Hydrological Modelling the Middle Magdalena Valley (Colombia)

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Abstract

Hydrological distributed modeling is a key point for a comprehensive assessment of the feedback between the dynamics of the hydrological cycle, climate conditions, and land use. Such modeling results are markedly relevant in the fields of water resources management. Here TopModel (TOPography based hydrological MODEL) is employed for the hydrological modeling of an area in the Middle Magdalena Valley (MMV), a tropical basin located in Colombia. This study is located in the intertropical convergence zone and is characterized by special meteorological conditions, with fast water fluxes over the year. It has been subject to significant land use changes, as a result of intense economic activities, i.e., agriculture, energy and oil & gas production. The model employees a record of 12 years of: * Daily precipitation database from observed gauges * Daily evapotranspiration database from temperature data * Streamflow database as observed data from calibration Calibration is performed using data from 2000 to 2008, and validation is performed with data from 2009 to 2012. The Nash-Sutcliffe coefficient is used to assess the robustness of our calibration process.(values of this metric being 0.62 and 0.53, respectively for model calibration and validation). The results reveal high water storage capacity in the soil, and a marked subsurface runoff, consistent with the characteristics of the soil types in the regions. The calibrated model provides relevant indications about recharge in the region, which is important to quantify the interaction between surface water and groundwater, especially during the dry season, which is more relevant in climate-change and climate-variability scenarios.

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Abstract

Hydrological distributed modeling is a key point for a comprehensive assessment of the feedback between the dynamics of the hydrological cycle, climate conditions, and land use. Such modeling results are markedly relevant in the fields of water resources management. Here TopModel (TOPography based hydrological MODEL) is employed for the hydrological modeling of an area in the Middle Magdalena Valley (MMV), a tropical basin located in Colombia. This study is located in the intertropical convergence zone and is characterized by special meteorological conditions, with fast water fluxes over the year. It has been subject to significant land use changes, as a result of intense economic activities, i.e., agriculture, energy and oil & gas production. The model employees a record of 12 years of:

- Daily precipitation database from observed gauges
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- Streamflow database as observed data from calibration

Calibration is performed using data from 2000 to 2008, and validation is performed with data from 2009 to 2012. The Nash-Sutcliffe coefficient is used to assess the robustness of our calibration process.(values of this metric being 0.62 and 0.53, respectively for model calibration and validation).

The results reveal high water storage capacity in the soil, and a marked subsurface runoff, consistent with the characteristics of the soil types in the regions. The calibrated model provides relevant indications about recharge in the region, which is important to quantify the interaction between surface water and groundwater, especially during the dry season, which is more relevant in climate-change and climate-variability scenarios.

Research Objective

We applied TopModel to evaluate the hydrological modeling of an area in the Middle Magdalena Valley (MMV)

Study Area

The basin of the Middle Magdalena Valley (Fig 1) is located geomorphologically along the central part of the valley, crossed by the Magdalena River, between the Eastern and Central mountain ranges of the Colombian Andes, covering an area of 32.000 km2. The Middle Magdalena region is divided between the departments of Antioquia, Bolivar, Boyacá, Cesar and Santander, and to a lesser extent between Caldas, Cundinamarca, and Tolima [1].

