National Technical University of Athens
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Article Cover letter

Dear Editor,

We would like to submit the revised version of our paper “Hydrological modeling using the SWAT Model in urban and peri-urban environments: The case of Kifissos experimental sub-basin (Athens, Greece)” by Evgenia Koltsida, Nikos Mamassis, and Andreas Kallioras.

We believe we emphasized the novelty of our study and its potential impact and that we followed all the proposed corrections by the reviewer that substantially improved the article. We are looking forward to hearing from you concerning the review process. We would also like to thank Ref. #1 for accepting our manuscript as is.

We confirm that this manuscript has not been published elsewhere and is not under consideration by another journal. The authors have no conflicts of interest to disclose and have all approved this submission.

Thank you for your time and consideration.

Sincerely,
Evgenia Koltsida, M.Sc.

Reply to comments of Referee #2

We thank Referee #2 for reviewing our manuscript and for giving comments and suggestions. Our answers are given in blue, below, while the original text of the review was kept in black.

Comments

General comment

The authors have evaluated the impacts of different precipitation resolution (daily and sub-daily) and runoff simulation methods (Curve Number and GAML) on SWAT simulations in the upper part of the Kifissos River Basin, Athens Greece. The topic is interesting, but the presentation of results (figures and tables) and discussion needs to be improved. Besides that, the contribution of this study is marginal and not up to the HESS's standard. I can't really find any new innovative elements in the manuscript. I personally feel that this manuscript is more suitable for a normal journal rather than HESS, unless the authors make a major revision by adding some new contributions, i.e., testing conditions or elements that have yet to consider in previous studies, development a better framework in characterize the uncertainty of methods or inputs in SWAT modelling, or improvement of SWAT in simulation of urban and peri-urban environment.

Reply: We thank the referee for the constructive feedback and comments. We will re-organize the Introduction and Results and Discussion sections. We will explain the study's objectives and novelty and emphasize the importance of the specific study area in the Introduction section. In addition, we will discuss the sources of uncertainty more accurately in the Results and Discussion section. We will also explain the figures, and we will improve the writing of the revised manuscript. We will make the suggested changes in the following comments.

Please find my comments as follows:

Comment #1

Line 71: I would expect to see the usage of the SWAT+ model since it has already been released last year.

Reply: We thank the referee for the suggestion. The option for sub-daily simulation in SWAT+ model is currently being worked on and should be available hopefully in the next release. We would like to test the model in the near future.

Comment #2

Lines 72 – 77: Too many objectives. Besides that, I am unable to see the novelty of this study. The comparisons of different precipitation resolution and runoff simulation methods on SWAT simulations have been widely conducted by previous studies as stated in lines 53-70, it seems like the authors just repeat the same thing. Ideally, the authors should propose a new framework or method to better quantify the uncertainties.

Reply: We thank the referee for the insightful comments and suggestions. We agree with the referee that the aims and novelty of this study should be emphasized more. Therefore, we will reorganize the Introduction and Results sections and discuss the many sources of uncertainty in this study in the revised manuscript. It is worth noting that this study aims to understand and estimate the hydrological components of the area and will establish a basis for further modeling applications. We will make the following changes in the revised manuscript:

