Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2018-125-AC2, 2018

Hydrology and Earth System Sciences
Discussions

Open Access

Interactive comment on "An improved method for calculating regional crop water footprint based on hydrological process analysis" *by* Xiao-Bo Luan et al.

Xiao-Bo Luan et al.

luanxb23@126.com

Received and published: 4 July 2018

<Manuscript number: HESS-2018-125> Dear Editors and Reviewers: Thank you for your letter and for the reviewers' comments concerning our manuscript "An improved method for calculating regional crop water footprint based on hydrological process analysis". We appreciate your comments and constructive suggestions very much, and they were valuable for improving the quality of our manuscript. We have revised the manuscript in detail according to the editor and reviewers' comments. We hope that these modifications, based on your suggestions and the reviewers' comments, will raise the quality of our manuscript to meet the publication standards of Hydrology and

Earth System Sciences. The revised portions are marked in red in the paper. The main corrections in the paper and the responses to the reviewer's comments are as follows:

Anonymous Referee #2

SUMMARY AND GENERAL COMMENTS The paper presents a semi-distributed approach to model effective water resource requirements in crop production in terms of the volume of water used per unit crop production. The approach differentiates between green and blue water sources and puts emphasis on conveyance losses of irrigation water. Modelling of the water cycle is based on SWAT, while conveyance losses between the water inlet of the irrigation scheme and the field are modelled depending on the location according to a new approach that, apparently, has not been published before. The novel contribution to the field of science by this study is limited to the location-dependent modelling of conveyance losses, which can potentially have significant effect on crop water footprint calculations. Unfortunately, the derivation of the approach is neither explained in much detail nor is its validity tested against measured data. Overall, the presentation of the theoretical background, methods and results is rather poor and, at least partly, hard to understand. The language is unprecise and redundant in major parts of the paper. It leaves room for interpretation (eg lines 64-66) and numerous sentences/paragraphs are unintelligible (e.g. lines 86-87, 90-93, 104-105, 207-209). I am not a native English speaker but I feel the text needs revision with regards to pure language issues (grammar, mode of expression). The paper does not provide a critical discussion of the approach and the results. In particular, uncertainties of inputs and results are hardly addressed. Major parts of the discussion section basically repeat the contents of the introduction. The conclusions section is basically a summary of the results and the few conclusions made are trivial. The title does not match the content of the manuscript (see comment on the term "water footprint" below). Response: Thank you for your comments. The main purpose of this study is find a better method to quantify crop production water footprint more comprehensively, because the current method of crop production water footprint does not fully contain all the water consumed in the crop production process, such as water loss from the channel when the water is transported to the field. In this study, we considered the water consumption associated with crop production in general, including canal water loss, which has not been studied by previous studies. At the same time, the spatial resolution of the results of the crop production water footprint in this study is higher, and the water footprint changes within the region can be found. These contribute to a truly quantified crop production water footprint, more accurately assessing the crop production water footprint in a given area, and thus more precise determination of water footprint hotspot areas. This will provide the basis for water resources management in the region. According to your comments, we have modified the thesis in the revised manuscript as suggested. At the same time, we have improved the language of the thesis (The paper was edited by Elsevier Language Editing Services).

