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Original Research Paper

Influence of spatio-temporal variability of soil surface states on the watershed hydrology behavior:A case study of El Hnach watershed in the semi-arid zone of Tunisia

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***[1]HAJJI Olfa, [1]ABIDI Sahar, [2]HERMASSI Taoufik, [3]MOHAMED Raouf Mahjoub and [1]HABAIEB Hamadi**

[1]National Agronomy Institute-Tunis (INAT), Rural Engineering Water and Forest Department, Tunisia.
[2]National Institute for Research in Rural Engineering, Water and Forest (INRGREF)
[3]Higher Engineering and Rural Equipment School-Medjez El Bab (ESIER), Hydraulics and Environment, Tunisia.

* Corresponding Author's
Email: olfa.hajji@yahoo.fr
Tel: +21621753512.

The objective of this paper is to analyse and understand the hydrological behavior of El Hnach catchment in Tunisia's semi-arid zone which constitutes 56% grassland, 40% annual crops and the rest being fallow. The OpenFLUID model which is a physically based hydrological model is used for this study. Six events were used for calibration and validation of the OpenFLUID model. Model performance was assessed using the Nash–Sutcliffe efficiency coefficient. A sensitivity analysis was conducted to systematically modify the input parameters to 10%, 25%, 50%, 100%, 125%, 150% and 200% of its initial value. The analysis showed that the model is particularly sensitive to saturated hydraulic conductivity (Ks); slightly sensitive to effective capillary pressure (Hf) and initial soil moisture content (θi). From the simulations representing different flood scenarios, it could be concluded that OpenFLUID model very well reconstitutes the hydrographic events from the soil parameters chosen primarily with Nash coefficient of up to 75%. This paper shows the performance of the OpenFLUID model and the important role played by soil surface conditions on runoff and infiltration in a semi-arid region. However, it also provides an understanding of the hydro-meteorological data in the studied watershed.

Key words: Hydrological model, parameterization, cultivated watershed, surface soil

INTRODUCTION

By its physical, geomorphologic and hydrologic conditions, Tunisia has long been home to significant degradation of its soil by water erosion. A national strategy for the conservation of soil and water was defined in 1991 and renewed in 2000. It led to the creation of nearly 850 hill reservoirs and dams and water and soil conservation techniques on slopes. The rapid siltation of some reservoirs located in the Tunisian Dorsal-Cap Bon reveals the need to develop a more effective strategy of anti-erosion in watersheds than it is now (Hermassi et al., 2012).
The present study's objective is to analyse and understand the hydrological behavior of a catchment in the semi-arid zone of the Tunisian Dorsal using a physically-based distributed model. By its structure, this model takes into account the spatial variability of environmental and hydro-meteorological data. Besides its reliability to protect lakes, the application of hydrological specialized models has extended to flood forecasting in engaged catchments, simulation of the effects of a change in land use in the simulation of pollutant transfer or for the production of suspended solids (Ambroise, 1999).
Hydrological processes modeling involves measurements at