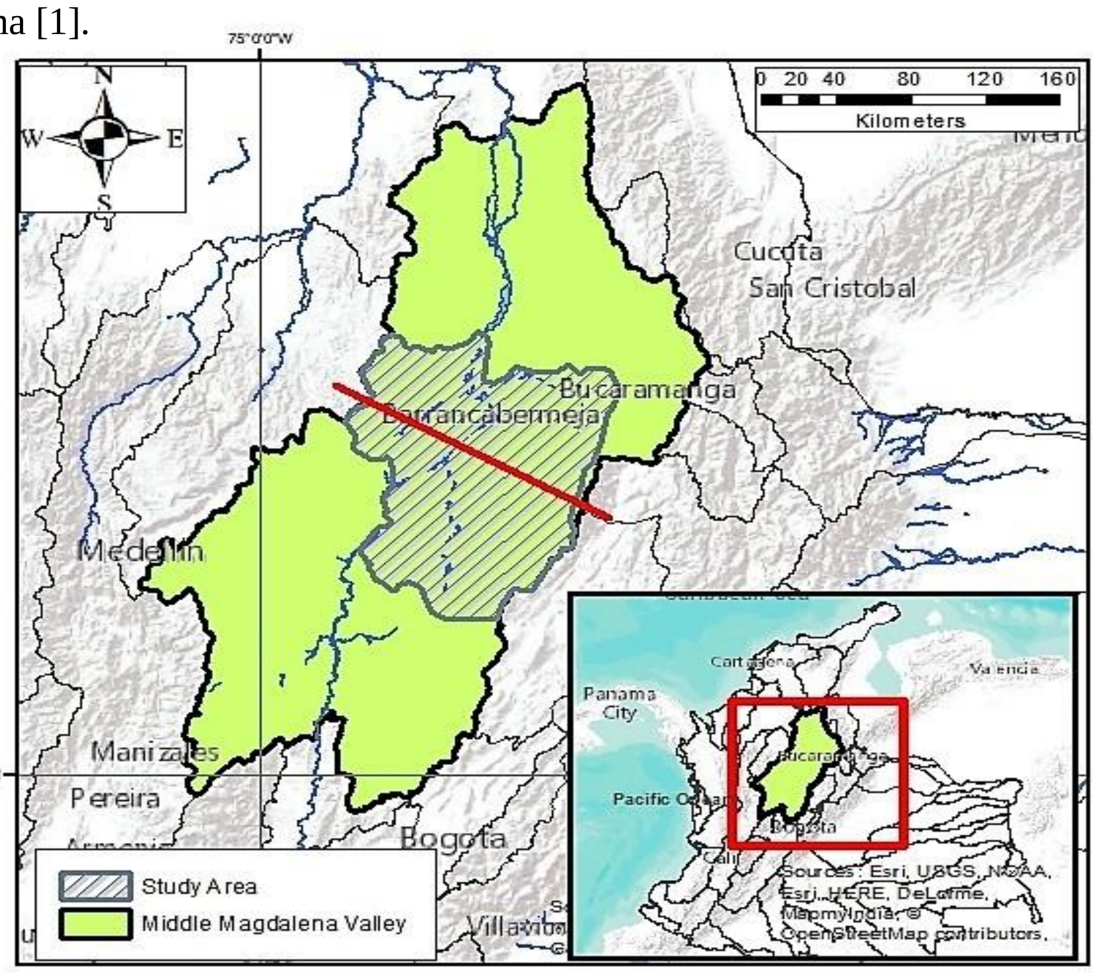

Fig. 1. Location of the Bear River Migratory Bird Refuge and its conveyance network

Model Formulation

TopModel is defined as a variable contributing area model in which the dynamics of surface and subsurface saturated areas is estimated on the basis of storage-discharge relationships established from a simplified steady state theory for downslope saturated zone flows [2]. The theory assumes that the local hydraulic gradient is equal to the local surface slope and implies that all points with the same value of the topographic index -TWI (Fig. 2).

