ISBN 978-93-86878-04-5
7th International Conference on Chemical, Agriculture, Environment and Natural Sciences (CAENS-2017)
Kuala Lumpur (Malaysia) Nov. 20-21, 2017

Stream flow Simulation by Wetspa Model in Garmabrood Watershed of Mazandaran Province, Iran

Mohammad Reza Dahmardeh Ghaleno[1], Mohammad Nohtani[1] and Saeedeh Khaledi[2]

[1] Assistant Professor, Department of Rangeland and Watershed Management, Faculty of Water and Soil, University of Zabol, Zabol, Iran

[2] M.Sc. student, Department of Rangeland and Watershed Management, Faculty of Water and Soil, University of Zabol, Zabol, Iran

Abstract: *Simulation of stream flow, prediction of the hydrological behavior of watersheds and understanding of various components of the hydrological cycle is important in order to plan for protection of water resources. The present paper aims to shed lights on application of a spatially distributed hydrologic model WetSpa working on a daily time scale. The model combines elevation; soil and land use data within GIS, and predicts flood hydrograph and the spatial distribution of hydrologic characteristics throughout the watershed. This model uses a modified rational method for runoff estimation. In this model, runoff is routed along the flow path using Diffusion-Wave Equation in turn depends on the slope, velocity and flow path characteristics. Garmabrood watershed is located in Mazandaran province in Iran with coordinates 53° 10´ to 53° 38´ E and of 36° 06´ to 36° 25´ N. the catchment is covered by an area about 1221 km2 and elevations in the catchment range from 217 to 3144 m at the outlet, with average slope of 27.77%. Results of the simulations show a good agreement between calculated and measured hydrographs at the outlet of the basin. The results showed that WetSpa model predicts the daily hydrographs and maximum flow rate with good accuracy, 59% and 80.79% respectively according to the Nash–Sutcliff criteria. Also WetSpa model has well simulated runoff in validation period*

Keywords: *Wetspa model, Runoff, Flood prediction.*

1. Introduction

Developing the technology of geographical information system has allowed widespread accessibility and management on parameters and spatial hydrologic variables. These techniques have provided effective methods to study hydrologic systems, and play an important role for expanding the spatially distributed models based on GIS, in which the spatial information are formed along with the hydrologic data as area units [3]. Considering missing statistics and high complexity and impossibility of fully understanding hydrological ecosystem in most of watersheds, applying some approaches and method to estimate runoff in watersheds with missing data or incomplete statistics will be essential [3].

Given adverse consequences and numerous damages caused by runoff as well as complexity of precipitation - runoff process, many methods and models have been proposed. Precipitation-runoff models can simulate processes within watershed and serves as a tool to estimate runoff and study hydrological processes [6]. WetSpa is a distributed, continuous and physical model with daily or hourly time step explaining processes of precipitation, runoff and evapotranspiration for both simple and complex contexts. Reference [6], applied WetSpa model with one hour time step in small watershed with an area 67.8 km^2 in Belgium. Statistical analysis of hydrographic derived from model and observed hydrograph showed that model can well predict its normal