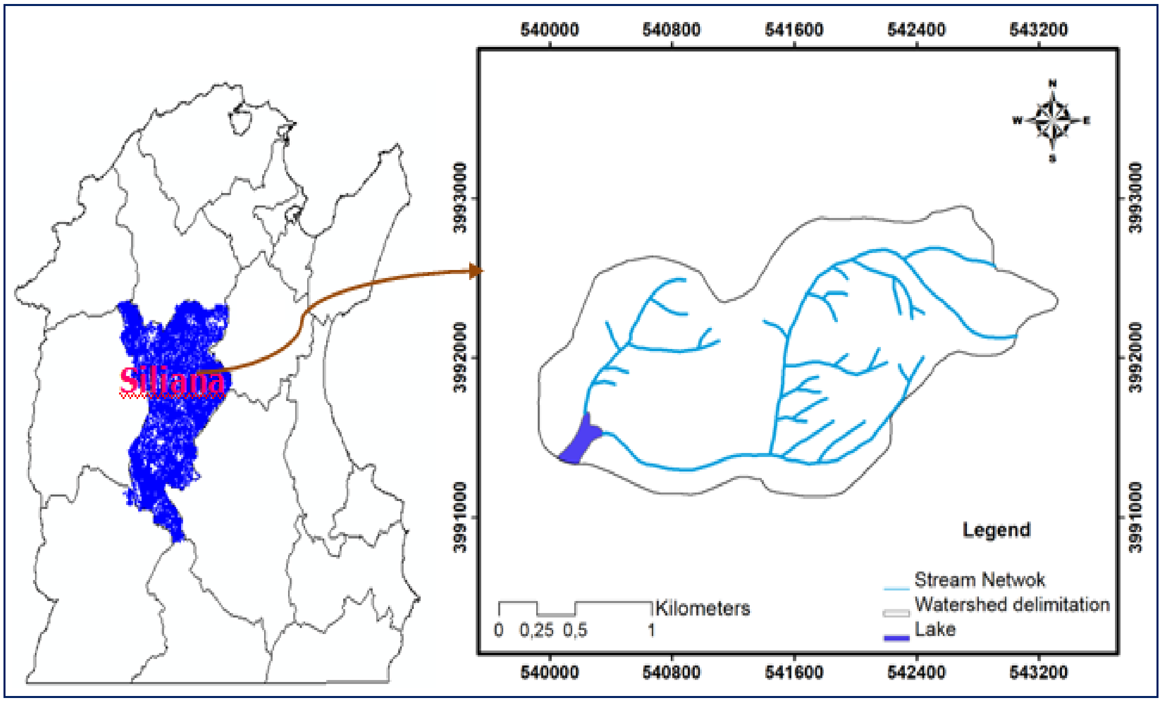

Figure 1: Location map of the watershed El Hnach

different scales of which the experimental approach cannot be done easily except only on very small spatial scale calibrated in square meters (Mahjoub, 2009). In addition, hydrological modeling validates the assumptions of hydrological functioning at different scales and integrates the spatial variability of processes (Hermassi, 2010). Depending on the processes they describe, these models require different types of data and parameters.

The present study is restricted to the application of hydrological modeling for flood forecasting in the short run. The main identified parameters to characterize hydrological processes in semi-arid regions are the hydrodynamic properties of the soil and its surface states, geometric characteristics of the surface (slope, roughness, flow directions) and water courses (length, slope, cross section, roughness) (Mahjoub, 1999). The model used was the OpenFLUID model which is applied to the El Hnach watershed (Siliana, Tunisia). In addition, strategies for identifying parameters and validation of the results were also performed

METHODOLOGY

Study sites

The El Hnach watershed is located in the central part of the Tunisien Dorsal in the Governorate of Siliana. It lies between Jbel Bargou in the East and the high plains of Siliana in the West. Similar to semi-arid Mediterranean landscapes, the watershed can be described as typical "hills" (Figure 1).

Methods

The methodological approach applied in the study is three fold. First, the area was mapped in a geographic information system (GIS) by interpretation of an aerial photograph that was completed with the use of a topographic and geological map of the study area (Hajji, 2011). Secondly, a hydrologic analysis was established to identify key input parameters of the model and to identify the hydro-meteorological data in a watershed in order to understand the hydrological functioning. Thirdly, the sensitivity of OpenFLUID model to explore the behavior of these parameters and to reduce the number of the calibration procedure (Refsgaard, 1997) was analysed.

In order to better characterize the sensitivity of the model, we will follow a pattern of calibration including a multi-objective optimization to measure several aspects of the hydrological response of the watershed in order of priority.

Cutting procedure

El Hnach watershed is divided into 110 hydrological units and 6 sections of the river system (Figure 2). This division is used to identify each hydrological unit by its size, slope average and distance to drainage downstream or downstream hydrologic unit.