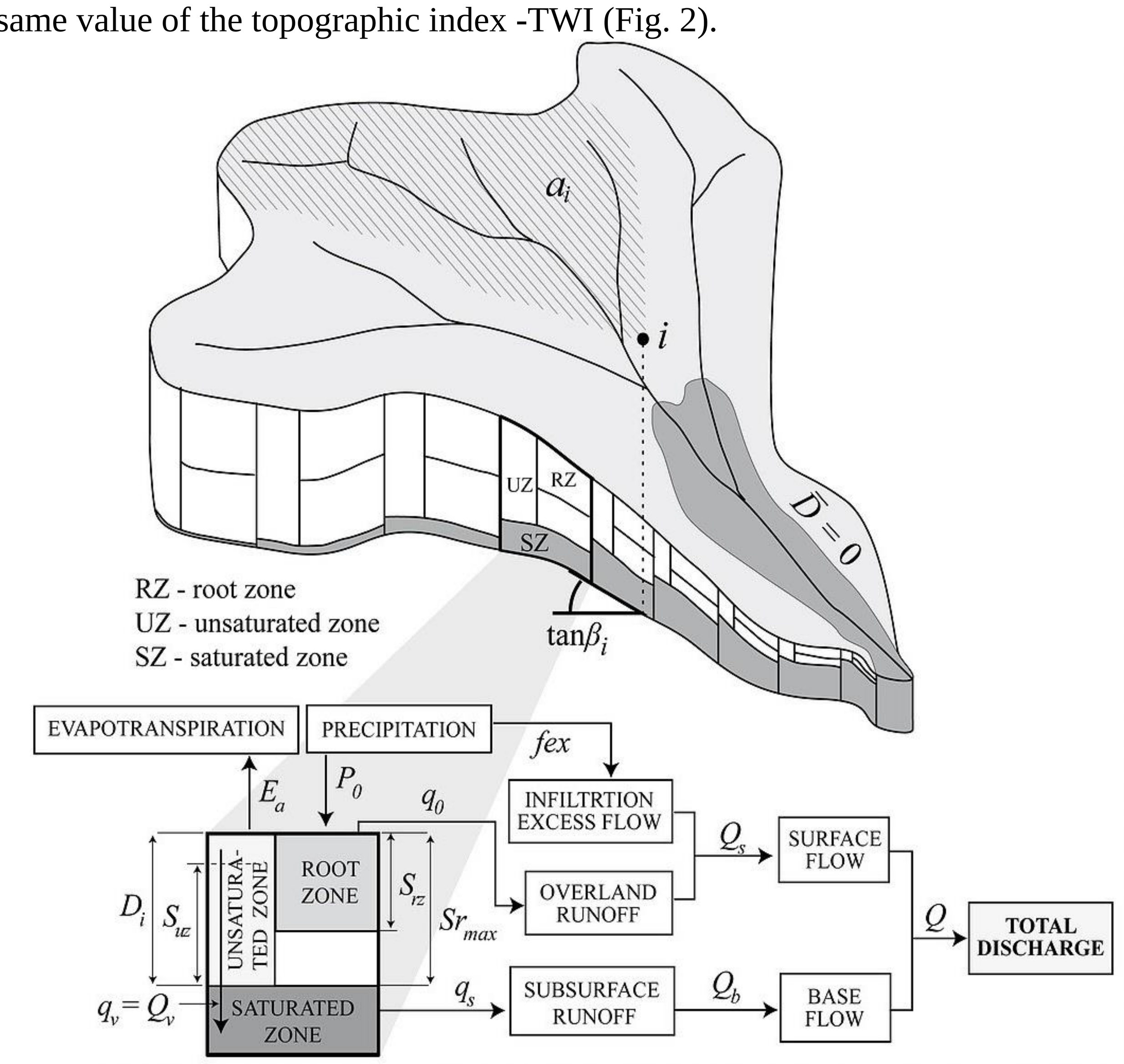

Fig. 2. TopModel model description. Source: [26]

Objective Function - OF

Calibration precedure was performed in the intervals showed in table 1, and the selected OF was the Nash Sutcliffe coefficient –NSE [4].

Parameters	Description	Unit	Set Range	
Qs0	Initial subsurface flow per unit area	m	0	0.00005
LnTe	Log of the areal average of Transmissivity	m^2/h	-7	6
M	Model parameter controlling the rate of decline of transmissivity in the soil profile		0	0.25
Sr0	Initial root zone storage deficit	M	0	0.02
Srmax	Maximum root zone storage deficit	M	0	0.2
Td	Unsaturated time zone delay per unit storage deficit	h/m	20	50
Vch	Channel flow outside the catchment	m/h	1200	10800
Vr	Channel flow inside catchment	m/h	50	2500
K0	Surface hydraulic conductivity	m/h	0	2
CD	Capillary drive	m	0	5
Dt	Time step	h	24	

Table 1. Initial interval of parameters used. Source: Author

During the calibration process, 50000 iterations were performed to determine the final set of parameters of the model. The predictions were considered acceptable when the NSE presented an efficiency value of 0.4 [5]. For validation process we used data from 2009 to 2012.

Results

Simulation

Topographic index map of the basin is presented in (Figure 3). High values of the topographic index are related to contributing areas which generate a discharge and return flows, associated with topographically convergent places or smooth slopes, and they are characterized by low transmissivity, thus the water table reaches the surface [6].

Results

The average value of the TWI for the basin was 10.3. The distribution of these values showed that the category where most of the pixels were grouped on the map has a value between 12 and 14.

Values of the index between 6 and 8, are associated with areas of higher slopes [7], which are very common on the border of the study area for being among the mountains ranges.

