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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Towards ecosystem accounting: a comprehensive approach to modelling multiple hydrological ecosystem services" *by* C. Duku et al.

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We would like to thank Dr E. N. Müller for her invaluable feedback and constructive comments. We have taken many of the comments and suggestions on board and we will incorporate them in the final paper. In the following, we provide a point by point response to her comments. For the sake of clarity we first repeat the reviewer's comments and then provide our response.

GENERAL COMMENTS

Comment 1: The overall structure of the manuscript is not well composed. Both ab-

stract and introduction do not give the right impression on the content of the article. It is not explained which hydrological ecosystem services exist and why four specific ones have been chosen for this study.

Reply 1: We have taken on board your useful suggestions and we will revise the abstract and the introduction sections accordingly.

Comment 2: Description of the study area lacks some critical information on type of land-use, specifically what kind of rain-fed crops and why kind of rice (wet or dry rice cultivation in a savannah ecosystem?), what kind of current water supply for domestic use, groundwater conditions, status of current land degradation, erosion, nutrient pollution of surface and groundwater resources. Without this background information, it appears difficult to understand the necessity to analyse corresponding ecosystem services.

Reply 2: We will provide additional information on the study area especially current water supply for domestic use, land use and the type of rainfed crops. We shall include these in the revised version.

Comment 3: Substantial lack in the application of the SWAT model: the given parameterisation data are not detailed enough, calibration and validation data on a monthly basis appears not to be sufficient to assess daily soil moisture patterns for the crop water supply, testing data for sediment and nutrient fluxes are not sufficient to say anything about model performance; not information are given on how the groundwater recharge is set up, which appears essential to evaluate groundwater abstractions of private households.

Reply 3: We have provided the detailed parametrisation data in the attached supplement. It provides information on how the groundwater recharge as well as other hydrologic processes was set up. We will also include this table in the final paper. We fully agree that daily calibration and validation is more appropriate for assessing daily soil moisture patterns of crop water supply. With our approach the initial set up was carried out with ArcSWAT (which is based on the HRU discretization). This setup was then calibrated and validated on a daily time-step using 12 years of daily streamflow data from 11 different monitoring stations within the watershed. This calibration and validation was carried out SUFI-2 optimization algorithm of SWAT-CUP. The calibrated and validated input parameter sets from the HRU-based setup were transferred to the grid-based setup of the SWAT Landscape model using the SWATgrid interface. The main process distinction of the grid-based SWAT Landscape model from the conventional SWAT model is the use of a spatially distributed topographic index to partition flow into landscape and channel components. This is determined by a parameter called drainage density factor (Rathjens et al., 2014). During simulation of the grid-based SWAT Landscape model, only this parameter was manually calibrated to make sure that model performance was still satisfactory. It was this manual re-calibration that was carried out with monthly streamflow data instead of daily data and the results included in the manuscript. We will re-evaluate the grid-based model with daily streamflow data and include this in the final paper instead of the monthly results. Concerning sediment and nitrogen fluxes, we acknowledge that the lack of validation introduces uncertainties with regards to model results. Data needs especially for calibration and validation of sediment and nitrogen fluxes for a region such as ours have always been a great challenge. We will therefore include a subsection “SWAT modelling uncertainties and limitations” in the Discussion section to discuss these inadequacies and limitations.

Comment 4: Section 3.2.3 on water purification and denitrification appears to be wrong. There are no information given on fertiliser rates of the agricultural fields; nutrient leaching through groundwater recharge and nutrient leaching into surface water resources are not considered, and it is not clear how the denitrification rate is linked to water supply.

Reply 4: Whereas we acknowledge that nutrient leaching through groundwater recharge and also into surface water resources are important components of water purification, we disagree with your opinion that using denitrification as an indicator