https://doi.org/10.17758/URST.U1117217

and flood currents. Reference [8] applied WetSpa hydrological model to predict runoff flow in Simiu, in the area of Lake Victoria in Tanzania. The results of the model showed that model can route flow in river. Reference [3] in a research tilted as distributed hydrological modeling and sensitivity analysis in Slovakia Turisa basin found a good conferment between observed and calculated hydrograph at the basin outlet. WetSpa model predicted the daily runoff with good accuracy, between 74–81% according to the Nash–Sutcliff criteria. The results showed that correction factor of actual evapotranspiration and Kg (evaporation of groundwater) accounted for the highest and lowest relative sensitivity respectively. Reference [10] evaluated application of distributed hydrological WetSpa model for Distributed Model Integration Project in US. They used integration criteria that reflect the differences in shape, size and volume of observed and simulated hydrographs for model performance assessment. Reference [5] evaluated WetSpa distributed hydrological model in the Gorganrood basin characterized with an area of 6717 km^2. The simulation results showed a good agreement between calculated and observed hydrograph, and given Nash - Sutcliffe criteria, model predicted daily hydrograph model accuracy about 71 to 77%. In another study using the WetSpa model, [1] simulated effect of land use change scenarios on flow hydrograph in Karkhe Dinawar basin. In this study, the capabilities of spatially distributed hydrologic WetSpa model - which simulates the river flow with hourly or daily time interval - along with GIS techniques has been applied, to prepare the map of and depression storage capacity. Results showed that model has potential to simulate daily hydrographs using 66% Nash Sutcliffe coefficients. In this paper, the methodology of producing the depression storage capacity in Dinevar watershed – 1731.49 km2 located in Kermanshah province, Iran – in turn are essential to identify and prioritize stormy. To put in a nutshell, these two parameters in WetSpa model are extracted from the Lookup table based on the three maps of land use, slope and soil. Reference [2] applied PEST model to investigate uncertainty of the WetSpa model parameters and its impacts on significant uncertainty in model prediction in Slovakia's Tourisa basin. The results showed that relative evapotranspiration correction factor has the highest relative sensitivity. Model uncertainty analysis provided insight into the proper parameter sets and proved that model parameter uncertainty does not have significant effects on uncertainty prediction. Reference [11] dealt with WetSpa model validation and verification in rural basins (Wkra, Kamienna, Sidra) in Poland. The model was auto-calibrated using PEST, Nash Sutcliffe and proved reliable quality for modeling high flow in two basins, Sidra and Kamienna; however, low flow quality was not confirmed. Values for Wkra basin were rated very good and good quality. Reference [12], simulated river's flow using WetSpa distributed hydrological model simulations in Chehelchai watershed located in Golestan province. Results of model simulations based on Nash-Sutcliffe criteria estimated daily hydrograph with relatively good accuracy over 50 and 57%, for the estimated calibration and validation periods respectively. Reference [13] assessed Impact of climate change and urbanization drawing upon Wetspa model in Belgium GroteNete basin. The results showed that simultaneous effect of these two factors significantly increase the frequency of floods in winter and low flow in summer. In general, an enormous study in different countries such as Luxembourg, Belgium, Slovakia, Hungary, Tanzania, Thailand, Poland and Iran suggest that WetSpa model in different areas with various geography and climate and diverse topographies as well as in small to very big basins is well able to simulate flow ranging from flood or daily flow of rivers. In such a way that allowed researchers to calculate impact of various factors affecting such as climate change and land use change on outlet flow as well as the different components of the water balance and hydrological phenomena in distributed manner.

2. Materials and Methods

Garmabrood watershed with an 1133 square kilometers area is located in Mazandaran province in Iran with coordinates 53° 10´ 55" to 53° 38´ 20" E and 36° 06´ 45" to 36° 25´ 30"N. Its minimum and maximum sea above elevation is 213 and 3136 m respectively [9]. Fig 1 shows study area location.

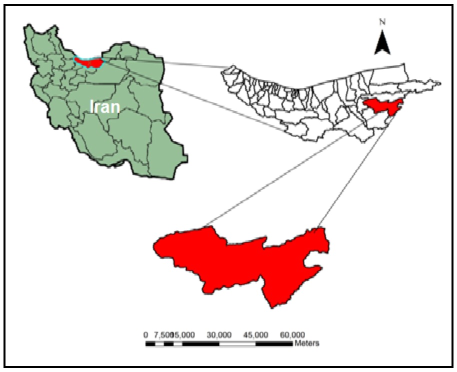

Fig. 1: Location of the study area.

WetSpa is a distributed, continuous and physical model with daily or hourly time step that explains processes of precipitation, runoff and evapotranspiration for both simple and complex contexts. This model uses a modified rational method for runoff calculation. In this model, runoff is routed along the flow path using Diffusion-Wave Equation in turn depends on the slope, velocity and flow route characteristics. In this model for each cell grid, four layers are considered in vertical manner which includes following: canopy cover layer, root zone, transportation zone and saturation zone. To running model, three land use, soil texture, and elevation classes' maps are required. Among climatological parameters, daily precipitation, daily temperature and daily evapotranspiration are necessary. Elevation classes' map for basin was prepared in size 90 m. Topographic data were also obtained using regional cartography maps. To run model, climate parameters on a daily basis, are required which these data were provided from the meteorological stations in the Garmabrood district of Mazandaran province. The Watspa model uses the Tissen method to obtain average climatic parameters in basin. It also is able to predict and simulate flood in the future. Outlet discharge is also obtained from the hydrometric station in Garmabrood watershed outlet. In this paper, the daily precipitation, temperature and discharge data are obtained from Mazandaran Regional Water Co. WetSpa model first calculates water balance in root zone because this is the most important area in water retention and at the same time it controls surface and subsurface runoff, evapotranspiration and groundwater flow. Equation 1 presents water balance in root zone for each cellular grid:

