Revision Notes (HESS-2021-80)

<u>Responses to the comments of Reviewer #1:</u>

We would like to thank reviewer 1 for his extensive and thoughtful comments. In this document we give a detailed response to all comments. Below we cite first the comment, this is followed by our response and often by a section how the text will be revised in the manuscript. The text in blue are changes and additions in the original text. For clarity we do not show any of the removed text.

Thank you so much.
Zailin Huo

General Comments：

This article presents a study that extends the Budyko framework to irrigated areas and applies it on several districts in China. The topic is clearly relevant for HESS and this article may guide further studies aiming at taking into account irrigated areas in hydrological modeling studies. But at this stage, the proposed study relies on many hypotheses that are not tested/mentioned clearly and consequently, the reach of the results is difficult to assess.

1. Applicability of the Budyko hypothesis in unclosed systems

The Budyko framework is usually intended to describe/model the partitioning of water fluxes at the catchment scale. The catchment scale is important since it allows to work on a closed system, where inputs and outputs can be clearly and unequivocally stated. In the proposed study, the Budyko framework is applied on irrigation districts and the different fluxes considered are, to my opinion inter-dependent. For example, in Eq. 4, equivalent precipitation is proposed as the sum of Precipitation, Irrigation and groundwater consumption. This suggests implicitly that the Irrigation water and Groundwater used for evapotranspiration are water fluxes originated from other sources than Precipitation falling over the district area, which is questionable. Consequently, using Eq.4 may lead to count Precipitation fluxes twice since water provided by irrigation (and possibly groundwater) originate from precipitation. This may be true depending on spatial and temporal scales considered but this is not discussed in the paper. Both references cited in the paper to present Eq. 4 are not relevant since Wang et al. (2011) did not consider irrigation but water storage and Chen et al. (2020) considered catchment scale modelling.

Response: Thanks for your suggestions. In our study, the irrigation data were measured and provided by China Irrigation and Drainage Development Center. Based on the issued report, the total amount of water diverted from external water resource was measured as irrigation water, indicating that the irrigation water was reasonable to be regarded as water input independent on precipitation. We agree with you the use of equation 4 is likely to cause double count of precipitation since the groundwater may be recharged by precipitation. Here, we will explain the independent role of groundwater uptake in water balance based on the new perspective to conduct water balance for vadose zone proposed only in our previous study (Chen et al., 2020). "The groundwater uptake is defined as the upward movement of groundwater induced by active crop growth and strong evaporation. While the aquifer was divided into soil layer and groundwater aquifer, the exchange flow between them should be considered as components for water balance analysis" (Fig.B2 in Appendix in revised manuscript, cited from Fig.3 in our previous study (Chen et al., 2020)). The groundwater recharge (GR) from infiltration of soil layer is supposed to be output component of water balance (Fig.B2 A). "For areas with groundwater depth less than 3 m, the upward movement of groundwater served as input component for water balance together with precipitation and irrigation water (Fig.B2 B). Evapotranspiration and infiltration to groundwater were taken as output components of water balance, together leading to the variation in soil water storage (Fig.B2 B)". In our previous study (Chen et al., 2020), it has been proven that 80% of total annual groundwater uptake with shallow groundwater occurred during April to September while the groundwater levels presented a continuously declining trend. According to the long term observation data of groundwater level, the visible rises in groundwater levels after each irrigation and precipitation event ranged from 0.01 to 0.1 m, indicating that most of irrigation water and precipitation tend to evaporate before infiltrating to groundwater during crop growing period due to the heavy crop water demand and strong evaporation (Chen et al., 2020). "Furthermore, the use of averaged groundwater depth offsets the effect of potential errors to an extent". Based on the above conclusions, "it is acceptable to neglect the double counting of water and regard groundwater uptake as a new component in water availability independent on irrigation and precipitation" in this study. In addition, the groundwater depths in 4/5 of the total irrigation districts were more than 3 m, where the groundwater consumption was negligible while only irrigation water and precipitation were considered as water availability. Considering the distribution of irrigation districts across China in this study, the accuracy of the water balance meets the precision requirements at national scale. In this study, the citation of Wang et al. (2011) tended to introduce the definition of equivalent precipitation. We have cancelled the citation of Wang et al. (2011) in revised manuscript to avoid ambiguity.

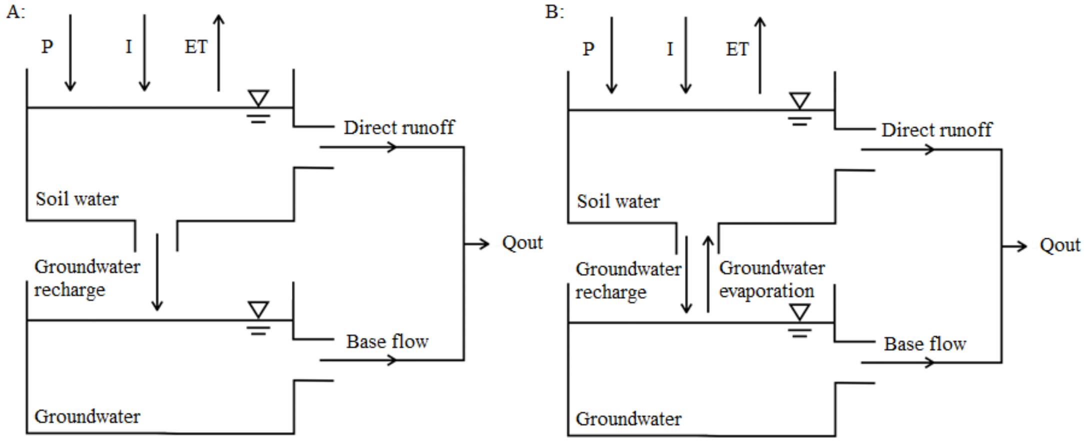

Fig.B2 Structure of water balance model in areas with deep groundwater (A) and shallow groundwater (B) (cited from the Fig.3 in study of Chen et al. (2020))

2. Lack of clear validation with observed data

The authors propose a validation of ET using MOD16 product but it should be stated that the comparison to MOD16 ET cannot be viewed as a strict validation since MOD16 ET relies heavily on modelling. The validation using streamflow time series at catchment scales is to my opinion the unique way to perform a real validation with independent data. The interpretation of Fig.3 is also complicated since all variables (ET/Pe, ET0/Pe) are derived from computation with associated uncertainties that are very difficult to quantify at this stage. Interpreting the deviation of the simulations and "observations" is thus impossible.

Response: Thanks for your suggestions. As far as possible, we tend to understand the variation pattern of evapotranspiration (ET) in large irrigation districts and conduct attribution analysis at national scale. Actually, it is extremely difficult to calculate actual evapotranspiration for the national scale. Here we use the water balance method with measured irrigation water to calculate ET, which we think is relatively accurate for the national scale under current conditions. We agree with you that "the comparison to MOD16 ET cannot be viewed as a strict validation", so we changed the "Validation of water balance equation" into "Comparison between water balance ET and MOD16 ET" as the subtitle of section 3.1 in revised manuscript. The relative expression about "validation" has been rephrased in revised manuscript as well. In the revised manuscript, it was revised as:

"3.1 Comparison between water balance ET and MOD16 ET

The values of annual ET derived from MOD16 product during the year of 2010-2017 are used to make comparison with those estimated by water balance method (Equation 10). As shown in Fig.2, the water balance equation performed well in estimating ET under current conditions compared with that of MOD16 product with RMSE of 124.4 mm/yr, MRE of 18.6%, and R2 of 0.6. In terms of national scale, it's reasonable to believe that the estimated results of water balance equation were relatively accurate in the following study."

Other comments

1. L52-53: Phrasing problems.

Response: Sorry for the phrasing problems. We have revised the sentence as "many studies subsequently derived parametric Budyko-type formulations" in revised manuscript.

2. L151: Why considering Pan evaporation in Eq.3 instead of Penman equation?

Response: Sorry for the ambiguous statement about phreatic evaporation equation. In the original Aver'yanov's phreatic equation, the water surface evaporation rather than potential evaporation was used to estimate groundwater evaporation. Thus, the pan evaporation (which is generally used to denote water surface evaporation) is considered instead of potential evaporation estimated by Penman equation. The explanation is revised as "Epani is the monthly water surface evaporation measured by pan evaporation, (mm)" in revised manuscript.

3. L197-198: Computing effective rainfall is highly uncertain. Eq. 8 is a way to estimate it but may leads to large errors. The USDA SCS method provides alternative ways to take into account soil types and land use classes. Besides, I failed to understand why ET0 is not involved in this calculus of effective rainfall. I would expect that the authors quantify the uncertainties related to this estimation, or at least provide the magnitude of effective rainfall compared to rainfall and Irrigated fluxes

Response: Thanks for your suggestion. According to the definition proposed by the Soil Conservation Service of U.S.D.A. (1967), effective rainfall is that which is received during the growing period of a crop and is available to meet consumptive water requirements. It does not include surface run-off or deep percolation losses (Dastane, 1978). The U.S. Department of Agriculture's Soil Conservation Service has developed a procedure for estimating effective rainfall by processing long term climatic and soil moisture data. In the absence of detailed data, however, "the empirical equation proposed by U.S. Department of Agriculture's Soil Conservation Service was suggested to estimate effective precipitation in areas with slope less than 5°, which has been widely used and performed well in numerous studies and crop models including in China (Cao et al., 2014a; Cao et al., 2014b; Qin et al., 2016; Zheng et al., 2020)".

In this study, the magnitude of effective precipitation compared to precipitation was expressed as the ratio of effective precipitation to the total annual precipitation, which was defined as effective precipitation efficiency as shown in Fig.9. "Only 30% to 70% of rainfall are consumed for crop use and the effective precipitation efficiency in arid and semi-arid regions are generally larger than those in humid and semi-humid regions". In the original Budyko formula, the evapotranspiration ratio (ET/P) denotes the partition of precipitation used for evapotranspiration, i.e., the precipitation use efficiency for plant growth and soil evaporation under natural condition. In our study, the actual evapotranspiration is estimated as the sum of net irrigation water (I_{net}) and effective precipitation (P_{eff}) shown in equation 10. The expression of ET/P can be transferred into $(I_{net} + P_{eff})/P_e$. Since the values of ω are determined by the relationship between ET/P_e and ET_0/P_e, we try to attribute the relatively smaller values of ω obtained for irrigation districts to the water use efficiency, including the irrigation water use efficiency and effective precipitation efficiency. The related analysis results are shown in Section 4.2 "Water use efficiency in irrigation districts" in revised manuscript.

4. L219: Typo in y-axis label.

Response: Sorry for the typo in y-axis label. We have revised the y-axis label as "Water balance ET (mm/yr)" in revised manuscript.

5. L237: Perhaps I missed something but why Pe is replaced with (I+P) in Semi-arid areas?

Response: Sorry for the typo. The water availability was used as Pe, i.e., the sum of irrigation water, precipitation, and groundwater consumption. Only for the areas with groundwater depth more than 3 m, Pe was replaced with (I+P) since the groundwater evaporation was negligible. We have revised ET_0/(I+P) for semi-arid areas as ET_0/Pe in Fig.3 in revised manuscript.

6. L279-281. Is there a clear justification why w is different according to the climatic settings? I would expect that w be more likely dependent on land use, soil and vegetation types, not climate.

Response: Thanks for your suggestions. We agree with you that the parameter ω were dependent on land use, soil, and vegetation types. According to the study of Wang et al. (2018)., it has been proven that the values of parameter ω varied greatly among different climatic conditions. In our study, the areas were firstly classified into four climatic conditions according to the values of aridity index, including arid area, semi-arid area, humid area, and semi-humid area. Meanwhile, the estimated values of parameter ω were grouped by climatic conditions as well to further explore the relationship between parameter ω and influence factors related to the climatic conditions. Since the study areas were irrigated districts and 95% of them were located in plain area with slope less than 5°, NDVI and soil texture were selected as influence factors. The relevant analysis results about the influence of land surface characteristics on parameter ω were discussed in Section 3.4 "Characteristics of ω and influence factors" in revised manuscript.

7. L379: "Effective precipitation efficiency" is not clearly defined. How is it computed and what is really shown on Fig.9?

Response: Sorry for the missing information about "effective precipitation efficiency". "Similar to the definition of irrigation water use efficiency, the effective precipitation efficiency is defined as the ratio of effective precipitation to the total annual precipitation (P_{eff}/P)". In the original Budyko formula, the evapotranspiration ratio (ET/P) denotes the partition of precipitation used for evapotranspiration, i.e., the precipitation use efficiency for plant growth and soil evaporation under natural condition. In our study, the actual evapotranspiration is estimated as the sum of net irrigation water (I_{net}) and effective precipitation (P_{eff}) shown in equation 10. The expression of ET/P can be transferred into $(I_{net} + P_{eff})/P_e$. Since the values of ω are determined by the relationship between ET/P_e and ET_0/P_e, we try to attribute the relatively smaller values of ω obtained for irrigation districts to the water use efficiency, including the irrigation water use efficiency and effective precipitation efficiency. The explanation about Fig.9 is revised as follow:

> "As shown in Fig.9, only 30% to 70% of rainfall are consumed for crop use and the effective precipitation efficiency in arid and semi-arid regions are generally larger than those in humid and semi-humid regions. The arid and semi-arid regions are generally suffering from severe soil salinization (Jiang and Shu, 2018; Peng et al., 2019; Qian et al., 2019) and a series of ecological environment problems caused by it (Besser et al., 2017; Haj-Amor et al., 2017) owing to the scarcity of rainfall and high potential evaporation. To alleviate the negative influence of soil salinization on crop yield, part of irrigation water is applied to flush accumulated salt from soil surface to prepare for the next season's crop (Tang, 2018; Wei and Xu, 2005; