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Research Article

Hydrological Simulation of Silver Creek Watershed using Soil and Water Assessment Tool (SWAT)

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Abstract

Silver Creek Watershed has a basin of 1213.11 km^2, located in Southern part of Illinois State (U.S.A), including highland silver lake and its east fork tributary. This research employs (Soil and Water Assessment Tool) to analyze the watershed as a function of land use parameters. Different parameters have been considered in sensitivity analysis to determine the most sensitive parameters for flow rate calibration within different hydrological response units (HRUs). Inputs parameters include precipitations and meteorological data such as solar radiation, wind speed and direction, temperature, and relative humidity. Model was calibrated with measured daily data for Troy gage station. The main objective was to simulate and calibrate the flow rate with SWAT model. Uncertainty analysis has been performed with SUFI-2 (Sequential Uncertainty Fitting Version-2) which is interfaced with SWAT applying iSWAT (generic coupling format program). Correlation between several stations within the domain has been calculated which showed a good range of Correlation (R^2) values which means the pattern of meteorological data was evenly distributed. Finally based on the root mean of squares error (RMSE), (R^2), NSE, and P-BIAS values, the accuracy of the calibration has been determined.

Introduction

Increasing demand for industrial and domestic usage of water, increases the pressure on available water resources needed to fulfill such demands. Abrupt and mostly unpredictable depletion of freshwater resources brings new concerns regarding water resource management. Climatic changes create another problem reminding us that the traditional water management solutions are not fully applicable to today's concerns. Hydrological models, either conceptual or computational could play an essential role in sustainable decision making to mitigate the negative environmental impacts and simultaneously suggesting viable approaches [1-3].

Study Area

Silver Creek Watershed is a sub-basin of the Kaskaskia Watershed in Sothern Illinois. Watershed land-use primarily consists of cropland, grassland, and forest. Like many mid-west watersheds, it currently experiences moderate to high levels of urbanization (Figure 1). shows Silver Creek within the Southern part of the Illinois state. All tributaries within the watershed flow into the mainstream of Silver Creek and eventually discharge into the Kaskaskia river and, finally into the Mississippi River. Flow direction is from north to south [1].

Model Objective

The scope of this research is to calibrate the flowrate. Discharge has been simulated and simulated flow rate was calibrated to determine the most sensitive parameters with the help of global sensitivity analysis. Having a good understanding of the affecting parameters in modeling the flowrate and availability of trustable flow measurement data are crucial in producing a well-calibrated hydrological model. In this study based on literature reviews as well as conducting global sensitivity analysis for different parameters, most sensitive parameters for flowrate were determined and based on available daily data for calibration period the accuracy of the model has been verified.

Previous Studies

Literature reviews categorized into two series of investigations. First set focused on those studies which consider SWAT and SWAT-CUP model reviews and, second category include reviews for Silver Creek Watershed. Abbaspour et.al has built and calibrated an integrated hydrological model of Europe, using SWAT model to quantify the water resources at sub basin level. Nitrate leaching into groundwater was also considered in their simulations. Monthly time intervals were applied for both simulations and calibration [4-9].

In another study, he has investigated 19 monitoring stations which includes main Switzerland rivers. SWAT model was used for catchment of Thur river basin with the area of 1700 km^2 [10]. Estimation of freshwater availability in the west African sub-continent using the SWAT hydrologic model [11-17]. Combination of different parameters which affects the land-use, climate, water pollution as well as water allocation results in different uncertainty analysis techniques. Abbaspour et. al., 2008 compared the differences and similarities between five procedures, three of them mentioned below: Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), Sequential Uncertainty Fitting algorithm (SUFI-2) [18-23]. Rouholahnejad 2012 constructed a

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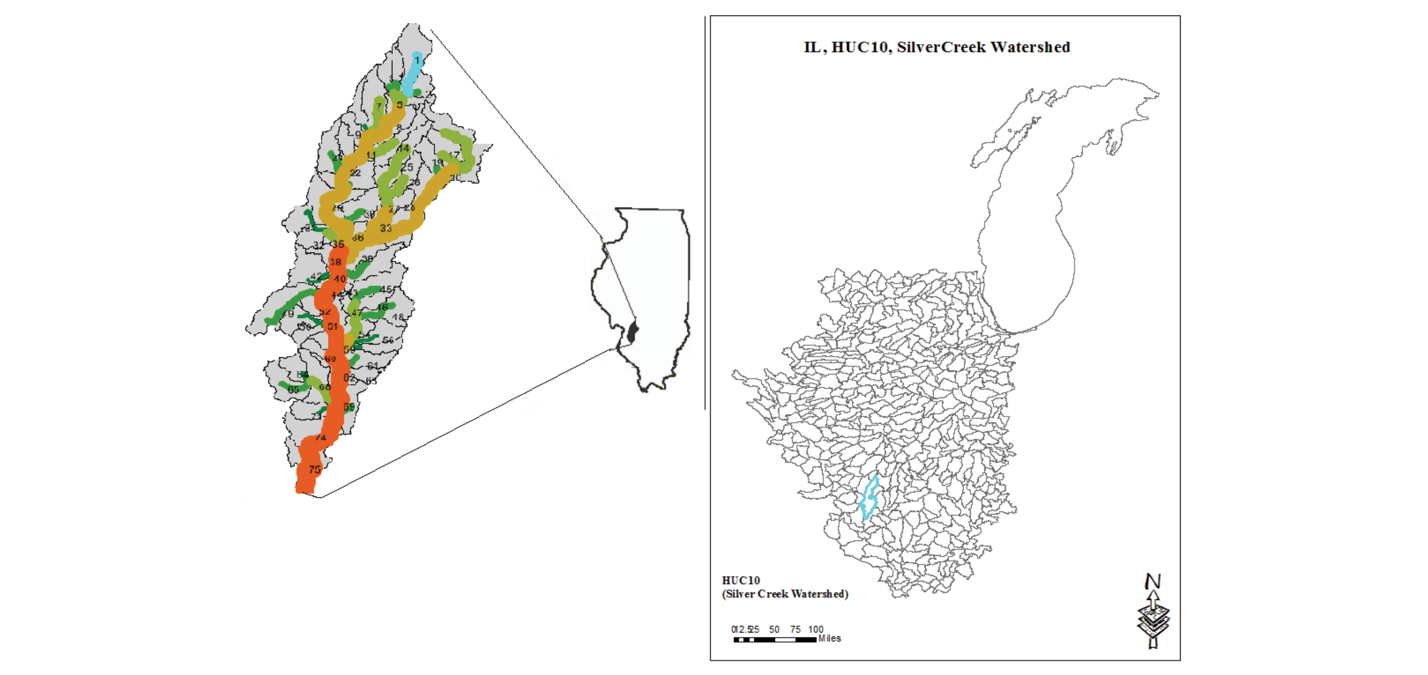

Figure 1: Location of Silver Creek Watershed (IL, U.S.)

parallel processing scheme to perform the parallel calibration of SWAT model. The parallel processing was implemented in the SWAT-CUP by using SUFI-2 optimization program [24]. Vaghefi et. al., 2013 studied the impact of the climate change on water resources and wheat yield where semiarid regions are in extreme needs for best practical water resources management decision making to have a future in terms of sustainability [25]. Amongst the works which studied silver Creek Watershed we can name generating alternative watershed-scale BMP designs with evolutionary algorithms, which controls the storm runoff within a watershed in a cost-effective approach based on the structural BMPs and meet the target peak flow and sediment reduction criteria [26], [19] [27-30]. Sediment survey within the reservoir investigated the sedimentation rate within the reservoir and calculated the remaining capacity at the current time of the survey. Silver lake was constructed to replace the city's old reservoir. The new reservoir has a capacity of 30 million gallons of water, later the capacity of the reservoir increased to 120 million gallons. The lake lies entirely within Madison County. The spillway elevation of the reservoir is 1500 m above mean sea level [31].

Materials and Methods

Preparing the initial requirement in ArcGIS platform

Preparations of DEMs (digital elevations models) and boundary delineation

DEMs (digital elevation models) were downloaded from the nationalmap.gov by using TNM download client for North America NAD 1983. To have a DEM which covers whole basin of Silver Creek four smaller DEMs has been combined and created a new DEM far bigger than Silver Creek basin, hence it has been easily extracted from the new DEM (Figure 2). shows new DEM including Silver Creek basin. Typically, DEMs resolution are available in 1km*1km, 90m*90m, 30m*30m, 25m*25m, but for accuracy of this model resolution of 9m*9m was selected for cell size of the DEM to get most reliable results based on high DEM resolution. Boundary of the Silver Creek Watershed was delineated after DEM extraction.

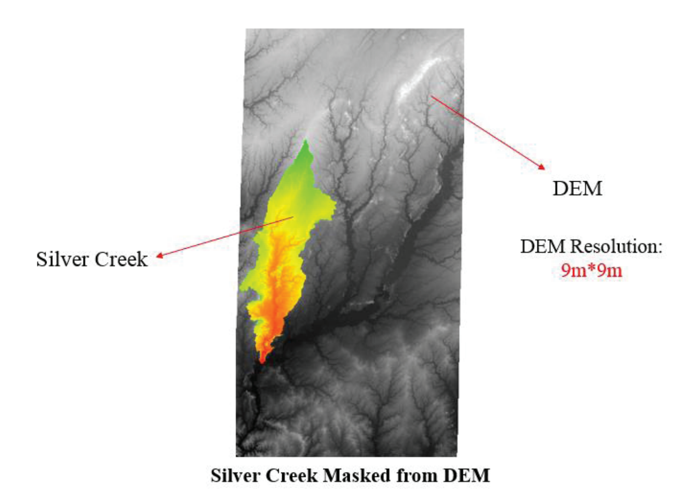

Figure 2: Silver Creek masked from DEM.

HUCs (hydrological unit codes)

HUC-10 and HUC-12 were used to select waterways within the Silver Creek basin. Then from U.S. streams, all streams within the Silver Creek Watershed were extracted (Figure 3). shows the streams lying within Silver Creek boundaries.

Settings for SWAT extension

Introduction to SWAT

SWAT is an appropriate tool to model the streams flowrate as well as water quality. Interface of SWAT consists of six parts as below: 1. SWAT project setup. 2.Watershed delineation. 3.HRU analysis. 4.Write input tables. 5. Edit SWAT inputs. 6. SWAT simulation [32].

Watershed delineation in SWAT

Silver Creek Watershed has been delineated as below. DEM entered

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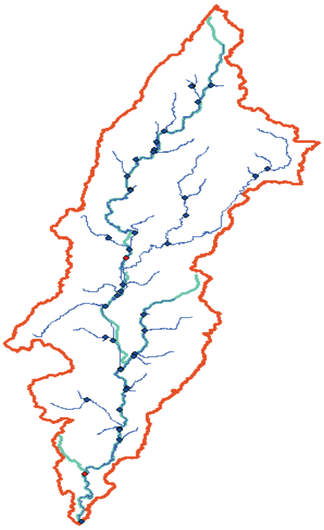

Figure 3: Silver Creek, mainstream, reaches and outlets.

to the model and mask procedure completed in ArcSWAT. Flow direction and accumulation have been calculated by SWAT based on the slope (north to south) as flow direction is towards the final outlet or pouring point of the watershed. Sub-basins have been classified from small sub-basins to larger ones in hectare (ha) distributed in size from an exceedingly small sub watershed to maximum possible size. Number of cells represents the resolution of the cell size of watershed grid. The smaller the cell size the higher the resolution and hence more computation time is needed. Number of cells for this study was 115,483 which results in 75 sub-watersheds. Streams, stream networks, and sub-basins were created as well as outlets for each sub-basin. The pouring point of the watershed considered as an outlet for entire watershed and finally the watershed has been delineated. By delineating the watershed, a polygon feature class appeared while sub-basins are added to the map documents. All parameters were attributed to the sub-basins and the locations of outlets were assigned. For this study, the daily data of flow for one observation gage station was available (Troy gage station) at the middle of watershed. Later this station considered as reference point to call back from SWAT-CUP to calibrate the results [33], Finally, HRUs were created.

HRU analysis

By defining the geometry of the watershed, land- use, soil type and slope of watershed were prepared and overlaid together to create HRUs (Hydrological Response Units). SWAT contains four raster datasets including: 1. Mask: optional, but always being used to speed up the process 2. DEMs: Digital Elevation Models which are attributed to the SWAT project in the units of m, km, yard. 3. Land-use: land-use or land-cover can be in in the form of grid or shape file or feature class. 4. Soil: needs to be linked to U.S. Soils database. Key procedures for defining the land-use/soil/slope are defining the land use dataset, reclassifying the land use layer, defining the soil dataset, reclassifying the soil layer and, finally overlaying land use, soil and slope layers all together to create HRUs [32].

In this study land-use data has been downloaded from the nationalmap.gov and, projected to the original DEM for Silver Creek Watershed, then clipped to the boundary of the basin. When land-use data was processed, soil data has introduced to the model. After processing soil data slope attributed to each HRU. Based on the information from the Silver Creek slope studies slope was classified into three slope classes as below: Class 1: 0-3%, class 2: 3-8%, and class 3: 8-max possible. Finally, combined information based on land-use, soil type and slope of the watershed was created as shown in (Figure 4).

Available data

For this study, WGEN-user (user defined weather generator data) was used. This part consists of weather generator data, rainfall, temperature relative humidity, solar radiation, and wind data. For temperature and rainfall data two series of data have been used: daily data and its text file containing the location of the stations. Daily data from available gage stations, under NOAA.gov site has been downloaded including all stations within the watershed boundary (Figure 5). Completed data for two stations amongst seven stations within the box were assigned to the watershed model. Input parameters to the SWAT models in terms of meteorological data are precipitation (p), relative humidity (rh), solar radiation (s), temperature (t), wind speed and direction (w). Series of the daily data have been used during 2000 and 2014.

Model setup information

Start and end of simulation were assigned to the model for the period of 14 years starting at 01/01/2000 and ending at 01/01/2014 and, the model ran for daily time intervals, considering three-year warm-up period.

Model Calibration

SWAT-CUP (Soil and Water Assessment Tool Calibration and Uncertainty Program) SWAT-CUP is a computer program for calibrating SWAT model. It enables us to perform sensitivity analysis and calibration of SWAT model. In this study SWAT-CUP 2012 has been used [33]. Sequential Uncertainty Fitting Version 2 (SUFI-2) algorithm was applied to calibrate the flowrate based on measured daily data.

Linkage of SWAT-CUP to SWAT model

SWAT-CUP is a generic interface wherein any calibration or sensitivity analysis would be easily linked to the main SWAT file. Schematic linkage between SWAT and five optimization program illustrated below in (Figure 6) [33].

Flowrate calibration procedure for Troy gage station

Flow data has been downloaded from USGS gage stations for Illinois. Calibration process described below. Most dominant flow parameters are CN2, SOL_AWC, and ESCO. Some are relative parameters, some absolute and some considered as replace parameters. SUFI2_SWAT Edit, defines the number of simulations for that specific iteration starting from one to maximum 2000 simulations. All observed data for entire calibration process of Troy station entered to the model, consisting of 365 daily collected data points. Simulated data recalled at the same location of Troy gage station. Simulated flow stands with FLOW_OUT and Troy located at sub-basin No 37. Objective function for SUFI2 is Nash-Sutcliffe (1970), where Q is a variable (e.g., discharge), m and s stand for measured and simulated, respectively, and the hat stands for average values [33].

$$NS = 1 - \frac{\sum_i^n (Qm - Qs)^2}{\sum_i^n \left(Qm,i - \bar{Q}\right)^2}. \qquad (1)$$

Another factor which has been considered was PBIAS. Percentage bias measures the average tendency of the simulated data. It says if they are larger or smaller than the observations. PBIAS reported in a percentile format and the values less than 10% are acceptable. Zero

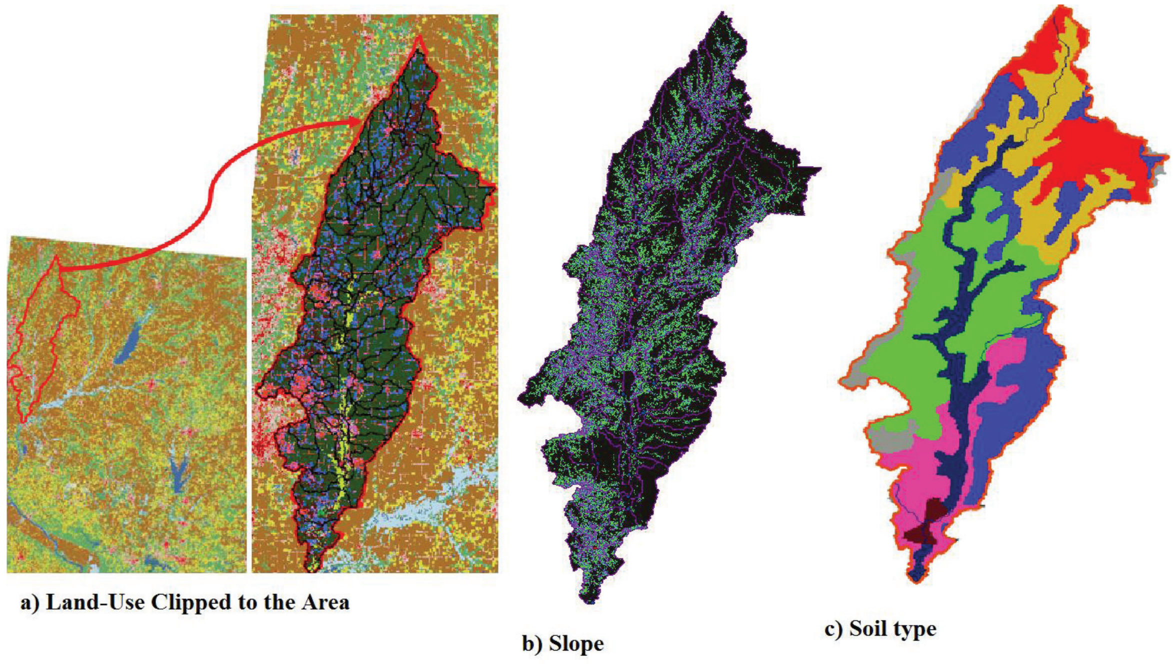

Figure 4: Silver Creek, Land-Use/Slope/ Soil Type Classifications.

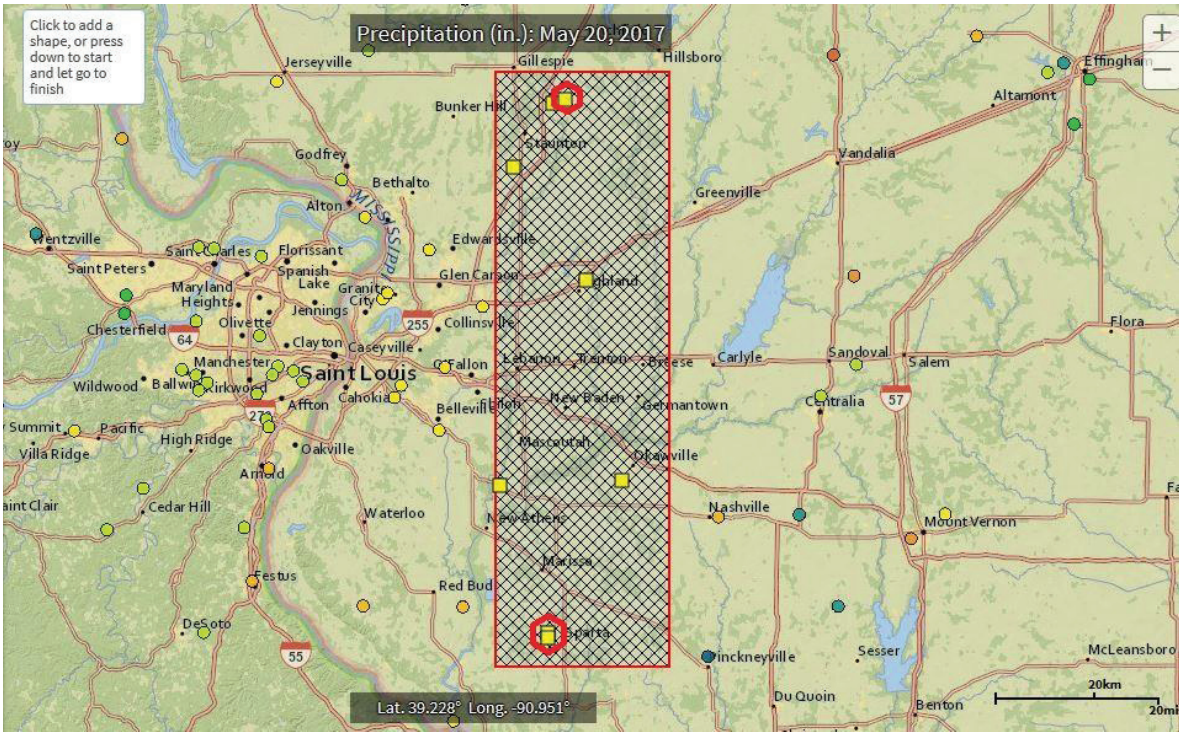

Figure 5: All available weather gage stations within the boundary.

percent is a theoretical ideal condition but not achievable in practice. Criteria of this study and its values are discussed in the conclusion section. Low values indicate better simulations. Positive values indicate model underestimation and negative values indicate model overestimation.

$$PBIAS = 100 * \frac{\sum_{i}^{n} (Qm - Qs)}{\sum_{i}^{n} Qm,i} \qquad (2)$$

Sensitivity analysis means finding the most sensitive parameters and is a critical step in simulation. Sensitivity analysis can be done in two approaches. First, one-at-a-time and second, global sensitivity. In one-at-a-time case, one parameter such as CN2 considered for the sensitivity analysis to find out whether that parameter is sensitive for discharge or not. In global sensitivity most often we need to consider a bunch of parameters because there is no single dominant parameter.

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In hydrological modeling a series of parameters affect the results hence figuring out a limiting criterion for those parameters such as Nash-Sutcliffe is essential hence global sensitivity analysis is a useful method. In this study flow rate were modeled for a period of 14 years (2000-2014), based on daily measured data. Calibration period considered as one-year period (2012-2013). Global Sensitivity analysis has been applied based on Nash-Sutcliffe objective function for this study.

Results and Discussion

Correlation results for gage stations

Two precipitation gage stations used in SWAT model were Stations 386-900 and, 389-900. Precipitation is in daily format in millimeters. Correlation between these two stations presented in Figure 7.a, which has a good compatibility which each other (R^2 = 0.843). Correlation between these two with other stations within the domain presented in (Figure 7, 8) respectively. Based on the correlation results they are in a good range of R^2 values. It means the pattern of meteorological data is evenly distributed. Correlation ratio close to one is a good indicator of compatibility between data for different gage stations. The range of variations for the first station (386-900) vs. other stations is mainly from 0.84 to 0.94. The range of variations for the second station (386-900) vs. other stations is mostly from 0.84 to 0.93

Application of the model

Before any further decision making to improve watersheds in terms of water quality, flood and erosion control or any other environmental aspects firstly we need a well-calibrated model [34-35]. Flowrate calibration is a basic step in further hydrological processes such as underground flow simulation, pollutant fate and transports within the shallow or deep aquifers and sediment transports. These are all mainly related to good calibration of flow rate. By calibrating the flow rate, SWAT model, can be applied in water quality and flood plain delineation. For instance, SWAT model can be used to calibrate the water quality

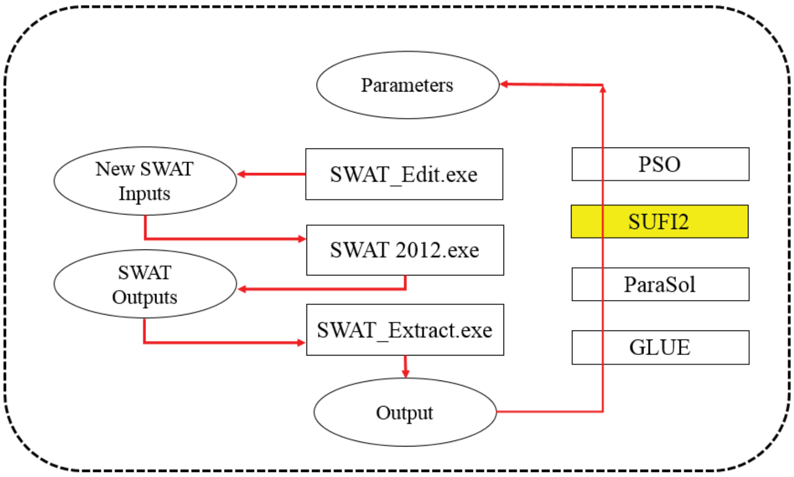

Figure 6: Linkage between SWAT and PSO, SUFI2, MCMC, Parasol and GLUE.

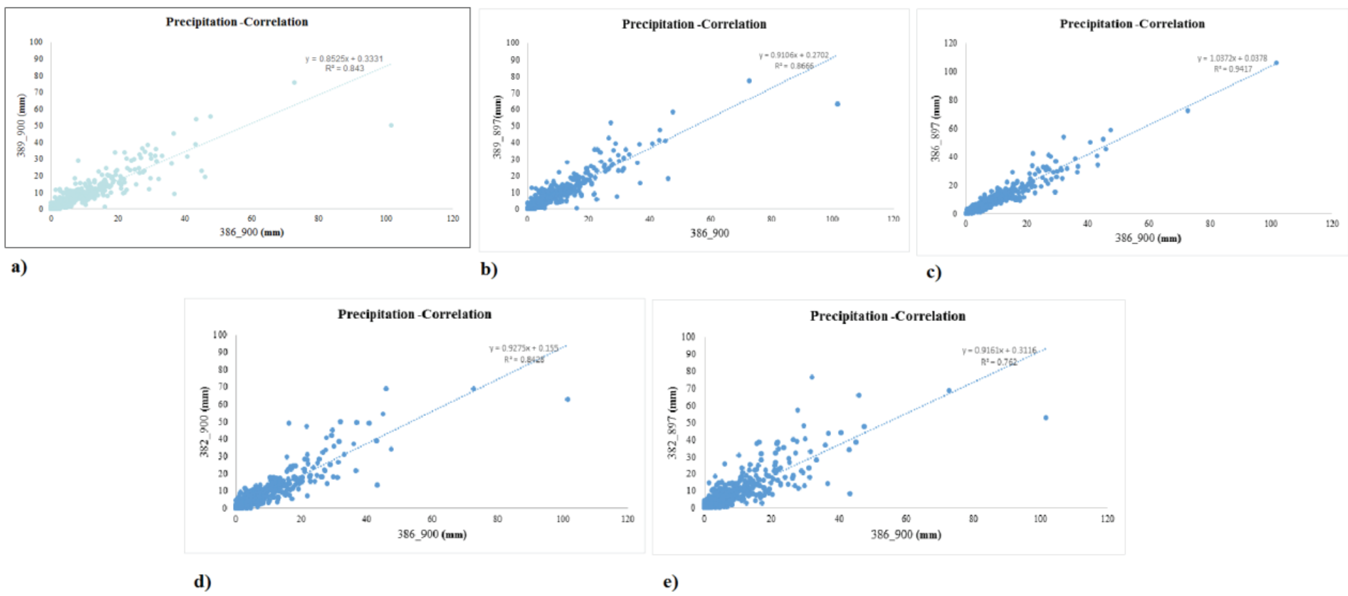

Figure 7: Correlation between first station (386-900) vs. others.

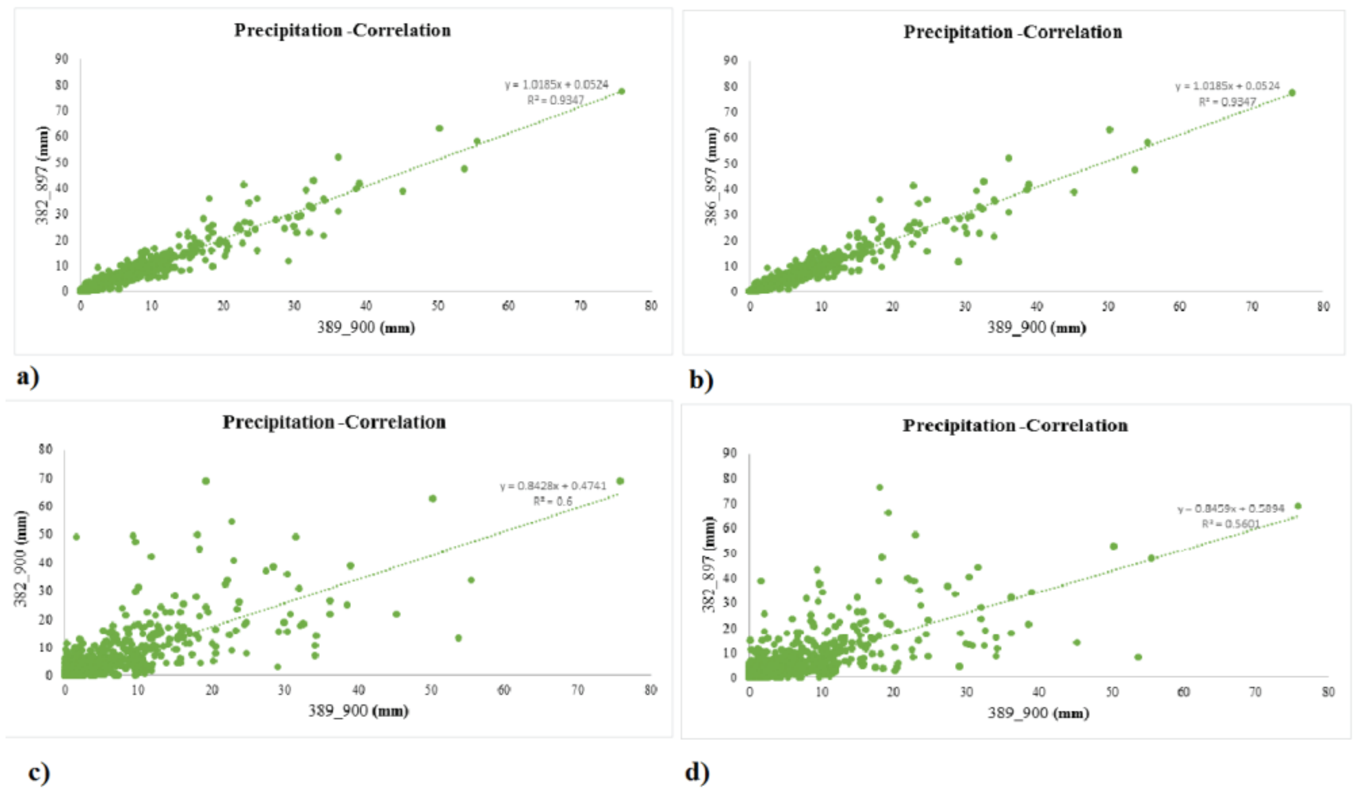

Figure 8: Correlation between second station (389-900) vs. others.

parameters such as nutrients entering the groundwater in the forms of nitrogen (N) and phosphate (P) in different forms. To calibrate the model for such elements discharge should be calibrated. In flood plain delineation based on climatic prediction application (weather generator models for future) the future discharge could be estimated. Erosion control can be estimated based on the amount of the sediment transported and remains in the watershed domain considering tons of sand and clay enters and exits from the main reach and its tributaries.

Uncertainties of the model

Some uncertainties of the model could be attributed to the below categories:

Hydrograph generalizations

Data used to create the hydrograph extracted from hourly data, but daily hydrograph was used to have the model with daily intervals hence some of the errors might occurs because of that averaging procedure.

Missing, or inaccurate precipitation data

There are some days with missing data or inaccurate reading in precipitation data which might results in having higher or lower discharge in simulations in comparison to measured data.

Inaccuracy in observed data

There are some uncertainties due to recording inaccurate measured data of discharge. For instance, if there would be deposition of sediment in the recording gages due to a storm event for the same amount of rainfall gage shows higher water surface elevation (WSE), results in inaccurate discharge reading for the same amount of rainfall.

Conclusion

Results showed simulated flow rate and measured one at the field has a good correlation hence the model is acceptable predicting tool to be expanded for future investigation such as water quality, contaminant and ground water tracking purposes. The results depend on temporal resolution hence, they are presented in daily, weekly, and monthly formats. Based on the root mean of squares error (RMSE), (R^2), NSE, and P-BIAS values, the accuracy of the calibration has been determined. Calibration results for year 2012 presented below based on daily, weekly, and monthly time intervals. Table -1 also shows that R^2 values improved from daily to weekly and from weekly to monthly. Daily results: based on daily results RMSE = 4.78, R^2 = 0.129, NSE = -0.65, P-BIAS = 4.87. Daily calibrated discharge shown in (Figure 9.a). Weekly results: based on weekly results RMSE = 2.12, R^2 = 0.485, NSE = 0.48, P-BIAS = 5.23 Weekly calibrated discharge shown in (Figure 9.b). Monthly calibrated results: based on monthly results RMSE = 0.97, R2 = 0.671, NSE = 0.66, P-BIAS = 4.2. Monthly calibrated discharge shown in (Figure 9.c) [36, 37].

(Table 1) below show the analytical parameters such as root mean squares of errors, correlation ratio etc. which obtained from simulation results. (Table 2) shows the parameters criteria according to Moriasi et al (2007).

Disclosure statement

No potential conflict of interest reported by the author.

Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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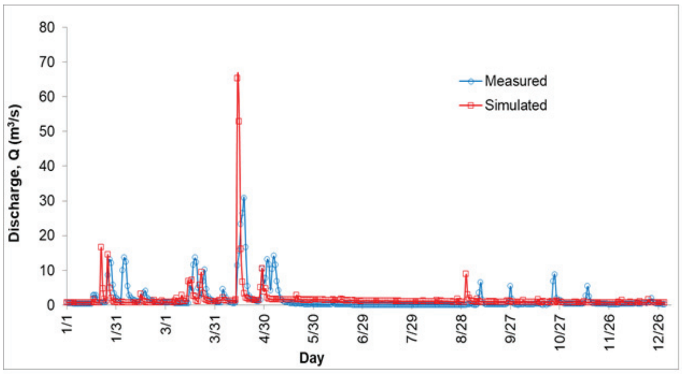
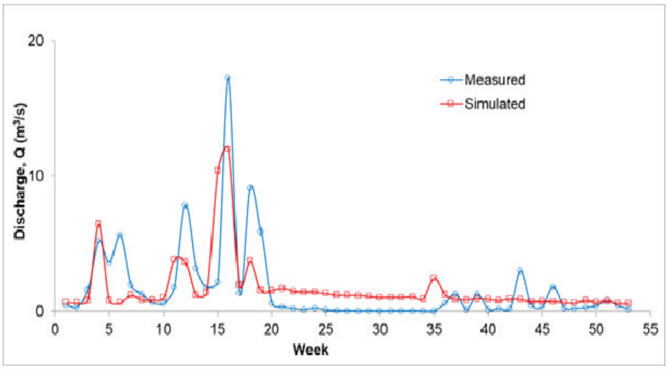
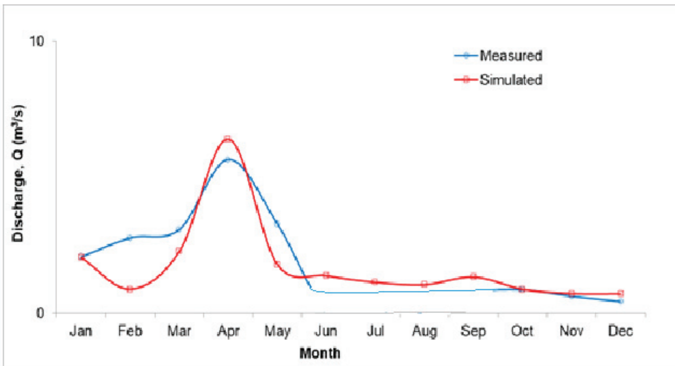


a) Comparison of measured and simulated daily avearge flows, 2012



b) Comparisn of measured and simulated weekly average flows, 2012



c) Comparison of measured and simulated monthly average flows, 2012

Figure 9: Calibration results for year 2012 base on daily, weekly, and monthly data.

Table 1: Statistical analysis parameters obtained based off simulations results.

Year (2012)	RMSE	Correlation (R^2)	NSE	P-BIAS (%)
Daily	4.78	0.129	-0.65	4.78
Weekly	2.12	0.485	0.48	5.23
Monthly	0.97	0.671	0.66	4.21

Table 2: Statistical analysis parameters criteria (Moriasi et al., 2007).

Performance	Correlation (R^2)	NSE	P-BIAS (%)
Very Good	1	0.75 < NSE < 1.00	< 10
Good	-	0.65 < NSE < 0.75	10 < PBIAS < 15
Satisfactory	-	0.5 < NSE < 0.65	15 < PBIAS < 25

Notes on contributors

Farhad Sakhaee is a Ph.D. Candidate in Civil engineering in the field of hydraulic at Saint Louis University. His research interests are hydraulic and hydrological modeling. This work is entirely done by Farhad Sakhaee at Southern Illinois University, Edwardsville, IL, USA. and, has no conflict of interest with other previous simulations.

Abbreviations

SWAT: Soil and Water Assessment Tool: SWAT-CUP: Soil and Water Assessment Tool Calibration and Uncertainty Program: HRU: Hydrological Response Unit: HUCs (Hydrological Unit Codes: DEM: Digital Elevation Model: WSE: Water Surface Elevation: GLUE: Generalized Likelihood Uncertainty Estimation: ParaSol: Parameters Solution: SUFI-2: Sequential Uncertainty Fitting Version-2: USGS: United States Geological Survey; CN2: Initial SCS Runoff Curve Number for Moisture; SOL_AWC: Available Water Capacity of the Soil Layer; ESCO: Soil Evaporation Compensation Factor; RMSE: Root Mean Square Error; NSE: Nash-Sutcliffe; R^2: Correlation; PBIAS: Percentage Bias

References

1. (2015) Upper Silver Creek Watershed Based Plan. Link: https://bit.ly/2MULzQn
2. Abbaspour KC, E.Rouholahnejad S.Vaghefi, R.Srinivasan, Yang H, et al. (2015) A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology, 524: 733-752. Link: http://bit.ly/3d06QTg
3. Faramarzi M, Abbaspour KC, Schulin R, Yang H (2009) Modelling blue and green water resources availability in Iran. Hydrological Processes: An International Journal 23: 486-501. Link: https://bit.ly/2MGdHXt
4. Faramarzi M, Karim C.Abbaspour, Saeid Ashraf Vaghefi, Mohammad RezaFarzaneh, Alexander J.B.Zehnder, et al., (2013) Modeling impacts of climate change on freshwater availability in Africa. Journal of Hydrology 480: 85-101. Link: http://bit.ly/2Lz4xez
5. Abbaspour K (2011) SWAT-CUP2: SWAT Calibration and Uncertainty Programs Manual Version 2. Eawag. Swiss Federal Institute of Aquatic Science and Technology, Department of Systems Analysis. Integrated Assessment and Modeling (SIAM), Duebendorf, Switzerland 106. Link: https://bit.ly/3rDXi4E
6. Abbaspour K, Van Genuchten MT, Schulin R, Schläppi E (1997) A sequential

uncertainty domain inverse procedure for estimating subsurface flow and transport parameters. Water Resources Research 33: 1879-1892. Link: https://bit.ly/3rAFveu

7. Abbaspour KC, Schulin R, Schläppi E, Flühler H (1996) A Bayesian approach for incorporating uncertainty and data worth in environmental projects. Environmental Modeling & Assessment 1: 151-158. Link: https://bit.ly/36XtzM4
8. Abbaspour KC, Jing Yang, Ivan Maximov, Rosi Siber, Konrad Bogner, et al. (2007) Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. Journal of hydrology 333: 413-430. Link: http://bit.ly/2LzEC6y
9. Moriasi DN, Jeff Arnold, Michael W. Van Liew, Ron Bingner, Tamie L. Veith, et al. (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50: 885-900. Link: http://bit.ly/3jAYRxu
10. Shouse P, Jobes J, Sisson J, Ellsworth T (1992) Estimating in situ unsaturated hydraulic properties of vertically heterogeneous soils. Soil Science Society of America Journal 56: 1673-1679. Link: https://bit.ly/2Z3xRgl
11. Sisson JB, van Genuchten MT (1991) An improved analysis of gravity drainage experiments for estimating the unsaturated soil hydraulic functions. Water resources research 27: 569-575. Link: https://bit.ly/3q5TwAl
12. Abbaspour KC, Johnson C, Van Genuchten MT (2004) Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure. Vadose Zone Journal 3: 1340-1352. Link: http://bit.ly/3a63qg4
13. Bell L, Binning PJ, Kuczera G, Kau P (2002) Rigorous uncertainty assessment in contaminant transport inverse modelling: a case study of fluoride diffusion through clay liners. Journal of contaminant hydrology 57: 1-20. Link: http://bit.ly/36ZXSlg
14. Beven K, Binley A (1992) The future of distributed models: model calibration and uncertainty prediction. Hydrological processes 6: 279-298. Link: https://bit.ly/2MPQbap
15. Bicknell BR, Imhoff JC, Kittle Jr JL, Donigian Jr AS, Johanson RC, et al. (1996) Hydrological simulation program-FORTRAN. user's manual for release 11. US EPA. Link: https://bit.ly/3q8Xet1
16. Gurtz J, Baltensweiler A, Lang H (1999) Spatially distributed hydrotope□ based modelling of evapotranspiration and runoff in mountainous basins. Hydrological Processes 13: 2751-2768. Link: https://bit.ly/3aUEbwc
17. Hargreaves GH, Samani ZA (1985) Reference crop evapotranspiration from temperature. Applied engineering in agriculture 1: 96-99. Link: https://bit.ly/3jHlzUv
18. Press W, Teukolsky S, Vetterling W, Flannery B (1992) Numerical Recipes in C". Cambridge University Press. Link: https://bit.ly/2Z4A7nQ
19. Ajami NK, Duan Q, Sorooshian S (2007) An integrated hydrologic Bayesian multimodel combination framework: Confronting input, parameter, and model structural uncertainty in hydrologic prediction. Water Resources Research 43. Link: https://bit.ly/3a3S5gf
20. Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrologic modeling and assessment part I: model development 1. JAWRA Journal of the American Water Resources Association 34: 73-89. Link: https://bit.ly/3cXJn53
21. Bates BC, Campbell EP (2001) A Markov chain Monte Carlo scheme for parameter estimation and inference in conceptual rainfall□runoff modeling. Water resources research 37: 937-947. Link: https://bit.ly/3rwm9XY
22. Bayarri MJ, James OB, Rui Paulo, Jerry Sacks, John AC, et al. (2007) A framework for validation of computer models. Technometrics 49: 138-154. Link: https://bit.ly/3tHR31t
23. Bekele EG, Nicklow JW (2005) Multiobjective management of ecosystem services by integrative watershed modeling and evolutionary algorithms. Water Resources Research 41. Link: https://bit.ly/2NdB4al
24. Yang J, Reichert P, Abbaspour KC, Xia J, Yang H (2008) Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China. Journal of Hydrology 358: 1-23. Link: http://bit.ly/3jHRMv2
25. Rouholahnejad E, K.C.Abbaspour, M.Vejdani, R.Srinivasan, R.Schulin, et al. (2012) A parallelization framework for calibration of hydrological models. Environmental Modelling & Software 31: 28-36. Link: http://bit.ly/3a3Yg3W
26. Ashraf Vaghefi S, Mousavi S, Abbaspour K, Srinivasan R, Yang H (2014) Analyses of the impact of climate change on water resources components, drought and wheat yield in semiarid regions: Karkheh River Basin in Iran. hydrological processes 28: 2018-2032. Link: https://bit.ly/3p7vRhZ
27. Arabi M, Govindaraju RS, Hantush MM (2006) Cost-effective allocation of watershed management practices using a genetic algorithm. Water Resources Research 42. Link: https://bit.ly/2LGmQyG
28. Bracmort KS, Arabi M, Frankenberger J, Engel BA, Arnold JG (2006) Modeling long-term water quality impact of structural BMPs. Transactions of the ASABE 49: 367-374. Link: https://bit.ly/36Z0xM1
29. Della Cioppa A, De Stefano C, Marcelli A (2004) On the role of population size and niche radius in fitness sharing. IEEE Transactions on Evolutionary Computation 8: 580-592. Link: http://bit.ly/3rE2yVN
30. Emerson CH, Welty C, Traver RG (2005) Watershed-scale evaluation of a system of storm water detention basins. Journal of Hydrologic Engineering 10: 237-242. Link: https://bit.ly/3tEld5L
31. Gill MK, Kaheil YH, Khalil A, McKee M, Bastidas L (2006) Multiobjective particle swarm optimization for parameter estimation in hydrology. Water Resources Research 42. Link: https://bit.ly/3p7CNvh
32. Bogner WC (1982) Sedimentation Survey of Highland Silver Lake, Highland, Illinois, Illinois State Water Survey. Link: https://bit.ly/2Z1tSAS
33. Winchell M, Srinivasan R, Di Luzio M, Arnold J (2013) ArcSWAT interface for SWAT2012. User's Guide. Blackland Research Center, Texas AgriLife Research, College Station 1-464. Link: http://bit.ly/3tN2sNi
34. Abbaspour KC (2013) SWAT-CUP 2012. SWAT Calibration and Uncertainty Program—A User Manual.
35. Sakhaee F (2020a) Bankfull discharge estimation for Fishpot Creek. Technium: Romanian Journal of Applied Sciences and Technology 2: 74-91. Link: https://bit.ly/2Z3dyzH
36. Sakhaee F (2020b) Steady and unsteady flow simulation with SRH-2D. Journal of Ocean Engineering and Science. 5: 297-309. Link: http://bit.ly/3aMNApE
37. Sakhaee F, Khalili F (2020) Sediment pattern & rate of bathymetric changes due to construction of breakwater extension at Nowshahr port. Journal of Ocean Engineering and Science 6: 70-84. Link: http://bit.ly/3rGudFG