of water purification is wrong. Ecosystem services are benefit dependent (Boyd and Banzhaf, 2007) and the selection of indicators for quantification and mapping are driven first and foremost by the benefits in question. In our study area, groundwater provides over 90% of the total household drinking water consumption that was why we focussed solely on water purification of groundwater resources and not that of surface water resources. The benefit of groundwater use by households is a function of its quantity and quality, however, the quantity and quality aspects are provided by different ecosystem services. Therefore, for water purification, our approach focussed on soil denitrification and looked at the quality aspect of groundwater provision. We understand that nitrate leaching through groundwater recharge may be another indicator of water purification. However, for this study and within the framework of ecosystem services and accounting, we argue that denitrification is a more appropriate indicator because it determines the quantities (after plant uptake) of nitrate available for leaching into groundwater systems (Jahangir et al., 2012). In order words, the rate of nitrate leaching into groundwater systems is dependent on soil denitrification. In addition, the challenge in terms of quantifying ecosystem services is the identification of management relevant indicators that can be enhanced through management interventions to augment the service production. Soil denitrification can be a management practice to reduce nitrate leaching into groundwater systems. For example, Kramer et al. (2006) observed that organic farming supports more active and efficient denitrifier communities leading to a considerable reduction in nitrate leaching as compared to conventional farming. We acknowledge and pointed out (page 3489 line 28 and page 3490 line 1 to 5) that denitrification as modelled by the SWAT model is simplified. The SWAT model does not explicitly simulate microbial processes and dynamics but rather it simulates the ecohydrological conditions suitable for denitrification to occur (Boyer et al., 2006). Therefore, there is an inherent assumption of spatial homogeneity with regards to microbial species composition and quantities. These methodological challenges notwithstanding, for our study denitrification is very suitable indicator of water purification.

In Table 4 (page 3516), we provided the total amount of nitrogen/nitrate added to each

SEAU either through fertilizer application or atmospheric deposition. Fertilizer use is increasing in the region and high fertilizer inputs is associated with crops such as maize, rice and cotton (Bossa et al., 2012). To simulate these high fertilizer inputs, we used the auto-fertilization routine in the SWAT model. Fertilizer (NPK and/or Urea) was applied automatically whenever the nitrogen stress fell below a specified level.

Comment 5: The ecosystem service function to assess soil erosion control is oversimplified: does Equation 7 include intercropping?

Reply 5: The focus of this part of our paper was to model and quantify the role of land/vegetation cover in soil conservation or controlling soil erosion. Empirical distinction of ecosystem service flow and ecosystem service capacity of regulating services such as soil erosion control has always been a challenge. However, approaches as such that used in our study are not uncommon in ecosystem services assessments (e.g. Leh et al., 2013;Terrado et al., 2014). In page 3500 line 15 to 29 and page 3501 line 1 to 16, we believe we have adequately discussed this challenge. Because we simulated only a single crop type (maize) in all agricultural fields Equation 7 does not include intercropping.

Comment 6: In the conclusion it was suggested that such a tool is appropriate for decision-making in water and land management, an idea which I strongly reject. Although it is relatively easy to set up a SWAT simulation run for larger catchments, it is extremely difficult to obtain spatially and temporally correct representations of the underlying (eco)hydrological processes and interactions. Without appropriate, high-resolution and high-quality testing data, SWAT results may be used in relative terms, but not in absolute, hence not for decision-making.

Reply 6: Yes, it is true that for larger catchments, it is extremely difficult to obtain spatially and temporally correct representations of the underlying hydrological processes and interactions. To achieve this, there is the need for multi-site calibration at different spatial scales with a sufficient length of time-series of data (Santhi et al., 2008). We

believe that for the hydrologic components we have adequately fulfilled these requirements. Calibration and validation were not carried out at the watershed outlet only. We used 12 years of daily streamflow data from 11 different monitoring stations that had varying spatial scale (from 297 km2 to 10,046 km2) as described in Table 3 in Page 3515. In addition, three quantitative statistics that measure different aspects of model performance were used for model evaluation with satisfactory results. Model results to support decision-making are always associated with a certain degree of uncertainty and the quantitative statistics provide a measure of these uncertainties. Using this tool as a decision-support such as for spatial prioritisation and conservation to augment and sustain service production should be carried out always with these uncertainties in mind.

SPECIFIC COMMENTS

Comment 1: P. 3480, line 12: in the contrary: discretisation type does have a significant effect on aggregated hydrological attributes.

Reply 1: We base this statement on Arnold et al. (2010)

Comment 2: P. 3480, line 20: not sure what is meant what 'ecohydrological models should do' – I would rather give a generic definition about the capacities of ecohydrological models, which processes and interactions with biogeochemical and vegetation processes are included, which models are available etc.