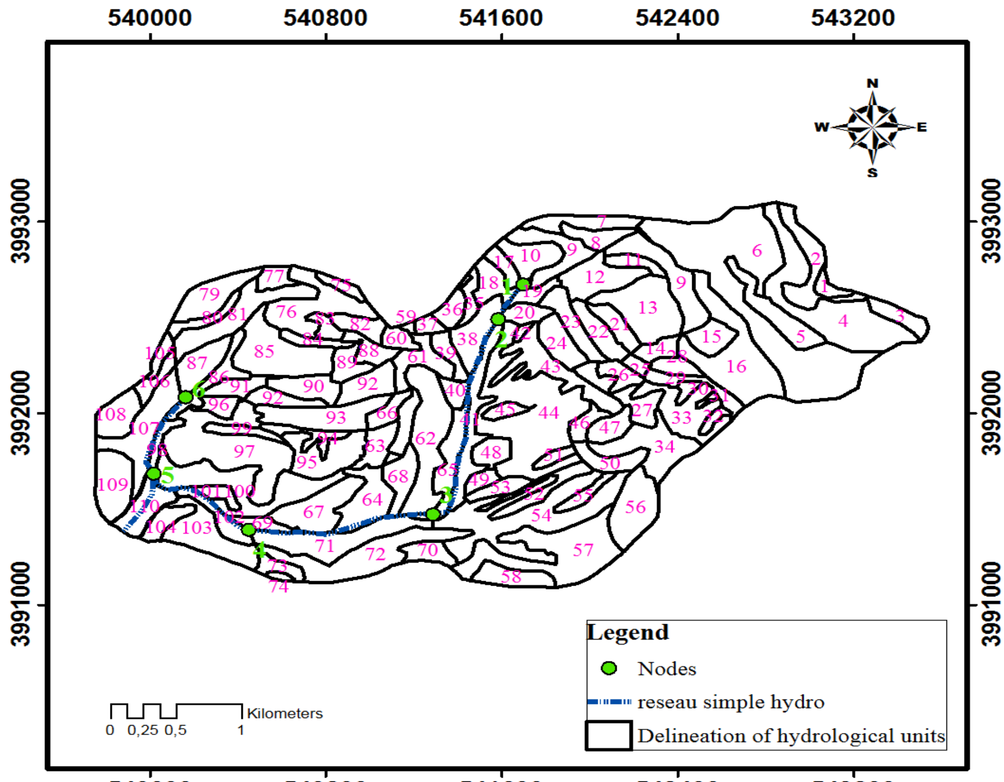

Figure 2:Cutting the watershed hydrological units in El Hnach homogeneous and sections of drainage

Table 1:Type the username of ground plot

Identifier plot	Soil type
H11 (upstream)	Lithosols, calcareous crusts, or crusting of course woody shrub
H12 (middle)	Clay-sand
H13 (downstream)	Heavy clay soils
H5 (H21) (upstream)	Brown calcareous soils Calcimagnesian
H4 (H22) (middle)	Soil Calcimagnesian brown calcareous silty clay
H3 (H23) (downstream)	Magnesium clay

Simulation sites plots

Simulation tests carried out in collaboration between the Department of Soils in General Directorate of Planning, Management and Conservation of Agricultural Lands (DG/ACTA) and Research Institute for Development (IRD) aims to characterize the hydrodynamic behavior of the basin soils under different surface conditions and moisture in order to model the behavior of the basin.

The hydrodynamic properties of the main types of surface soil were measured on 1 m^2 plots. Three intensities were applied successively: 35, 60 and 90 mm/h until a steady infiltration is observed. Two main sites were selected, HI and HII, after reconnaisance of the watershed. These sites are representative of the study area taking into account the diversity of the physical environment and incorporating the maximum variability.

Both sites HI and HII have textures, topography and occupation variables. Table 1 summarizes the type of soil for each plot.

RESULTS

Determining the parameters of the model

The input parameters of the model were determined using the results of rainfall simulations per square meter scale, Laboratory analyses for different soil types and interpretations by Green and Ampt method. All steps

Table 2. Characteristics of soil hydrodynamic watershed

Plot	Ks (mm/h)	Hf (mm)
H11	47.4	14.3
H12	10.4	62.7
H13	34.6	11.8
H5(H21)	14.8	50.9
H4(H22)	45.5	17.8
H3(H23)	36.2	18.0

helped to clarify the soil granulometric compositions and textures, the saturated hydraulic conductivity (Ks) and the effective capillary pressure (Hf). The saturated and residual soil moisture (θs and θres) were determined by the pedotransfer method from their textures taking into account the values provided by literature (Maidment, 1993). Table 2 shows the main hydrodynamic characteristics and calibration parameters of soils in the watershed of El Hnach.