Lines 72-77: "The selected study area has been severely urbanized from 1990 till today, at the expense of forests and agricultural areas. During this period, the artificial surfaces increased by 69.93%, and the agricultural areas and the forests decreased by 54.14% and 14.34%, respectively (Corine Land Cover, CLC 1990-2018). The area is portrayed as an urban/peri-urban system with about 51% of artificial surfaces, 13% of agricultural areas, and 36% of forests and semi-natural areas. The interaction between different land uses (e.g., urban and rural characteristics) contributes to the formation of a complex environment characterized by high variability in management practices, rapid response, and diverse hydrological processes, which may increase problems of model uncertainties (Boithias et al., 2017). Land use maps and soil maps may not capture this complex environment precisely, enhancing the SWAT model's difficulty in representing and simulating the actual conditions of the basin, which can affect water discharge. In addition, the study area is a typical Mediterranean catchment, vulnerable to natural hazards (i.e., flash floods and forest fires). In order to interpret the behavior of such a complex environment, the SWAT 2012 hydrological model (rev 681) was used for its realistic representation. The available studies that used the sub-daily option of the SWAT model refer mainly to agricultural (Bauwe et al., 2016; Boithias et al., 2017; Cheng et al., 2016; Ficklin and Zhang, 2013; Golmohammadi et al., 2017; Maharjan et al., 2013; Yang et al., 2016; Yu et al., 2018) or small urban catchments (Campbell et al., 2018; Jeong et al., 2010; Li and DeLiberty, 2020) and rarely in peri-urban catchments. Thus, the suitability of the sub-daily option of the SWAT model to simulate discharge in a peri-urban catchment has not been extensively tested. The main objectives were (i) to investigate which parameters are more sensitive under different temporal time steps in a mixed-land-use basin (i.e., blended combinations of land use, management practices, and hydrological processes), (ii) to compare the results of the hourly time-step simulation (Green and Ampt Mein Larson method) to those obtained from daily time-step simulation (Curve Number method) and (iii) evaluate the sub-daily option of the SWAT model for discharge simulation by examining peak discharges and time of the peak of selected rainfall events. The calibration methodology developed in this catchment can be applied to areas with similar hydrological-meteorological and geomorphological attributes (i.e., Mediterranean peri-urban areas). This study provides essential hydrological knowledge and contributes to understanding the critical processes of an urban/peri-urban system to analyze the mechanisms governing surface runoff at the catchment scale. The outcomes will establish a basis for further modeling applications, which will be helpful for local planners to use in future regional urban development strategies. The study area information, methodology, and data input are presented in Section 2, results and discussions are detailed in Section 3, and conclusion is provided in Section 4.”

Comment #3

Line 110: What is the accuracy of the 2018 Corine land cover map?

Reply: The mapping methodology used in CLC 2018 was the same as in CLC 2012. More than 15 countries larger than 90.000 km^2 were evaluated separately, while countries smaller than 90.000 km^2 were grouped together (7 groups). Independent experts evaluated more than 25.000 sampling locations. Overall, the results showed that the 85% target accuracy has been achieved; however some differences between countries exist, due to geographic complexity. Table 1 presents the characteristics of the CLC 2018.

Table 1. Corine land cover characteristics (Corine Land Cover, 2018).

Product characteristics	Corine Land Cover (CLC) 2018
Satellite data	Sentinel-2 and Landsat-8 for gap filling
Time consistency	2017-2018
Geometric accuracy, satellite data	≤ 10 m (Sentinel-2)
Min. mapping unit/width	25 ha / 100 m
Geometric accuracy, CLC	better than 100 m
Thematic accuracy, CLC	≥ 85%
Change mapping (CHA)	boundary displacement min.100 m; all changes ≥ 5 ha are to be mapped
Thematic accuracy, CHA	≥ 85%
Production time	1.5 years
Documentation	standard metadata
Access to the data (CLC, CHA)	free access for all users
Number of countries involved	39

Comment #4

Lines 115-118: I would suggest the authors to collect up-to-date hydro-climatic data for longer calibration and validation periods.

Reply: We thank the referee for the suggestion. The monitoring station was installed at the end of 2017 and provided discharge data from 01/01/2018 to 31/12/2019. Before this date, there were no discharge measurements, and the estimation of the water balance components of the area was not feasible. We know that the time period is not long, but there were no observed discharge data in this area. Therefore, due to data availability, we split the data from 01/01/2018 to 31/12/2018 for calibration and from 01/01/2019 to 31/12/2019 for validation. In the future, we intend to update the calibration and validation periods when more data becomes available.

Comment #5

Lines 163-164: It would be better to conduct calibration from 2018 to 2019 and validation from 2020 to 2021.

Reply: We agree with the referee. In the future, we intend to update the calibration and validation periods when more data becomes available (See also Comment #4).

Comment #6

Lines 191-193: This sentence has been described in lines 163-165. Can consider to remove it.

Reply: We agree with the referee. We will remove this sentence in the revised manuscript.

Comment #7

Line 263: Is the "infiltration" correct term? Suppose methods for runoff simulations. Right?

Reply: We agree with the referee, we will make the following changes in the revised manuscript.

Line 263: "Figure 2a and Figure 2b show the temporal dynamics of the hydrographs reproduced by both runoff estimation methods."

Comment #8

Lines 269-273: This part should describe about the differences in statistical values between CN and GAML methods. Not only the results for the CN method.