$$D\frac{\Delta\theta}{\Delta t} = P - I - V - E - R - F \tag{1}$$

Where D denotes root depth (m), $\Delta\theta$ denotes soil moisture variation (m3/m3), Δt is time step (h/day), P is precipitation (m/h/d), $I = I_a + D_a$ is initial loss including stem flow(Ia) and depression storage (Da) in time step m/h/d, V is surface runoff or surplus precipitation, E is evapotranspiration(m/h/d), R is percolation on root zone(m/h/d) and F is subsurface flow in time(m/h/d). Model applies modified rational method to calculate runoff and applies GDD to estimate snow melt runoff. Subsurface is obtained based on Darcy's law and kinematic wave equations. Groundwater flow is determined using linear reservoir method. Runoff is routed along the flow path using diffusion wave approximations equation, which is in turn dependent on slope, velocity and flow path parameters. Stream flow and surface flow were routed along river by Saint-Venant diffusion wave approximations equation and is calculated using following relation:

$$\frac{\partial Q}{\partial t} + c\frac{\partial Q}{\partial x} - d\frac{\partial^2 Q}{\partial t^2} = 0 \tag{2}$$

Where Q is discharge (m2/s), t is time (days), X is distance in flow direction (m), C denotes kinematic wave velocity in pixel and is calculated from (3). V is flow velocity (m/s) and d is diffusion factor in pixel derived from (4) where R is hydraulic radius or average depth and S0 is stream bed slope and is constant. These two parameters depend on velocity and depth [5]. To calculate flow rate at the end of the flow path, Equation 5, is used as a Saint-Venant linear response function [4].

$$C = (5/3) \times v \tag{3}$$

$$d = \left(\frac{VR}{2S_0}\right) \tag{4}$$

$$\sigma = \sqrt{\int \frac{2d}{c^3} dx} \tag{5}$$

Considering a limited system between upstream and downstream cross-section, solution for equation 2 in pixel outlet can be expressed using a Gaussian probability density function as in (6).

$$U\,(t) = \frac{1}{\sigma\sqrt{2\pi t^3 / {t_0}^3}} \exp\left[-\frac{(t-t_0)^2}{\frac{2\sigma^2 t}{t_0}}\right] \tag{6}$$

Where U(t) is flow response function used to determine unit hydrograph and allows routing flow path to basin outlet.t0 is flow travel time(T), σ is flow time standard deviation and finally flow hydrographs in outlet which combined in downstream are calculated from (7):

$$Q(t) = \int A \int_0^{\tau} V(\tau)\, U(T-\tau)\, d\tau\, dA \tag{7}$$

Where $Q(t)$ represents discharge, U is flow path response function, τ is lag time and V is outlet runoff volume. Model inputs include digital elevation data, soil type, land use, time series of precipitation and evaporation so that all hydrological processes cab be simulated in Gis.

In the present research, daily data on flow, rainfall, temperature and evaporation in Terosk hydrometric stations for years 2012-2013, 2013-2014, 2012-2013 and 2013-2014 were used for calibration and Validation.

2.1. Model Validation and Efficiency Metrics

- Model Bias

Model bias can be simulated as relative mean difference between the observed and predicted flow in a great simulation and these criterion is expressed as follows:

$$MB = \left[\frac{\sum_{i=1}^{N}\left(QS_i - Qo_i\right)}{\sum_{i=1}^{N}\left(Qo_i\right)}\right] \tag{8}$$

Were MB is model bias, Qsi and Qoi represents simulated and observed flow in ith time step (m3/s) and N is the number of time steps during simulation. MB low values indicate a better fitting and value zero represents perfect simulation of observed flow.

- RMSE

$$RMSE = \sqrt{\frac{\sum\left(XO - XS\right)^2}{N}} \tag{9}$$

whereXO and XS is observed and simulated discharge respectively, N represents number of time steps during simulation. The lower this value, the better simulation model will be and it has not a given interval.

- Nash-Satclieffe coefficient

Nash-Sutcliffe criterion (1970) indicates that how well flow rates simulated by the model are correct, the equation is as follows.

$$NS = 1 - \sum_{i=1}^{N}\left(Q_{si} - Q_{oi}\right)^2 \Big/ \sum_{i=1}^{N}\left(Q_{oi} - \overline{Q}_o\right)^2 \tag{10}$$

Where NS is Nash-Satclieffe efficiency index used to evaluate potential to simulate flow channel, ranging from a negative value to 1 and is 1 represents full compliance between observed and simulated hydrograph.

- Nash-Satcliffe Low

Logarithmic Nash - Sutcliffe (11), focuses on evaluation of low-flow simulation.

$$NSL = 1 - \frac{\sum_{i=1}^{N}\left[\ln(Qs_i) - \ln(Qo_i)\right]^2}{\sum_{i=1}^{N}\left[\ln(Qo_i) - \overline{\ln(Qo_i)}\right]^2} \tag{11}$$

log Nash-Sutcliffe efficiency coefficient NSL is used to assess low flow rates. In a complete simulation, NSL equals to one.