Hydrological study of El Hnach watershed

A detailed hydrological analysis was performed at the watershed with the following scale:

1. Degree of prior rain (soil types and bioclimatic).
2. Surface state (date of plowing and rainfall sum after plowing).
3. Land use (changing the density of the canopy).

Hydrological analysis at the scale of the event were:

1. Rainfall with runoff (runoff).
2. Rainfall without runoff (infiltration).

The El Hnach watershed is characterized by events that are slightly different from one season to another. We conclude that for wet soils, the lower rain intensity could trigger runoff while for dry soils, runoff requires high intensities. Based on this hydrological analysis, six events were selected taking into account many scenarios of soils surface state in El Hnach watershed with each scenario having an arbitrary event for calibration and the other one for validation:

- The first phase; for autumnal situation; before plowing and high wetness, rain events of 22/09/1995 and 22/10/2000.
- The second phase in spring; for soil with vegetation and moderately moistened, rain events of 10/05/1996 and 07/05/2002.
- The third situation; for slightly moistened soil with partially degraded plowing, rain events of 23/12/1997 and 17/03/2002.

Sensitive analysis of the model

To perform the calibration and validation of OpenFLUID model parameters, we first perform a sensitivity analysis of the model:

- For three parameters of the production function (the saturated hydraulic conductivity, effective capillary pressure and initial moisture).
- And a parameter of the transfer function (the roughness) knowing that velocity and diffusivity are taken as global parameters.

The choice of the three parameters of the production function to perform a sensitivity analysis of OpenFLUID model is justified taking into account the fact that the other two parameters, namely saturation moisture and residual moisture depend only on the soil type and in particular, their particle size compositions.

Regarding the choice of roughness as a parameter of the transfer function, it is justified by the fact that it is the main parameter of the transfer function, the other parameters being determined by the morphology of the units and sections (surface, length and slope).

In order to better characterize the sensitivity of the model, we will follow a pattern of calibration including a multi-objective optimization to measure several aspects of the hydrological response of the watershed in order of priority:

- The timing of the shape; raw priority;
- The timing of the maximum flow; secondary objective;
- The timing of the flood volume; tertiary objective.

Therefore the purpose of the sensitivity analysis is twofold: to explore the behavior of the parameters and to reduce the number of the calibration procedure (Refsgaard, 1997). Since the parameters are not independent, the problem of equifinality (Beven, 2001) may in part be limited if we do not keep a minimum of parameters affecting the functions of production and transfer across a hydrological unit.

Sensitivity analysis was carried for the following parameters in the OpenFLUID models:

a. 3 parameters of the production function: Saturated hydraulic conductivity (Ks), Effective capillary thrust (hf) and Initial moisture content (θi).

b. 1 parameter of the transfer function: Manning roughness coefficient (n).

DISCUSSION

The results of the sensitivity analysis showed that the OpenFLUID model is more sensitive to saturated hydraulic conductivity (Ks), slightly sensitive to effective capillary pressure (hf) and initial moisture content (θi) for essentially a variation of 10% of the parameters. However, concerning the transfer function, the model is twice sensitive to the saturated hydraulic conductivity than roughness.

This sensitivity analysis shows that it is possible to calibrate the production function by changing the saturated hydraulic conductivity. Therefore the main OpenFLUID parameter appears to be the saturated hydraulic

