Does the simple dynamical systems approach provide useful information about catchment hydrological functioning in a Mediterranean context? Application to the Ardèche catchment (France)

M. Adamovic, I. Braud, F. Branger, and J. W. Kirchner

A peer review

Summary

The manuscript by Adamovic et al. adjusts the data driven approach of Kirchner (2009) in a Mediterranean environment. This paper provides valuable information and data for the analysis of the Kirchner method in the Mediterranean area. The Kirchner method has already been applied at different locations and environments like Wales (Kirchner, 2009), Alzette (Krier,2012) and the Swiss prealpines (Teuling, 2010). This approach has not yet been assessed in a Mediterranean environment. Therefore I support the publication of the paper, however I suggest some minor improvements. The suggestions are particularly in the analysis of evapotranspiration in the model, taking into account other parameters like hydrophobic conditions in dry environments and the structure of the article.

The study takes places in the Ardèche, France, at four different catchments. The Kirchner method applies an equation where discharge and water storage in a catchment can directly be connected. In this way the precipitation rate can be estimated based on discharge changes. This method is applied in the Ardèche and shows a good simulation of discharge during the wet periods. However, in dry periods (especially summer) the simulation does not correspond well with the observed values. This is probably due to the high influence of evapotranspiration conditions and imprecise measurements during the dry periods. The author suggests to improve the actual evapotranspiration rate in the Kirchner model and to explore more significant parameters on the hydrological cycle, like geology and land use.

Overall the paper is clearly written, however the structure of the article is a bit chaotic. At the beginning of each paragraph a short summary explains clearly the structure of the paragraph. However the wide explanations make it sometimes difficult to find out the main point, for example in paragraph 2 where the Kirchner method (2009) is explained. I think a short clear conclusion at the end of each paragraph will improve the clarity of the paper. More detail about the structure is mentioned later in this review.

The tables of the article are well constructed and adjust comprehension to the article. In general the figures illustrate the model simulations well, however some figures have a overload of information and colours(see specific recommendations).

Problems

The paper takes into account different important factors for the simulation of precipitation and discharge, like the impact of using different equations (choosing Turc (1954) or Fu (1981)), however in my opinion some important factors could be explained more widely or clearly.

Firstly I would like to zoom in at the strong influence of evapotranspiration during summer on the simulations. The high influence of evapotranspiration during summer is also mentioned in other papers (Krier, 2012; Teuling, 2010). Having knowledge of a poor correlation in the model of precipitation and discharge during summer caused by evapotranspiration. Still the actual evapotranspiration(AET) is assumed to be equal to potential evapotranspiration(PET). Other factors like soil moisture (Huza, 2014) and hydrophobic conditions (Martínez-Murillo, 2006) of the soil can have a high influence on the discharge. The explanation of the used parameters (precipitation, discharge) in the simulation is well done, however I suggest that the realistic influence of AET and PET is better explained for a better comprehension why the assumption AET=PET is made. Also it would be nice to look at the possible hydrophobic factors as described below, I think it can have a significant adjustment in paragraph 5.3.2 for the discussion.

Martínez-Murillo (2006) illustrates that at the end of a long dry summer in a Mediterranean climate the soil can create hydrophobic conditions. The infiltration capacity of the soil is strongly reduced, even if the surface conditions are suitable for infiltration. This can cause a high rate of surface flow during intensive rainfall events. It is important to take this into account applying the Kirchner method. Hydrophobic conditions are not included in this method and maybe therefore a Mediterranean environment is not sufficient for this method. Martínez-Murillo mentions that in autumn the hydrophobicity decreases and the soil moisture and infiltration capacity increase. In a wet period the circumstances are sufficient for the Kirchner method, this is also the case in the Ardèche.

Secondly, as mentioned before, the paper assumes that AET is equal to PET the whole year. The AET is calculated using the Turc equation (1954). While the potential evapotranspiration can be much higher at the end of the summer. Assuming that AET=PET and rescaling three of the four catchments can have a negative influence on the simulation. Considering that AET has the same values as PET in a dry period is probably not realistic, for example does the AET increases faster that PET during a rain event (Lauenroth, 2012). Also the different values of the AET and PET during drought can be interpreted based on the article of Lauenroth (2006). Therefore I suggest an improved explanation of the assumption for AET=PET, because it can cause an unrealistic view on applying this method.

In the paper the AET is calculated with the Turc (1954) formula. Pike (1964) mentions that the Turc method is especially applicable in humid areas, this is not the case in a Mediterranean environment which is a semi-arid area. The reference used for the Turc method is the ‘Evaluation des besoins en eau d’irrigation , evapotranspiration potentielle, formuleclimatique simplifee et mise a jour’ from 1961. However I found in different articles (Kluge, 2006; Pike 1964; Watson, 1995) another reference using the equation for this specific calculation of AET: ‘Turc L., 1954, Le bilan d'eau des sols. Relation entre la précipitation, l’evaporation et l’ecoulement, *Ann. Agron*., 5, 491–569’. Based on these articles it seems that you are in fact using the equation developed by Turc in 1954.

Another important, but relatively easy to fix, issue is the clarity of the main research questions in the abstract and introduction. The main question summarizes the goal of this study very well, however the phrasing differs between the abstract and introduction. I suggest you use the same question twice to prevent confusion. After reading the article several times intensively, the answers to these questions can be found by the reader. I suggest that the conclusions based on these questioned will

be explicit explained in the conclusion (paragraph 6). Below my interpretation and opinion for the questions:

Can such a Mediterranean catchment be adequately characterized by simple dynamical systems approach and what are the limits of the method under such conditions?