Reply: Lines 269-273 describe the performance statistics for the daily model, the hourly model, and the aggregated hourly to daily model. The main difference between the daily and the hourly model in SWAT is that surface runoff is estimated using the CN method in the daily model and the GAML method in the hourly model. Hence, by describing the differences between the daily and the hourly model, we also compared the performances of the CN and GAML method, respectively. We thank the referee, and we will clarify the differences between the two models in the revised manuscript.

Comment #9

Line 285 Figure 2: Need to be more specific when labelling each sub-figure. For example, I am not sure sub-figure (a) refer to what condition, calibration, validation or any infiltration methods.

Reply: We agree with the referee. We will update the Figure caption. We merged Figures 2 and 3. We will make the following changes in the revised manuscript:

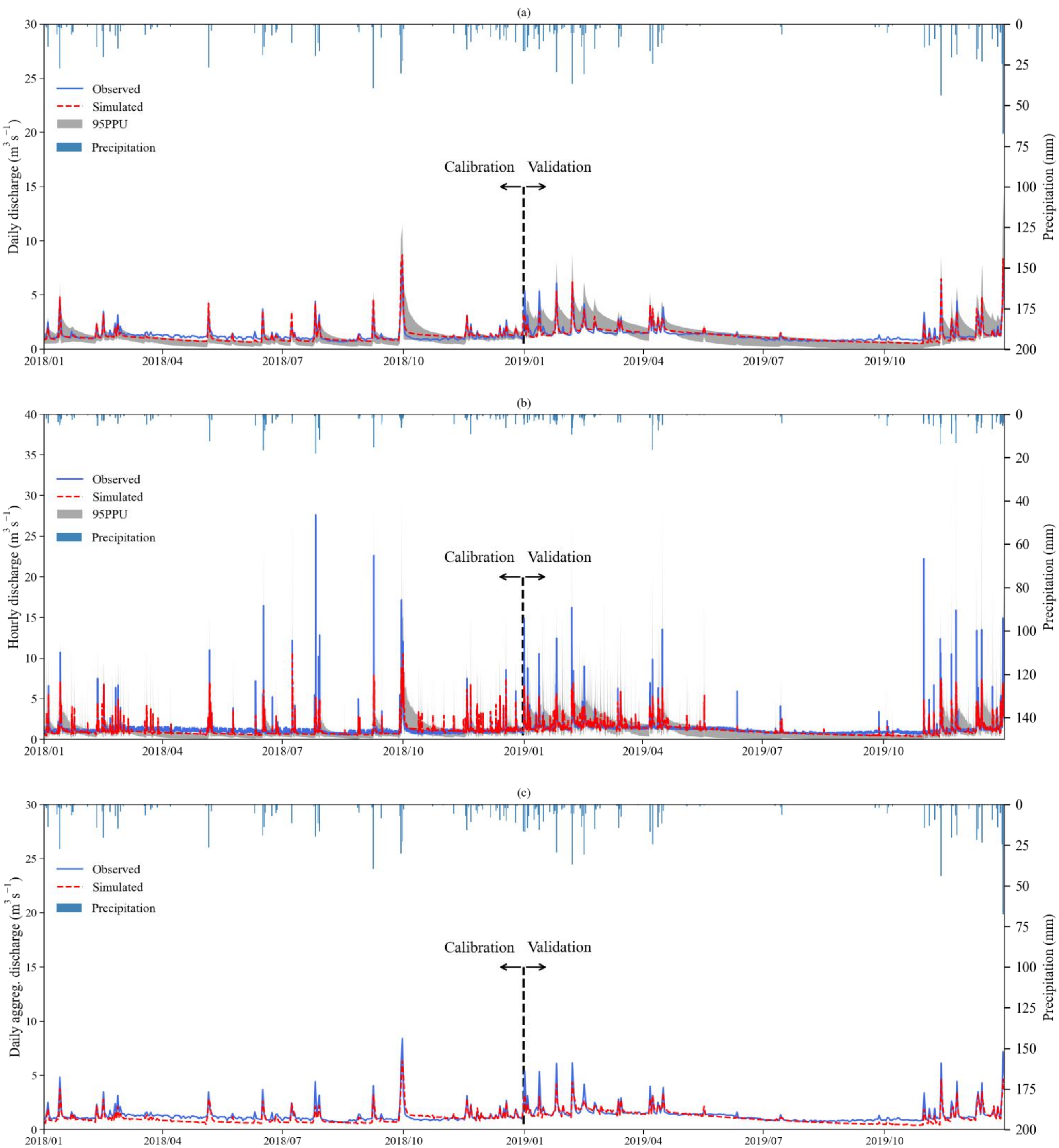

Figure 1. Observed and simulated discharge (m^3s^{-1}) during calibration and validation periods: daily time step (a), hourly time step (b), and daily time step aggregated from hourly outputs (c). The CN method with daily rainfall observations was used for the daily model and the GAML method with hourly rainfall observations was used for the hourly model.