Reply 2: The statement highlights the importance of landscape spatial interaction in ecohydrological models that are to be used to support ecosystem accounting. This is important for simulating the impact of upstream land and water management on downstream processes. However, in some models including the standard SWAT model currently in use, this process is not incorporated (Arnold et al., 2010;Bosch et al., 2010;Volk et al., 2007). The impact of upstream land management and uses downstream cannot be simulated if they are not in the same HRU. We however, will reframe this section in the final paper to make this point clearer.

Comment 3: P. 3481, line 6: which type of stakeholder? Not sure why this is mentioned here.

Reply 3: We will revise this section accordingly.

Comment 4: P. 3481, line 12: there should be a longer section in the introduction on hydrological ecosystem services and here a explanation, why these ones have been selected

Reply 4: We will revise this section accordingly.

Comment 5: P. 3481, line 15: refer to other studies who used SWAT in Benin, e.g. C. Hiepe, 2008, PhD thesis at Uni Bonn, or the studies by Bossa et al. 2012.

Reply 5: We will revise this section accordingly.

Comment 6: P. 3481, line 24-25: land degradation has not been mentioned before – is that an important feature of the catchment? If yes, where is it addressed (potentially in the erosion control service)? Competition for scarce water resources (e.g. agricultural versus domestic use) should be mentioned earlier in the introduction. Section 3.1.1: this should include a short description of the model processes, spatial and temporal scales and resolution etc.

Reply 6: We will revise this section accordingly.

Comment 7: P. 3483, line19: not sure how raster cells of 500x500 metres will solve SWAT's original problem of matter routing, this resolution is still too coarse to capture many heterogeneities regarding land-use, slope, hillslope-river connections and connectivity patterns

Reply 7: There is always a trade-off between increased spatial detail and run-time efficiency in the SWAT model (Arnold et al., 2010;Notter et al., 2012). We acknowledge that 500m by 500m grid cell resolution may not be the best, however, we believe that we have sufficiently discussed this modelling challenge in Page 3498 line 21 to 25 and in

Page 3499 line 1 to 18. We would also like to point out that the problem of matter routing in the SWAT model during the land phase of the hydrological cycle is not because of the coarseness of a spatial resolution or because of the spatial discretization type but mainly because of the lack of spatial interaction between HRUs. It is this lack of spatial interaction that the modified SWAT model, SWAT Landscape (Arnold et al., 2010;Volk et al., 2007) used in this study seeks to address. Therefore, even though 500m by 500m may be relatively coarse it does not in matter routing because of the use of SWAT Landscape model.

Comment 8: P. 3485 line 5: information on the extraction rates from shallow aquifers and streams are required.

Reply 8: We will include this data in the revised version.

Comment 9: P. 3486, line 5: The approach to re-calibrate and re-validate manually the grid-based simulations of the model requires justification. Section 3.2: this section belongs to the introduction section

Reply 9: The main process distinction of the grid-based SWAT Landscape model from the conventional SWAT model is the use of a spatially distributed topographic index to partition flow into landscape and channel components. This is determined by a parameter called drainage density factor (Rathjens et al., 2014). It was this parameter that was re-calibrated manually to make sure that model performance of the grid-based SWAT Landscape model was satisfactory. We will revise Section 3:2 accordingly.

Comment 10: P. 3487, line 2: more information are required on the agricultural system, especially on the rice plantations: why kind of rice is grown, - I assume upland, rainfed rice, - is this adequately included in the SWAT parameterisation?

Reply 10: For our study, rice cultivation is simulated only in inland valley lowlands (which are the most dominant agro-ecology for rice cultivation in our study area). A map of inland valleys in our study area obtained from field surveys was used for the spatial delineation. The pothole function was used to simulate these lowlands are rice paddy fields.

Comment 11: P. 3489, line 3: water consumption per capita has to be given.

Reply 11: We will include this data in the revised version.

Comment 12: Section 3.2.3: water purification appears to be the wrong wording, also check comments in the general comment section above.

Reply 12: Please see Reply 4 under General comments

Comment 13: L 3496, line 11: does the model state that soil erosion is currently not a problem? Is there any other evidence?

Reply 13: We will revise this section and provide supporting evidence.