Based on the information mentioned earlier I would say a Mediterranean catchment cannot completely be characterized by the simple dynamical system approach of Kirchner(2009). This is because the complications during summer. At least some other parameters have to be taken into account like hydrophobic aspects or more precise measurements of evapotranspiration

The limits of these methods are mentioned a few times in the paper, like difficulties of measuring evapotranspiration or discharge during summer is explained in the article. This is done very well, however I suggest they will be repeated explicit in the conclusion part

What information about dominant predictors of hydrological variability can be retrieved from this analysis in such catchments?

The information from this analysis is the impact of precipitation during a wet period to the discharge.

My final comments in this review deals with the structure of the article. For example the explanation of the Kirchner method(2009). It is nice that a detailed derivation of the Kirchner method is provided so the reader can fully understand the methodology. However the method is already described in detail in several other studies (Kirchner, 2009;Teuling, 2010; Krier, 2012; Brauer, 2013). Therefore I think a more briefly explanation or even only mentioning equation 5, 6, 14 and 17 and referring to previous studies for more detail can help to focus the attention of the reader to the new results rather than an existing and widely-applied methodology.

Moreover I think that paragraph 2.3 *Rescaling of water balance fluxes* maybe can be reduced. The explanation of choosing the Turc method (1954) is very clear and it is interesting comparing it with other formula's. However the formula's of, for example, Fu(1981) or Schreiber (1904) do not adjust value information to the main study mentioned in this paper.

In paragraph 3.4 the testing of the model efficiency is precisely explained with equations 18 and 19. However I think the reference or short explanation for both equations is sufficient enough and there is no need showing these precise equations. This will shorten the paragraph and make it more comfortable to read.

Specific comments

Page 10732, line 5: The reference for 'Electricité of France' is missing.

Page 10733, line 11-15: 'In our study, we assumed that actual evapotranspiration is equal to potential evapotranspiration (PET) … modulated by a crop coefficient depending on the nature of vegetation ….'. Improvement: 'In our study, we assumed that actual evapotranspiration (AET) is equal to potential evapotranspiration (PET)… modulated by a crop coefficient (Kc) depending on the nature', in this way also the parameters of function (1) are directly explained.

Page 10733, line 25: twice ET_0 mentioned. 'ET_0 and ET_0', while no ET_0 is mentioned in table 3.

Page 10736 line 5: P/ET_0 is not mentioned in equation 4

Page 10739 line 14: 'defined as a period between sunrise and sunset'. Improvement: 'defined as a period between sunset and sunrise'.

Page 10744, line 5: twice the words 'is the'.

Figure 4: twice the word 'using'

Figure 6: A label for the right y-axis will make the graph more complete

Figure 8&9: I suggest using less information in this figure, for example in figure 9 only sim. flow -4, -3.4 and -3. For example the observed flow (red line) can be illustrated with a dotted line above the other lines.

References

Brauer, C. C., Teuling, A. J., Torfs, P. J. J. F., & Uijlenhoet, R. (2013). Investigating storage-discharge relations in a lowland catchment using hydrograph fitting, recession analysis, and soil moisture data. *Water Resources Research*, *49*(7), 4257-4264.

Fu, B.P. (1981). On the calculation of the evaporation from land surface, *Sci. Atmos. Sin.*, 5, 23-31

Kirchner, J. W. (2009). Catchments as simple dynamical systems: catchment characterization, rainfall–runoff modeling, and doing hydrology backward, *Water Resour. Res*., 45

Kluge, J., Kessler, M., & Dunn, R. R. (2006). What drives elevational patterns of diversity? A test of geometric constraints, climate and species pool effects for pteridophytes on an elevational gradient in Costa Rica. *Global Ecology and Biogeography*, *15*(4), 358-371.

Krier, R., Matgen, P., Goergen, K., Pfister, L., Hoffmann, L., Kirchner, J.W., Uhlenbrook, S., Savenije, H. H. G. (2012). Inferring catchment precipitation by doing hydrology backward: A test in 24 small and mesoscale catchments in Luxembourg. *Water Resources Research*, *48*(10).

Lauenroth, W. K., Bradford, J. B. (2006). Ecohydrology and the partitioning AET between transpiration and evaporation in a semiarid steppe. *Ecosystems*,9(5), 756-767.

Lauenroth, W.K., Bradford, J.B. (2012) Ecohydrology of dry regions of the United States: water balance consequences of small precipitation events, E*cohydrology,* 5,*46-53.*

Martínez-Murillo, J. F., & Ruiz-Sinoga, J. D. (2007). Seasonal changes in the hydrological and erosional response of a hillslope under dry-Mediterranean climatic conditions (Montes de Málaga, South of Spain). *Geomorphology*, *88*(1), 69-83.

Pike, J. G. (1964). The estimation of annual run-off from meteorological data in a tropical climate. *Journal of Hydrology*, *2*(2), 116-123.

Schreiber, P. (1904) Über die Beziehungen zwischen dem Niederschlag und der Wasserfüru g der Flüsse in Mitteleuropa, *Z. Meteorol.*, 21, 441-452.

Teuling, A. J., Lehner, I., Kirchner, J. W., & Seneviratne, S. I. (2010). Catchments as simple dynamical systems: Experience from a Swiss prealpine catchment. *Water Resources Research*, *46*(10).

Turc, L. (1954). Le bilan d'eau des sols. Relation entre la précipitation, l'evaporation et l'ecoulement, *Ann. Agron*., 5 , 491–569

Turc, L.(1961). Evaluation des besoins en eau d'irrigation, evapotranspiration potentielle, formuleclimatique simplifee et mise a jour, Ann. Agron., 12, 13–49, 1961

Watson, I., Burnet, A.D. (1995). Hydrology, An environmental approach, Theory and applications of ground water and surface water for engineers and geologists, *Lewish publishers,* 434