DETAILED COMMENTS ON SUBSTANTIAL SHORTCOMINGS OF THE MANUSCRIPT 1. Comment: The authors refer to the water resource requirements of crop production as “water footprint”, which is inappropriate two reasons. Firstly, indirect water uses, an important aspect of a footprint indicator, are not considered in the study. Secondly, the paper lacks a clear definition of the system (consumer or producer) that causes the footprint. Response: Thank you for your comments. 1. Crop production consumes plenty of water resource. Fertilizers, pesticides and machinery also contain indirect water footprints. Due to the lack of above data, to quantify water footprint of crop production in the world mainly focus on the evaluating water use during crop production, which is the direct water footprint. The reference are as follows: Bocchiola, D., Nana, E., & Soncini, A. (2013). Impact of climate change scenarios on crop yield and water footprint of maize in the Po valley of Italy. Agricultural Water Management, 116(2), 50-61. Cao, X., Wu, P., Wang, Y., & Zhao, X. (2014). Water Footprint of Grain Product in Irrigated Farmland of China. Water Resources Management, 28(8), 2213-2227. Hoekstra, A.Y., & Mekonnen, M.M. (2012). The water footprint of humanity. PNAS, 109(9), 3232-3237. Mekonnen, M.M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. Hydrology & Earth System Sciences, 15(5), 1577-1600. Zhuo, L., Mekonnen, M. M., & Hoekstra, A. Y. (2016). Benchmark levels for the consumptive water footprint of crop production for different environmental conditions: a case study for winter wheat in China. Hydrology & Earth System Sciences Discussions, 20(11), 4547-4559. 2. As for your second suggestion, we have explained in this manuscript that the water footprint in this study is generated during crop production.

2. Comment: The paper presents water resource requirements for the production of three different crops (m3 water use/t of crop production, referred to as "water footprint") in subbasins of the Hetao Irrigation District (HID). Obviously, the "water footprint" is defined for a producer. It is not stated whether the footprint figures are calculated for (a) a single producer, i.e., the aggregate of "farms" growing a single crop type in the HID, or (b) many different producers, i.e., the aggregates of farms growing that crop within individual subbasins. However, this is important in order to understand the results correctly. In case (a) the volume of water used to produce xi tonnes of crop in subbasin i needs to be related to the total crop production in HID (X). If ri is the water resource requirement in sub-basin i, the water footprint of the HID-wide crop production in sub-basin i calculates as Fi=xi/X*ri. In contrast, the water footprint of subbasin-wide crop production (case (b)) in subbasin i is given as F'i=ri. Note that in case (b), the "water footprint" indicator is no longer geographically explicit, another important aspect of the water footprint, as the subbasins are the smallest geographical units presented. The range of results shown in the maps implies that the water footprint is defined according to case (b). However, water resource requirements for crop production are intrinsic properties of the irrigation system in each subbasin and are independent of the actual allocation of crop production. Hence, the study is not a footprint analysis but, simply, an analysis of resource requirements (comparable to a potential analysis). However, the representativeness of the results is questionable due to methodological limitations. Subbasins are sub-divided into hydrological response units (HRU) based on land use (supposedly land use=crop type) and soil type. Although it is not stated explicitly, one must assume that the results on HRU-level, based on the actual pattern of crop alloca-

tion and irrigation timing/quotas, are aggregated to subbasin-level (aggregation method not specified). This way, the results are only representative for potentially small parts of a subbasin, i.e., one or more HRUs within a subbasin under the given crop, as the conditions (soil type, canal losses, etc.) may be different in the remaining parts of the subbasin. The reader cannot judge the related uncertainties as the actual patterns of crop allocation and soil types are not shown. Response: Thanks you for your comments. In this study, water footprint during crop production was calculated by SWAT model. SWAT model divides the region into subbasins according to DEM and water system. Then subbasins are divided into HRU according to land use type, soil type and slope. Among them, subbasin is the smallest geographic unit. Therefore, the steps to calculate the water footprint during crop production are as follows: At first, water consumption for a certain crop in a certain subbasin was calculated, that is, the total water consumption of each HRU. Then crop production in each HRU was calculated (HRU area multiplies crop yield per unit area). Then total water consumption was divided by total crop production in this subbasin to obtain the water footprint during crop production in this subbasin. This study mainly focused on analysis on water use in irrigated area, and irrigation water loss during convey was taken into consideration. The results of this research have improved spatial resolution with more detailed reflection of water footprint changes inside the region compared to former researches, which is of vital significance to local water resource management. Due to the limited resolution of land use data, the specific distribution of each crop in study area couldn't be distinguished. Additionally, in the Hetao irrigation district, farmers generally plant three crops (wheat, corn, sunflower) to diversify their business risk. Because of the large population, the total farmland of each farmer is small. Therefore, three crops are evenly distributed as a certain proportion in the entire HID. As a result, in the SWAT model's HRU partition setting, we further divide agricultural land into small parts by Land Use Refinement tab, which depends on the proportion of three crops, so that the SWAT model can distribute three crops evenly across the irrigated area. It is an important reference to divide the HRU. The SWAT model distributed all three crops proportionally to the irrigated area, and land use types might influence the calculation of water footprint results. In addition, there were more than ten types of soil in this study area, but the influence of soil types on water footprint is not clear. Therefore, the uncertainties of land use types and soil types on water footprint have not been taken into account in this study, but you have provided us with a new ideas for future study, thank you very much.