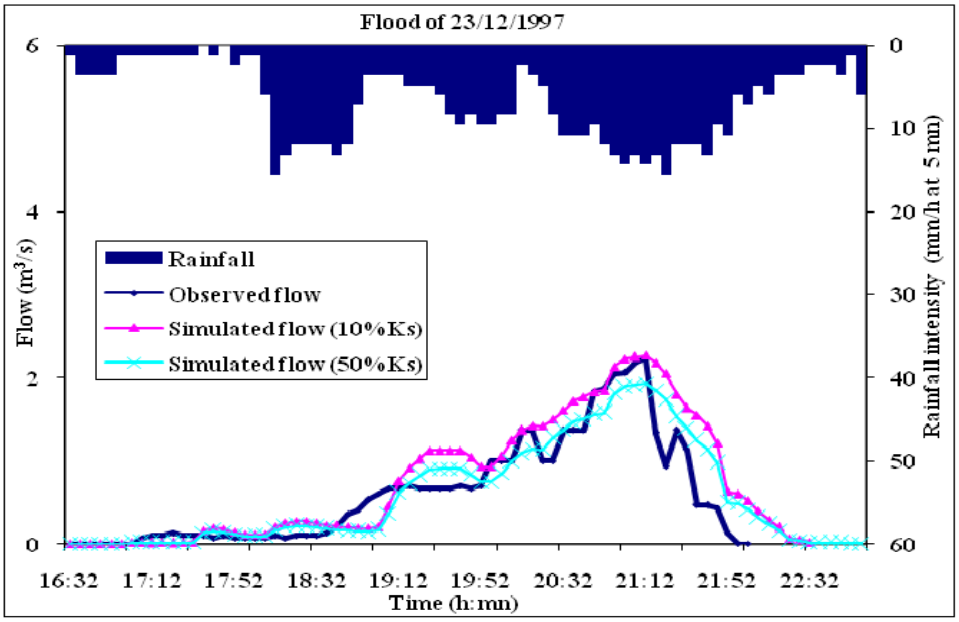

Figure 3: Reconstitution of the event (23/12/1997)

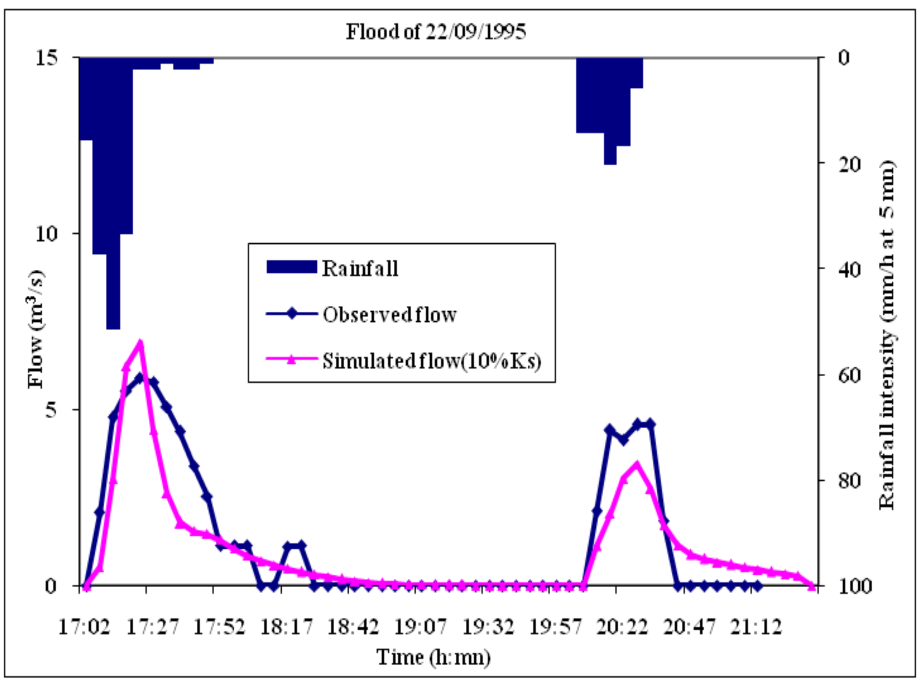

Figure 4:Reconstitution of the event (22/09/1995) after calibration

conductivity (Ks). The best simulation is obtained for a reduction (Ks) of 50% (Figure 3).

Model validation and calibration

We note that the simulation of the flood of 22/09/95, with parameter values determined from simulations of rainfall provides an underestimate of the volume and flow of the flood (of the order of 90%). To improve the calibration parameters, we proceeded to a reduction of saturated hydraulic conductivity. The best calibration was obtained for a reduction of the saturation hydraulic conductivity to 10% value. The results of calibration are shown in Figure 4. Based on the analysis of different scenarios, we concluded that:

1. The review of the first scenario shows that the model has simulated the form of floods and possesses a good ability to reproduce hydrographs events from the selected parameters for the description of soils with a Nash coefficient of up to 73% with a slight overestimation of runoff volume. Overall, these results are satisfactory and show the need for a good estimate of the volume spilled so that we can improve the model simulations.