- Nash-Satcliffe High

Nash – Sutcliffe criterion provided in (12) which is used to evaluate potential to simulate high flow.

$$NSH = 1 - \frac{\sum_{i=1}^{N}\left(Qo_i + \overline{Qo}\right)\left(Qs_i - Qo_i\right)^2}{\sum_{i=1}^{N}\left(Qo_i + \overline{Qo}\right)\left(Qo_i - \overline{Qo_i}\right)^2} \tag{12}$$

3. Results

Once wetspa model was run, given daily data on flow, rainfall, temperature, evaporation and land use, soil and digital elevation maps, first model was calibrated for a two years period (2011-2012 to 2012-2013) and was validated for two statistical years (2013-2014 to 2014-2015). Results are presented in table 1. As it can be seen in Table 1, results of the assessment criteria indicated that in calibration period model was run with necessary efficiency.

TABLE I: Values for Model Efficiency Criteria During Calibration Period

Efficiency criterion	calibration	Validation
model bias to flow volume balance	-0.11	-0.07
RMSE	60.81	63.14
Total Nash-Satcliffe coefficient (%)	59.04	53.09
Nash-Satcliffe high (%)	80.79	78.19
Nash-Satcliffe low (%)	28.18	27.15

Comparison of observed and simulated hydrograph given fig 2 and 3 shows that model can well simulate high flow (peak flow) to runoff estimation, but it has low accuracy in prediction of low flow which it can presumably attributed to simplification of groundwater in model or lack of accurate evapotranspiration of groundwater estimation during dry periods. At the same time, using base flow in the summer to agriculture and farming can be considered as determinant factor.

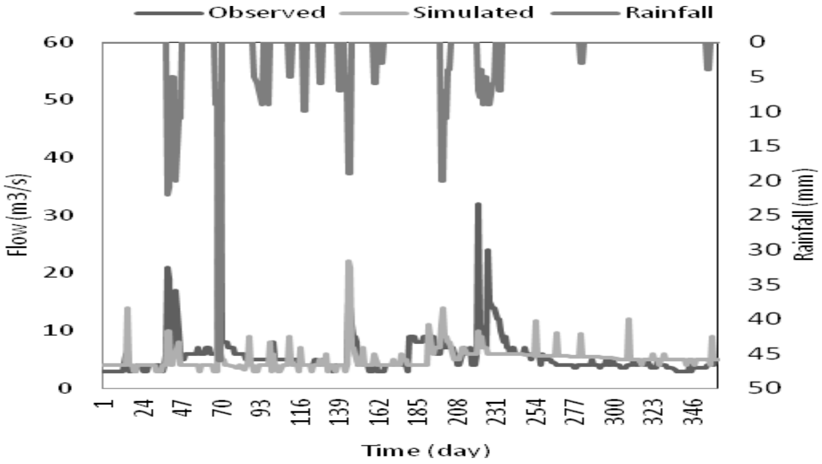

Fig. 2: Model calibration during two statistical years (2011-2012 to 2012-2013)

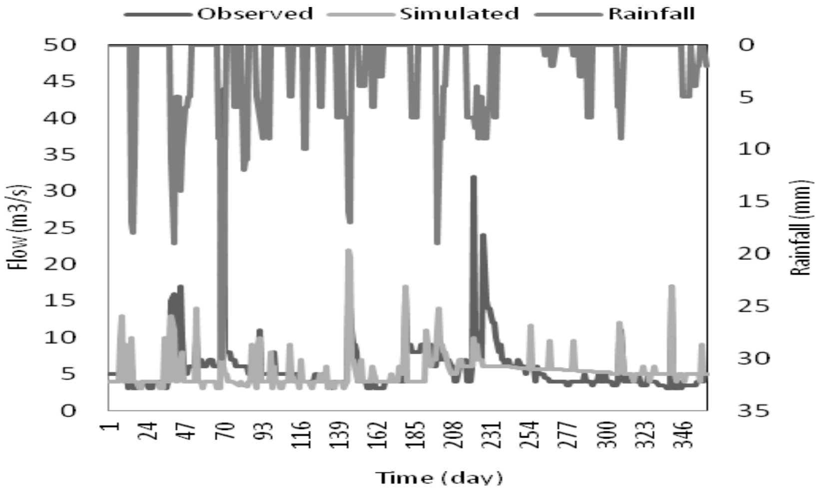

Fig. 3: Model validation during two statistical years (2013-2014 to 2014-2015)

