): 671-678.