2. The study of the 2nd scenario indicated that OpenFLUID model simulates quite well the shape of the flood, with a Nash coefficient of up to 83%. However, we also obtained the problem of distribution of rainfall in the watershed and the need to know enough hydro-meteorological data to better understand the functioning of a watershed.

- The results of the 3rd scenario showed that OpenFLUID model simulates quite well the form of flood. The Nash coefficient is about 82%. However, we observed an overestimation of the volume that can be explained by evaluating the initial moisture which assumes that the soil is homogeneous over the root depth which is not the case in nature and especially the need to take into account the succession of rain events.

Conclusion

The hydrological physically based model OpenFLUID was developed to take into account specific farming heterogeneities. As well as all spatial models, OpenFLUID requires a number of parameters to describe the hydrological units and sections of the river system (Lisah, 2008). Some of these parameters are determined from field measurements and others from the literature.

The sensitivity analysis shows that OpenFLUID model is more sensitive to the saturated hydraulic conductivity (Ks), slightly sensitive to the effective capillary pressure (hf) and initial moisture content (θi). However, regarding the transfer function; the model is more sensitive to saturation hydraulic conductivity than the roughness (Hajji, 2011).

From the simulations representing different flood scenarios, one could conclude that OpenFLUID model can reproduce hydrograph rainfall events, very well simulate the form of floods and it has a good ability to reproduce hydrographs events from the selected parameters. This proves the effectiveness of this physics-based spatial model as it adapts perfectly to small cultivated watersheds.

In conclusion the results obtained in this work has deduced the important role played by soil surface conditions on runoff and infiltration in semi-arid areas. For estimating runoff volumes, the main parameter appears to be the saturated hydraulic conductivity.

This work has highlighted the need for a good estimation of parameters and variables, but has also created an understanding of hydro meteorological data in a watershed that is needed for its operation.

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REFERENCES

Ambroise B (1999). Genèse des débits dans les petits bassins versants ruraux en milieu tempéré : modélisation systématique et dynamique. Revue des Sciences de l'Eau 12(1) : 123-153.

Maidment D (1993). GID and Hydrologic modelling. Environmental Modelling with GIS. Oxford University press: 147-167.

Refsgaard J (1997). Parametrisation, calibration and validation of distributed hydrological models. J. Hydrol. 198: 69-97.

Beven K (2001). Rainfall-runoff modelling : the primer. John Wiley and sons, Chichester.P.360

LISAH (2008). Manuel d'utilisation d'OpenFLUID 21p.

Mahjoub MR (1999). Identification des mécanismes de ruissellement dans un bassin versant méditerranéen : application des modèles hydrologiques au bassin versant de Béni Atta, Tunisie. Thèse Doctorat. UCL. AGRO/MILA/GERU – Unité de génie rural. Louvain-la-Neuve.

Mahjoub MR (2009). Course of modeling in hydrology, for students of Master of Water Resources: Hydrology & Hydrogeology 1 :8-10.

Hajji O (2011). Analyse et compréhension du comportement hydrologique du bassin versant (El Hnach) en zone semi aride de la Dorsale Tunisienne (Siliana) par un modèle à base physique spatialisé (OpenFLUID). Ecole Supérieur des Ingénieurs de l'Equipement Rural de Medjez El Beb,104p.

Hermassi T (2010). Paramétrisation des modèles hydrologiques à base physique sur les petits bassins versant des lacs collinaires de la Dorsale tunisienne. Thèse de Doctorat en sciences agronomiques de l'Institut National Agronomique de Tunisie, P.263.

Hermassi T, Debebria A, Boufaroua M, Lamachere JM, Habaieb H (2012). Impact des aménagements hydro-forestiers sur l'envasement des lacs collinaires". Int Conf Sediment Transport Modeling in Hydrological

Watersheds and Rivers. November 14-16, Istanbul, Turkey.