4. Discussion and Conclusion

Until now, Wetspa model has been applied and studied in enormous areas including Barbic basin in Belgium [4], Alzette River Basin in Luxembourg [7], karst river basin Somui in Vietnam [6], Hornad watershed in Slovakia [3]. Literature review indicated that model might well handle a variety of hydrological processes under diverse topography, soils, land-use, and areas and has great potential in this field. In this study, model was validated in Garmabrood watershed with time series 2-years data on daily rainfall, temperature, evaporation rate. According to calibration results, model outperforms under high flow compared to high flow which this may be attributed to model weakness in low flow estimation but as a whole model simulated total flow with acceptable accuracy. In this case, small Nash - Sutcliffe coefficient for low flows can be found in elsewhere [10], [3] and [8]. However validation results are unacceptable and this may be due to the model structure or data and basin conditions.

5. Acknowledgments

This research was supported by the University of Zabol with the UOZ-GR-9517-110 Grant code.

6. References

[1] M. Azinmehr, A. Bahremand, and A. Kabir, “Simulating the effects of landuse change scenarios on flow hydrograph using the spatially distributed hydrological model, WetSpa, in the Dinvar Watershed, Karkheh, Iran, “*Watershed Engineering and Management*, vol. 7, pp. 500-511, 2016.

[2] A.Bahremand, and F. De Smedt, “Distributed hydrological modeling and sensitivity analysis in Torysa watershed, Slovakia, “*Journal of Water Resources Management*, vol. 22, pp. 393-408, 2007.

[3] A.Bahremand, F. De Smedt, J. Corluy, Y.B. Liu, J. Poorova, L. Velcinicka, and E. Kunikova, “WetSpa Model Application for Assessing Reforestation Impacts on Floods in Margecany–Hornad Watershed, Slovakia, “*Watershed Resource Management*, vol. 21, pp. 1373-1391, 2006.

[4] F. De Smedt, Y.B. Liu, and S. Gebremeskel, “Hydrological modeling on a catchment scale using GIS and remote sensed land use information“. pp: 295– 304. In: C.A. Brebbia (ed.), Boston: WTI Press. 2000.

[5] A. Kabir, M. Mahdavi, A. Bahremand, and N. Noora, “Application of a geographical information system (GIS) based hydrological model for flow prediction in Gorganrood river basin, Iran, “ *Journal of Agricultural Research*, vol.5, pp. 23-31, 2010.

[6] Y.B. Liu, and F. De Smedt, “Flood Modeling for Complex Terrain Using GIS and Remote Sensed Information, “*Water Resources Management*, vol. 19, pp. 605-624, 2005.

[7] Y.B. Liu, S. Gebremeskel, F. De Smedt, L. Hoffmann, and L Pfister, "A diffusive transport approach for flow routing in GIS-based flood modeling. "*Journal of Hydrology*, vol. 283, pp.91-106, 2003

[8] J. Rwetabula, F. De Smedt, and M. Rebhun, "Prediction of runoff and discharge in the Simiyu River (tributary of Lake Victoria, Tanzania) using the WetSpa model. "*Hydrology and Earth System Sciences*. Vol. 4, pp. 881-908. 2007.

[9] K. Saber Chenari, H, Abghari, M, erfanian, and S. Gholizadeh, "Short-term model of optimization operation of water resources using particle swarm optimization and compared with genetic algorithm. " *Watershed Management Research*. vol. 97, pp.97: 63-72. 2013.

[10] A. Safari, F. De Smedt, and F. Moreda, "WetSpa model application in the Distributed Model Intercomparison Project (DMIP2). "*Journal of Hydrology*. vol. 418, pp.78-89, 2012.

[11] B.Porretta, J. Chormanski, S. Ignar, T. Okruszko, A. Brandyk, T. Szymczak, and K. Krezalek, "Evaluation and verification of the WetSpa model based on selected rural catchments in Poland. "*Journal of Water Land Dev*. vol.14, pp.115- 133, 2010

[12] F. Yaghoubi, and A.R. Bahremand, "Streamflow Simulation using Spatially Distributed Hydrologic Model, WetSpa in Chehel-Chai Watershed in Golestan Province. "*Journal of Water Land Dev*. vol.18, pp.115- 185, 2011.

[13] T. Vansteenkiste, M. Tavakoli, V. Ntegeka, and P. Willems, "Climate change impact on river flows and catchment hydrology: a comparison of two spatially distributed models. "*Hydrological processes*. vol.27, pp. 3649-3662, 2013.

https://doi.org/10.17758/URST.U1117217