3. Comment: The description of the methods to calculate the “water footprint” is difficult to understand. As the system boundaries are not defined precisely, the reader is forced to examine several possible system boundaries in order to judge whether the equations 6-9 are likely to be correct. For instance, it depends on the sys-tem boundary whether field discharge (Qd) is actually consumption, i.e. it is a flow out of the system (to another basin or the sea), or returns to system itself. As the authors stress that the approach is regional-scale, a certain share in field discharge is likely a return flow, which would invalidate equation 7, which defines field discharge as water consumption. Equations 6-9 use a set of variables that are calculated for two different scenarios (s1=with irrigation, s2=without irrigation) but the notation is ambiguous as the scenario is not clearly indicated in the equations except for for ET (index s1 or s2). It might be considered obvious that canal losses (Qc) and ET of field irrigation (Qf) is only defined for the scenario with irrigation (s1). (Note, those variables can also be defined for s2, though with a value of zero.) However, capillary rise of groundwater (Qg) and field discharge (Qf) definitely can have non-zero values for s2. Hence, it must be indicated from which scenario the values are taken. Qg must not be added in eq 7. Although Qg is per definition blue water, it simple changes soil moisture. The share of Qg that is consumed is already included in Qf+Qd. Response: Thanks you for your comments. In this study, crop production was obtained by local statistic data, and the green and blue water were obtained by SWAT model. Due to the little precipitation which was difficult to meet the growing needs of crops, green water consumption was equal to the effective precipitation. In this study, we have set scenario 2 without irrigation to calculate the effective precipitation (formula 6). The blue water consumption includes water loss in canal system, the consumption of irrigation water in the field, and the drainage in

the field. Water loss in canal system during convey was obtained by irrigation water consumption in the field which was obtained by SWAT model and effective utilization coefficient of canal water. The consumption of irrigation water in the field was the ET of irrigation water, obtained by total ET minus green water consumption. The drainage in the field was the extra water discharged from the field, obtained by the outputs of SWAT model (formula 10). According to your comments, we have modified the description on calculation process. In this study area (HID), drainage in the field eventually flowed out of the irrigated area and could no longer be used in the irrigated area. Therefore, in this study drainage in the field was part of the blue water consumption. Of course, for other areas, if drainage in the field didn't flow out of the irrigated area and could be reused, then the field drainage was not blue water consumption, which needed to be clarified before calculation. The situation of each indicator in the formula is indeed not clearly pointed out. According to your suggestion, we added the situation of each indicator in the formula. We fully agree with your opinion. Qf+Qd has included Qg. During crop growth, the sources of ET are precipitation, soil water and groundwater. If groundwater rises into the soil, it is consumed by crop evaporation or drainage. We have revised the formula according to your suggestion. Due to the sufficient amount of irrigation in the study area, there was little use of groundwater, which have little impact on this research. The modified parts are as follows: Page 11, 12, line 198-226. Water consumption in the fields consists of 4 parts including the actual ET of precipitation, irrigation water, groundwater utilized by crops, and field drainage. This study set up two scenarios and calculated the above water consumption by changing the sources of water in the SWAT model. In scenario 1 (S1), crop water consumption was derived from precipitation and irrigation water (irrigation systems and irrigation quotas are based on local irrigation methods), i.e., the actual situation of crop water use. In scenario 2 (S2), crop water consumption was only derived from precipitation without irrigation. The S2 was used to calculate the consumption of green water. In this study area (HID), because of less rainfall, the effective precipitation formed by precipitation is all used for crop growth. Therefore, the consumption of green water for crops is equal to the effective precipitation, which means that green water is reflected by calculating the effective precipitation stored in soil by SWAT model. The calculation formula is as follows. (5) (6) (7) (8) (9) (10) where WF is the water footprint of crop production (m3/t), WFg is the green footprint (m3/t), WFb is the blue water footprint (m3/t), Wg is the green water consumption during the crop growth period (m3), Wb is the blue water consumption during the crop growth period (m3), Y is the crop yield (t), PRECIPs2 is the precipitation during the crop growth period in Scenario 2 (m3), SUPQs2 is the surface runoff during the crop growth period in Scenario 2 (m3), LATQs2 is the soil lateral flow during the crop growth period in Scenario 2 (m3), Qc is the amount of water loss in the canal system (m3), Qf is the actual ET of field irrigation water (m3), Qd is the field discharge (m3), It,s1 is the total amount of irrigation water diversion in Scenario 1 (m3), and If,s1 is the actual amount of water irrigated in the field in Scenario 1 (m3). ks1 is the effective utilization coefficient of canal water in Scenario 1(Obtained from the local Water resources management department), ETs1 is the crop actual ET during the crop growth period in Scenario 1 (m3), WYLDs1 is the total amount of water leaving the HRU in Scenario 1 (m3). The data of parameters PRECIPs2, SUPQs2, LATQs2, It,s1, ETs1, WYLDs1 were obtained from the SWAT model.

4. Comment: As I understand, canal losses in eq 7-8 are informed by the modelling approach represented by eq 10-15 but it remains unclear which of the variables mentioned in eq 10-15 are actually used and how. The notation of eq. 10-15 is confusing as I suspect most readers are familiar with a notation where n is the total number of elements and i is a running index. Here, it is used the other way around, which is not wrong but makes it more difficult to understand. Response: Thanks you for your comments. In this study area (Hetao irrigation district), irrigation canal system is complicated, which is totally seven levels from big to small, and water exists in the general main canal and the main canal during crop growth period (for timely irrigation for crop), while in other channels water only exists in irrigation periods. Thus, according to the characteristics of canal system in the study area, we have divided canal system into two parts to calculate the total water loss, in which Part A is water loss in the general

main canal and the main canal, and Part B is water loss in other canals. According to the simplified model in the paper and the methods of interpolation in ArcGIS software, the two parts of water loss were distributed throughout the irrigation area respectively, then the two interpolation results were added to obtain water loss distribution in this irrigation canal system. In formula 10-15, Wa and Wb are the total amount of canal system water loss of Part A and Part B respectively. The variables kgc and kmc are the canal system water utilization coefficient of the general main canal and the main canal respectively, which are used to calculate the canal system water loss of part A. Qji and Qj are water loss of the canal system per unit area in Part A and Part B used for interpolation in ArcGIS software. Sj is the area that a certain canal can irrigate. n in formula Qn is the total number of elements. The symbol of this formula is not written correctly. Thank you for your advice and we have modified this formula. The modified parts are as follows: Page 13-16, line 228-280. Water transfer loss is a kind of water loss in the process of channel water delivery, and it is an important part of blue water consumption in crop production. For a piece of cultivated land, the water loss during the process of the crop production includes the loss of water from the water source to the field flowing through the canal system. In the Hetao Irrigation District, irrigation canal is composed of seven grades (general main canal, main canal, sub-main canal, branch canals, lateral canals, field canals, and sub-lateral canals). Because of the complex distribution of canal system and the lack of hydrological data in irrigation districts (the lack of effective utilization coefficient of canal water below the main canal). Therefore, in calculating the water loss of canal system during crop production process, we generalized Hetao Irrigation District into a model similar to the histogram (Fig. 4). We divide the total water loss of canal system into two parts. Part A is the loss of the main canal and canal, and Part B is the loss of the remaining canal system (the water loss of the sub-main canal and its sub-channels at all levels). The calculation of water loss in part A is as follows: first, the water loss of each section is calculated by dividing the main canal into equal distances (10 km). Then the water transfer loss of each section of the canal is allocated to each field downstream [Equation 10], thereby obtaining the water transfer loss in the crop production process on the field block. Therefore, the actual water loss caused by irrigation in a field is the sum of the water loss of the transfer canal and the canal in the upstream. We assign the actual water loss of the field by irrigation (Qji, formula 11) to the midpoint of the each section, and use Kriging interpolation in ArcGIS to obtain the water loss distribution map of the figure a (Part A). Due to the lack of the effective utilization coefficient of canal water and the distribution map of the canals at all levels and below, the calculation process of the water loss in Part B is as follows: the remaining canal loss in each irrigation canal is divided by the main canal irrigation and the unit area loss of the canal control area is obtained. Then, the amount of water loss per unit area within the control range of each main canal in the irrigation area (Qj, formula 15) is obtained, and the data is brought into ArcGIS for the water loss distribution map of figure b (Part B). Finally, the figure a and the figure b are superimposed and calculated in the ArcGIS using the map algebra module of the spatial analysis tool to obtain the water loss distribution map of the canal system in HID. The formulas are as follows: (11) (12) (13) (14) (15) (16) where Qji is the actual amount of water loss per unit area of the i section of the jth main canal (m3/ha), Wjn is the water loss per unit area of the section of the jth main canal in part A (m3/ha), j is the number of the main canal, i is the number of the equidistance sections in the jth main canal, n is the total number of the sections in the jth main canal, m is the total number of the main canals, WA is the amount of water loss in part A (m3), kj is the coefficient of the water distribution from the general main canal to the jth main canal, Sjn is the area of each sections in the jth main canal (ha), It,s1 is the amount of total irrigation water diversion in Scenario 1(m3), kgc is the water conveyance efficiency of the general main canal, kmc is the water conveyance efficiency of the main canal, Sj is the area controlled by the jth main canal (ha), Qj is the water loss per unit area of the jth main canal (m3/ha), WB is the amount of water loss in part B (m3), and Qc is the amount of water loss in the canal system (m3).

Fig. 4. Model for calculation of water loss in canal system Note: Sjn is the area of each sections in the jth main canal, Wjn is the water loss per unit area of the section

of the jth main canal in Part A, Qji is the actual amount of water loss per unit area of the i section of the jth main canal, Sj is the area controlled by the jth main canal, kj is the coefficient of the water distribution from the general main canal to the jth main canal, Qj is the water loss per unit area of the jth main canal in Part B, kgc is the water conveyance efficiency of the general main canal, kmc is the water conveyance efficiency of the main canal, j is the number of the main canal, i is the number of the equidistance sections in the jth main canal.

5. Comment: The section on calibration and validation of the model is wordy and interrupts the description of the modelling approach. For instance, the R2 metric is widely used and there is no need to show the formula. If equations 2-4 are considered necessary, the notation should be corrected as the index i is missing in numerous terms. Response: Thank you for your comments. According to your suggestion, we have deleted the corresponding formula. And for more perfect presentation, we have put calibration and validation of SWAT model section to supplement information. The modified parts are as follows: Page 15, 16, line 178-186. 2.4 Calibration and validation The Sequential Uncertainty Fitting (SUFI-2) algorithm in SWAT-CUP was applied for calibration and validation (Abbaspour et al., 2007; Abbaspour, 2012) by comparing the simulated stream discharge from the model with the measured discharge data. The global sensitivity analysis integrated within SUFI-2 was used to evaluate the hydrologic parameters for the discharge simulation and then the optimal simulation is established by adjusting the sensitivity parameters and through multiple iterations. The calibration period was from 2006-2009, and the validation period was from 2010-2012. The result of the SWAT calibration and validation process is satisfactory, the detailed process are available in support information.

CONCLUSIONS Given the shortcomings addressed above, the quality of the manuscript is, in my opinion, not acceptable for publication, although the underlying material fits the scope of the journal and might be worth publishing. Due to missing definitions and precise description of the methods, I can hardly judge the validity of the

Printer-friendly version

Discussion paper

work. I think the necessary revisions are too extensive to be done within a peer-review process. Apart from this, addressing all the issues where I see the need for revision in this reviewer comment would be an unreasonable effort. Therefore, my recommendation is to reject the paper. Response: Thanks for your careful review of this paper and constructive suggestions. According to the comments, major revisions have been done which are as follows: 1. In the revised manuscript, detailed description has been added about methods and parameter in this paper. 2. The innovations of the research have been restated

Thank you for your helpful suggestion regarding our manuscript. We have revised the manuscript according to your comments carefully. We hope these modifications, based on your suggestions, will raise the quality of our manuscript to meet the publication standards of Hydrology and Earth System Sciences. We appreciate the editors and reviewers' work. Once again, thank you very much for your comments and suggestions.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2018-125/hess-2018-125-AC2-supplement.pdf

---

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2018-125, 2018.

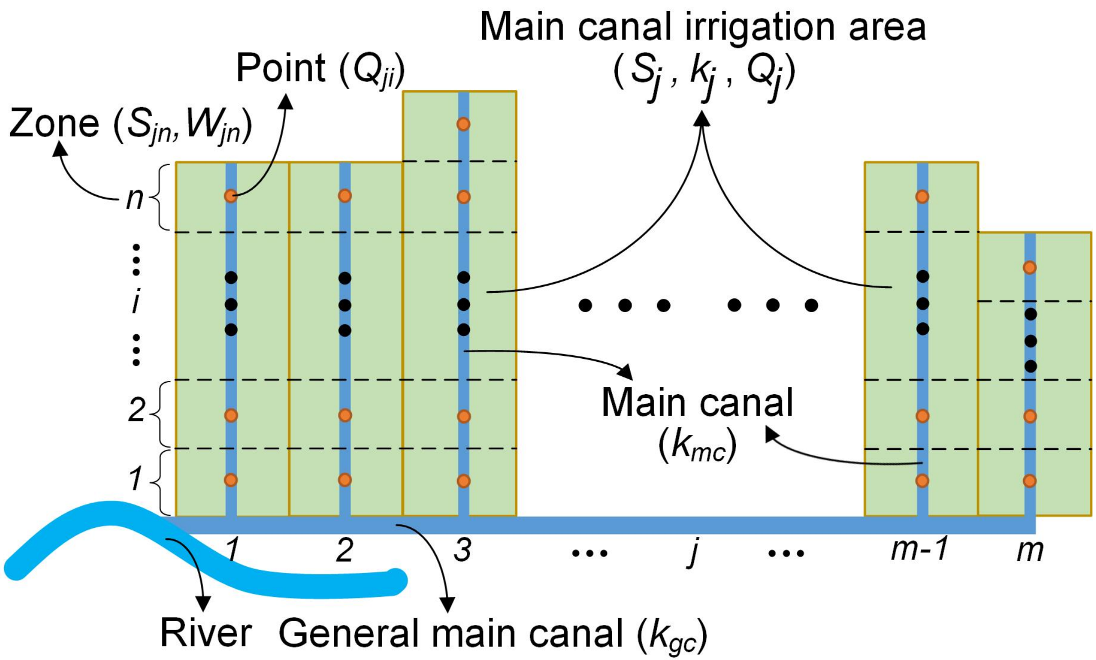

Fig. 1. Fig. 4. Model for calculation of water loss in canal system

Printer-friendly version

Discussion paper