Comment #10

Line 285 Figure 2(c, d): It seems like SWAT underestimated peak flows simulated under hourly scale. Any justification for this situation?

Reply: Figure 2 (c, d) (Figure 2b in the revised manuscript) shows that the hourly model produced lower peak flows than the daily model. We believe these results could be explained by disadvantages of the GAML method, errors in the input data, uncertainties in the observed data, and characteristics of the study area.

We will make the following changes in Results and Discussion section.

3.3 Comparison of selected rainfall events.

Lines 301-308: "Figure 4 shows the hydrographs of selected high rainfall events that occurred in the years 2018 and 2019 (Tatoi station, Lagouvardos et al., 2017). According to the study area's intensity-duration-frequency (IDF) curves the approximate return period of the selected episodes was ten years (T=10 years). These events were investigated to examine the accuracy of the sub-daily model and to compare the peak discharges and time of the peak of the two models. Table 6 displays the rainfall characteristics of each event (i.e., peak discharge, time of peak, and average discharge).

Generally, the hourly model underestimated the peak flows with values much lower than the observations for the majority of the events. These results confirm that the daily model using the CN method estimated better the observed values than the hourly model using the GAML method and was able to estimate with greater accuracy the peak discharge in most of the events. In addition, Figure 5 (a-c) shows that the discharge simulation improved after the main peak discharge event, especially in the last peaks. The improvement of the simulation as the rainfall events progressed indicates that the simulation requires time to adapt to the hydrological processes and conditions of the catchment (e.g., antecedent soil moisture conditions). These outcomes are similar to those of previous studies, which concluded that the best sub-daily performance for streamflow simulation appeared in wet antecedent soil moisture conditions and suggested that the GAML method needs to improve the equation for infiltration routine (Jeong et al., 2010; Kannan et al., 2007; Meaurio et al., 2021)."

We will also revise the Discussion and Conclusion sections in the following comments.

Comment #11

Line 296 Table 5: The authors should include the statistical results for both the CN and GAML simulations.

Reply: Table 5 presents the statistics of the daily, sub-daily, and daily aggregated from hourly outputs SWAT models for the calibration and validation periods. The CN method with daily rainfall observations was used for the daily model, and the GAML method with hourly rainfall observations was used for the hourly model. The statistical results of the daily and hourly model reflect the performance of the CN and GAML method, respectively. We thank the referee and will emphasize the difference between the two models in the revised manuscript.

Comment #12

Lines 303-304: A comparison of the simulated flows under both the CN and GAML methods should be displayed in figures. In short, the quality of figures need to be improved.

Reply: The CN method with daily rainfall observations was used for the daily model and the GAML method with hourly rainfall observations was used for the hourly model. Therefore, Figure 4 shows the hydrographs of selected high rainfall events that occurred in the years 2018 and 2019 using the GAML method. We will clarify this in the Figure caption.

Line 303-304: "Figure 2. Observed and simulated hourly discharge (m^3 s^{-1}) using the GAML method for the heavy rainfall events that occurred in 2018 and 2019: (a) event from 12/01-14/01/2018; (b) event from 05/05-07/05/2018; (c) event from 29/09-01/10/2018; (d) event from 05/02-07/02/2019; (e) event from 12/11-14/11/2019; (f) event from 29/12-31/12/2019."

Comment #13

Lines 308-318: As mentioned earlier, many studies have compared the performance of CN and GAML in SWAT simulations and concluded that the CN method had a better performance. The authors only reported the same finding that already been confirmed in literature. So, what is the contribution of this study to the current knowledge on this topic?

Reply: The available studies that used the sub-daily option of the SWAT model refer mostly to agricultural (Bauwe et al., 2016; Boithias et al., 2017; Cheng et al., 2016; Ficklin and Zhang, 2013; Golmohammadi et al., 2017; Maharjan et al., 2013; Yang et al., 2016; Yu et al., 2018) or small urban catchments (Campbell et al., 2018; Jeong et al., 2010; Li and DeLiberty, 2020) and rarely in peri-urban catchments. Therefore, the suitability of the sub-daily option of the SWAT model to simulate discharge in a peri-urban catchment has not been extensively tested. Brighenti et al. (2019) concluded that the requirement of high-resolution input data, which is necessary for the sub-daily simulation, is the main challenge. In general, we believe that the application of the SWAT sub-daily option is a critical topic, and it is limited, especially in peri-urban catchments. Sub-daily calibration and validation are also limited; therefore, we believe this study will help other SWAT users with similar case studies to choose the most sensitive parameters and provide them with a calibration methodology. The outcomes will establish a basis for further modeling applications, which will be helpful for local planners to use in future regional urban development strategies. Overall, the results of our study suggest that the hourly option of the SWAT still needs improvement in timing-related routines and antecedent soil moisture conditions estimation. In the future, when more data becomes available, more events will be analyzed in order to investigate a correlation between antecedent moisture conditions and hourly model performance.

Comment #14

Line 320: Since the GAML method had a poorer performance than the CN method, I was wondering why the authors still applied the GAML method to assess the influence of daily and hourly scales precipitation data in SWAT modelling.

Reply: We thank the referee for highlighting this issue. Modeling results are very useful for managers and stakeholders for urban planning management. However, results at a daily or monthly time step may not capture accurately the intensity of precipitation and the distribution of the hydrological processes. The CN method which is used for daily models does not account for rainfall intensity and duration, only total rainfall volume (King et al., 1999). Therefore, results at a sub-daily time step may be sufficient to capture the rapid response of peri-urban catchments. The CN method with daily precipitation data inputs was used for the daily model and the GAML method with sub-daily (hourly) precipitation data inputs was used for the sub-daily (hourly) model. We selected the SWAT model (Arnold et al., 2012) because it can perform long-term continuous simulation at a sub-daily time step and can also simulate single events which are important to understand and analyze runoff generation at the catchment scale. Since it first release, the SWAT model has been improved with algorithms for streamflow, erosion and sediment simulation (Jeong et al., 2014, 2010). In the near future, the new version SWAT+ will include algorithms for continuous sub-daily simulation and we would like to test its suitability (Bieger et al., 2017).

Comment #15

Line 331: I would expect to read more about the urban/peri-urban environment as stated in title and objective, but the description is relatively limited in the manuscript. One of the novelties that the authors can consider is the improvement or modification of SWAT simulations in urban/peri-urban environment. Otherwise, I don't think this manuscript is suitable to be published in HESS.

Reply: We thank the referee for the suggestions. We will present the many sources of uncertainty that exist in the study area, explain the results, and emphasize the study's importance in the Introduction, Results& Discussion, and Conclusion sections. We will make the following changes in the Results& Discussion and Conclusion sections.

Results and Discussion

3.3 Comparison of selected rainfall events

Lines 319-333: "Hydrological calibration includes uncertainties due to conceptual simplification, processes not incorporated in the model, and unknown processes to the modeler which interfere with the natural behavior of the system (Abbaspour et al., 2015). In this study, the sources of uncertainty can be explained by:

(i) The characteristics of an urban/peri-urban catchment. The study area is a hybrid landscape in which urban and rural characteristics coexist and interact. The different and changing land uses create a complex system with high variability in management practices and diverse hydrological processes (Becker et al., 2019). Furthermore, these systems are characterized by man-made interventions (e.g., unidentified discharges, agricultural activities, and dumping of construction materials), which are not well known to the modeler and increase uncertainty (Immerzeel and Droogers, 2008).

(ii) The inaccuracies in the quality of input and observed data. The interaction between the urban environment and agricultural activities may not be captured by the resolution of the soil and land use maps. This could increase the difficulty for the SWAT model to represent the actual conditions of the study area and further affect the results. The spatial variability of precipitation and discharge were not also captured accurately by the monitoring stations of the study area, which could have contributed to the simulation uncertainty. In addition, inaccuracies in the estimation of channel and hillslope velocities and channel geometry, in the nature of the sensor, environmental conditions, and data collection can generate variability, lead to undesired trends, and influence the model results (Guzman et al., 2015; Kamali et al., 2017).

(iii) The differences behind the mechanisms of the CN method and the GAML method for surface runoff estimation. In this study, the daily model produced higher discharge peaks than the hourly model and generally estimated better the observed values. These results could be explained by the disadvantages of the GAML method. The CN method requires minimum land use, soil, elevation, and daily rainfall data as input. On the other hand, the GAML method requires detailed soil information and high-resolution rainfall data in a sub-daily time step as input which can be challenging and difficult to obtain (King et al., 1999). The GAML method also assumes that the soil profile is characterized by homogeneity and that the previous soil moisture is distributed uniformly in the soil profile (Jeong et al., 2010). In addition, according to the GAML method, when the precipitation rate is less than the infiltration rate, all precipitation will infiltrate the soil profile (Ficklin and Zhang, 2013; King et al., 1999). Figure 2 reflects the assumption of the GAML method that surface runoff is estimated only when the precipitation rate is greater than the infiltration rate. Hence, the uncertainty in the resolution of the rainfall data, the heterogeneity of the soil formations, the size of the catchment, and the upcoming difficulty in determining the parameters' values for parameterization could affect the method's efficiency (Jeong et al., 2010). The selection of sub-daily precipitation input time step as well as the resolution of the precipitation data have a significant impact on model results when using the GAML method, and it should be based on the scale and characteristics of the watershed (Bauwe et al., 2016; Kannan et al., 2007).

(iv) The conceptual simplifications made during the model parameterization process. The initial ranges of the calibrating parameters were set according to literature and sensitivity analysis. Then, based on the performance of the default model, specific parameters were parameterized using calibration protocols (Abbaspour et al., 2015). The ranges of the calibrating parameters should be kept within reasonable limits using quantitative statistics and graphical comparisons to ensure that hydrological processes represent the characteristic of the study area (Daggupati et al., 2015). The choice of the objective function and the selection of the values of the parameters that influence surface runoff, groundwater, channel routing, and evapotranspiration is a critical point in model calibration which can increase the uncertainty of the results (Polanco et al., 2017)."

Conclusion

Lines 356-371: "Quantitative statistics of the observed and the simulated records indicate that the calibration and validation processes produced acceptable results for both runoff estimation methods. Additionally, graphical techniques at the outlet station show that both models succeed in capturing the majority of seasonality and peak discharge. Generally, the daily model performed better than the sub-daily model in simulating runoff. The CN method produced higher discharge peaks than the GAML method and estimated better the observed values. In particular, from the comparison of the selected rainfall events, it is also evident the critical role of the antecedent soil moisture conditions of the catchment and their impact on sub-daily performance, indicating the need for improvement of the SWAT sub-daily option for soil moisture estimation. The differences in the calibrated values of the two models lay mostly in the different runoff estimation methods used by the two models. In addition, errors in the quality of input data, diverse management practices and hydrological processes of an urban/peri-urban environment, unknown processes to the modeler, and conceptual simplifications made during the model structure/calibration process may increase the uncertainty of the outputs.

Overall, the general agreement between observations and simulations in both models suggests that the SWAT model appears to be a reliable tool for predicting discharge in a mixed-land-use basin with high complexity and spatial distribution of input data. This study contributed to understanding the mechanisms controlling surface runoff and the parameters that influence the hydrological processes that take place in an urban/peri-urban hydrological environment. Furthermore, the results of this study could help planners and managers to decide which time step is more useful regarding their goals and will provide a calibrated tool to assess potential hydrological impacts of future planning and development activities. However, it should be noted that several factors such as data limitation, observational errors in input data, spatial and temporal scales complexities, and inaccuracies in model structure may lead to uncertainty in model outputs. In the future, emphasis will be placed on the investigation of a correlation between antecedent moisture conditions and hourly model performance when more data becomes available and onquantifying the parameter uncertainty by including more observed variables in the calibration process, such as evapotranspiration and soil moisture satellite data."

Comment #16

Line 336 Figure 5: Again, I am not sure these simulations are actually based on which precipitation resolution and runoff method.

Reply: Figure 4 shows the observed and simulated hourly hydrographs of selected high rainfall events that occurred in the years 2018 and 2019 using the GAML method. We will emphasize the method in the figure caption.

Line 336: "Figure 4. Observed and simulated hourly discharge ($m^3\ s^{-1}$) using the GAML method for the heavy rainfall events that occurred in 2018 and 2019: (a) event from 12/01-14/01/2018; (b) event from 05/05-07/05/2018; (c) event from 29/09-01/10/2018; (d) event from 05/02-07/02/2019; (e) event from 12/11-14/11/2019; (f) event from 29/12-31/12/2019."

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