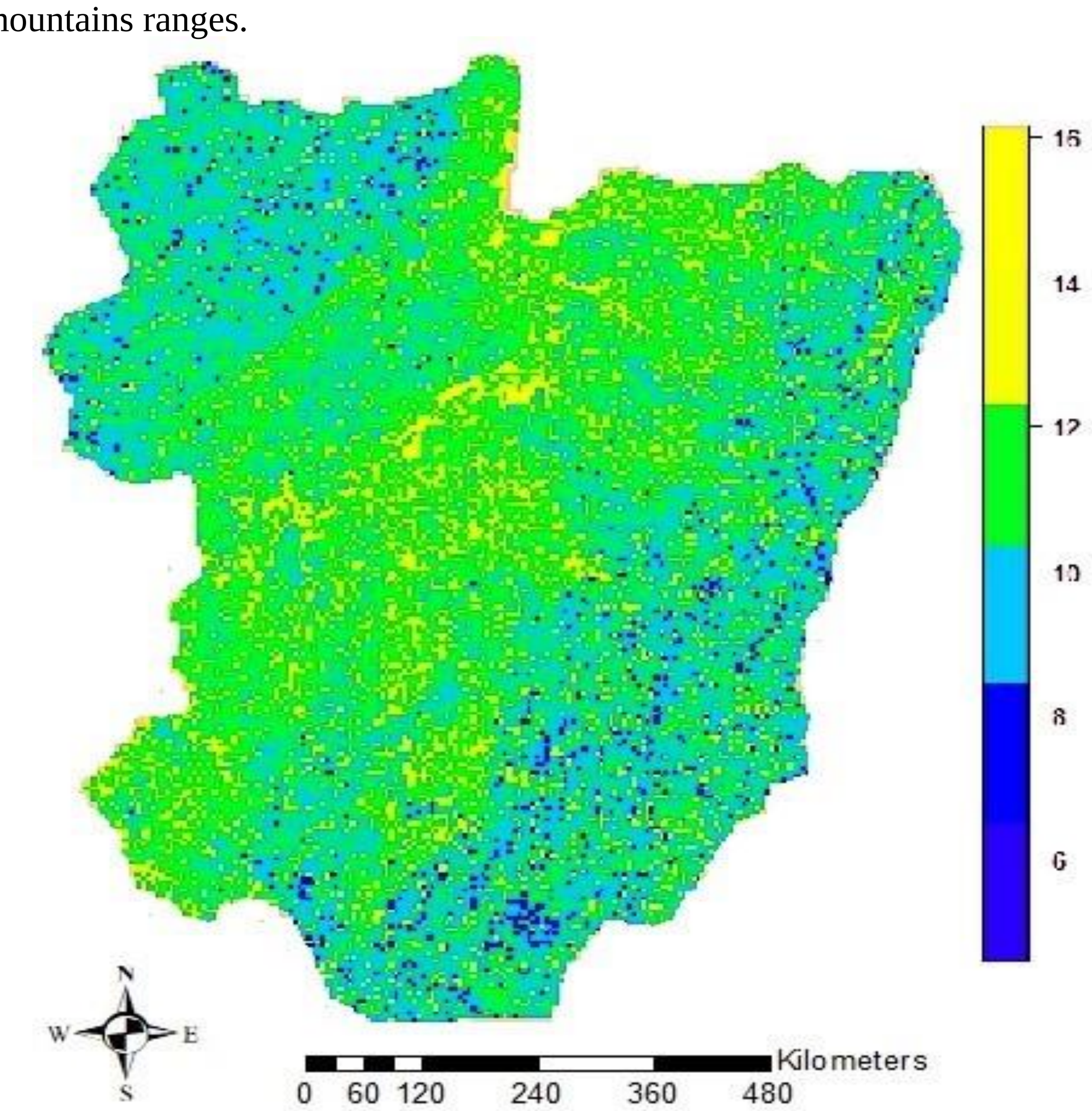

Fig. 3. Spatial distribution of the topographic index in the Middle Magdalena Valley

Calibration and Validation Model

During the calibration process, values of model parameters were selected using an uniform distribution. Each parameter set had an associated objective function value to assess its performance

The results from calibration (Table 2) generated a sets of parameters with efficiency of 0.62 for the objective function. The highest efficiencie was reached after 40.000 iterations, meanwhile other parameter sets were near the objective function a parameter values.

Parameter	Description	Value
Nash	Nash-Sutcliffe efficiency	0.57
Qs0	Initial subsurface flow per unit area	0.000069
LnTe	Log of the areal average of Transmissivity	1.18
m	Model parameter controlling the rate of decline of transmissivity in the soil profile	0.21
Sr0	Initial root zone storage deficit	0.01604
Srmax	Maximum root zone storage deficit	0.00021
td	Unsaturated time zone delay per unit storage deficit	86.07
Vch	Channel flow outside the catchment	1882.72
Vr	Channel flow inside the catchment	1074.28
K0	Surface hydraulic conductivity	7.70
CD	Capilary drive	3.46

Table 2. Best performing parameter for calibration the model. Source: Author

This set of parameters was used to calculate the simulated flows by TopModel during the period studied, presenting an underestimation of the maximum flows. When validating these parameter set, the value of efficiency was near to 0.53. Simulated flows are shown in the figure 4.

More Results

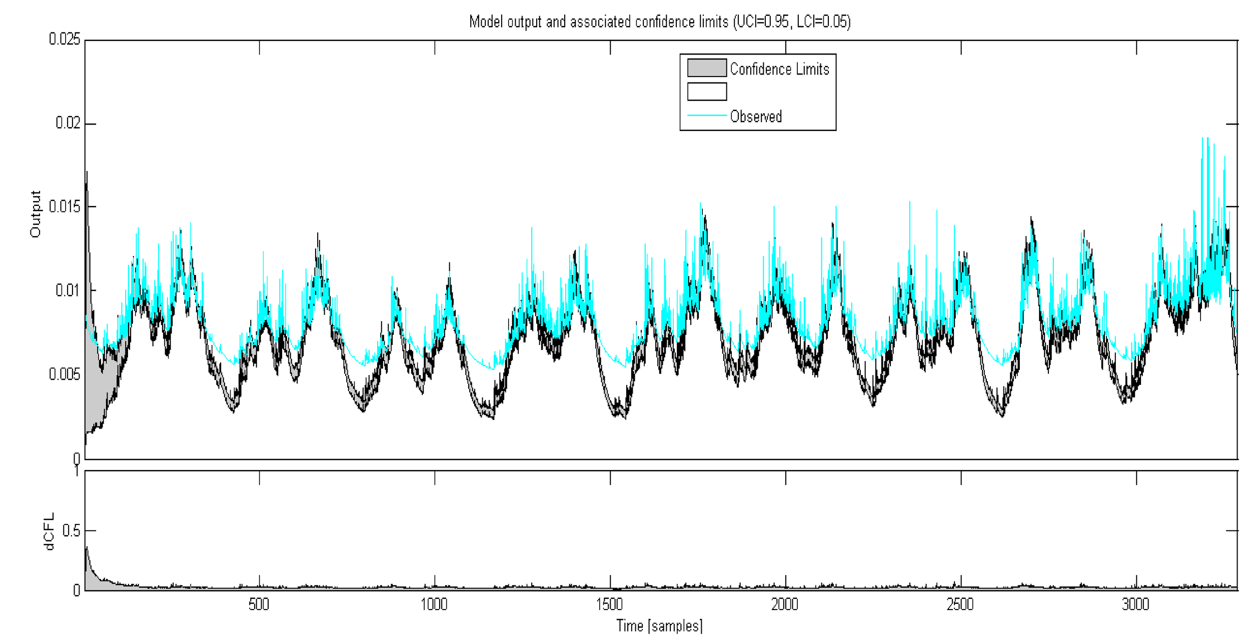

Fig. 4. Observed (cyan) and simulated flows (gray) with confidence limits for the study area in MMV. Source: Author

Conclusions

- TopModel was able to reproduce the main pattern of the hydrograph with acceptable accuracy for the case-study. A low performance to simulate some patterns (baseflow) can be attributed to input data error, calibration inaccuracy, parameter uncertainty and model structure. The most probable cause of those results is linked to the uncertainty of the data series analyzed. Low accuracy of the model can also be an effect of the model inability to represent distributed rainfall pattern.
- Complicated environment and lack of soil data makes the calibration of parameters challenging. The Monte Carlo simulation produces the most suitable parameter sets, but they may not correspond to the actual conditions of the basin.
- The application of hydrological model, developed in this research contributes to national efforts and the availability of results for the development of comparative studies in Middle Magdalena Valley at basin scale. This work constitutes a sample of the advantage of applying a widely used semidistributed model that is freely accessible to the scientific community, contrary to the limitations of using a model that depends on the singularity of the study area. The results obtained here will be used as input data in the hydrogeological analysis of the area.

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