Comment 14: P. 3501, line 1-2: This sentence needs re-writing: are you referring to the temporal scaling of water fluxes, i.e. quick runoff of water originating from high-intensity storms versus low intensity rain and its capacity to increase soil moisture? How is this related to crop and land management?

Reply 14: We will revise this section accordingly.

REFERENCES

Arnold, J. G., Allen, P. M., Volk, M., Williams, J. R., and Bosch, D. D.: Assessment of Different Representations of Spatial Variability on Swat Model Performance, Transactions of the Asabe, 53, 1433-1443, 2010.

Bosch, D. D., Arnold, J. G., Volk, M., and Allen, P. M.: Simulation of a Low-Gradient Coastal Plain Watershed Using the Swat Landscape Model, Transactions of the Asabe, 53, 1445-1456, 2010.

Bossa, A. Y., Diekkrüger, B., Giertz, S., Steup, G., Sintondji, L. O., Agbossou, E. K., and Hiepe, C.: Modeling the effects of crop patterns and management scenarios on N and

P loads to surface water and groundwater in a semi-humid catchment (West Africa), Agricultural Water Management, 115, 20-37, 10.1016/j.agwat.2012.08.011, 2012.

Boyd, J., and Banzhaf, S.: What are ecosystem services? The need for standardized environmental accounting units, Ecological Economics, 63, 616-626, doi:10.1016/j.ecolecon.2007.01.002, 2007.

Boyer, E. W., Alexander, R. B., Parton, W. J., Li, C. S., Butterbach-Bahl, K., Donner, S. D., Skaggs, R. W., and Del Gross, S. J.: Modeling denitrification in terrestrial and aquatic ecosystems at regional scales, Ecological Applications, 16, 2123-2142, doi:10.1890/1051-0761(2006)016[2123:Mditaa]2.0.Co;2, 2006.

Jahangir, M. M. R., Khalil, M. I., Johnston, P., Cardenas, L. M., Hatch, D. J., Butler, M., Barrett, M., O'flaherty, V., and Richards, K. G.: Denitrification potential in subsoils: A mechanism to reduce nitrate leaching to groundwater, Agr Ecosyst Environ, 147, 13-23, doi:10.1016/j.agee.2011.04.015, 2012.

Kramer, S. B., Reganold, J. P., Glover, J. D., Bohannan, B. J. M., and Mooney, H. A.: Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils, Proceedings of the National Academy of Sciences of the United States of America, 103, 4522-4527, 10.1073/pnas.0600359103, 2006.

Leh, M. D. K., Matlock, M. D., Cummings, E. C., and Nalley, L. L.: Quantifying and mapping multiple ecosystem services change in West Africa, Agr Ecosyst Environ, 165, 6-18, doi:10.1016/j.agee.2012.12.001, 2013.

Notter, B., Hurni, H., Wiesmann, U., and Abbaspour, K. C.: Modelling water provision as an ecosystem service in a large East African river basin, Hydrology and Earth System Sciences, 16, 69-86, doi:10.5194/hess-16-69-2012, 2012.

Rathjens, H., Oppelt, N., Bosch, D. D., Arnold, J. G., and Volk, M.: Development of a grid-based version of the SWAT landscape model, Hydrological Processes, n/a-n/a, 10.1002/hyp.10197, 2014.

Santhi, C., Kannan, N., Arnold, J. G., and Di Luzio, M.: Spatial calibration and temporal validation of flow for regional scale hydrologic modeling, Journal of the American Water Resources Association, 44, 829-846, doi:10.1111/j.1752-1688.2008.00207.x, 2008.

Terrado, M., Acuna, V., Ennaanay, D., Tallis, H., and Sabater, S.: Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin, Ecological Indicators, 37, 199-209, doi:10.1016/j.ecolind.2013.01.016, 2014.

Volk, M., Arnold, J. G., Bosch, D. D., Allen, P. M., and Green, C. H.: Watershed configuration and simulation of landscape processes with the SWAT model, MODSIM 2007 International Congress on Modelling and Simulation, edited by: Oxley, L., and Kulasiri, D., Modeling and Simulation Society of Australia and New Zealand, 2007.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/12/C2395/2015/hessd-12-C2395-2015-supplement.pdf

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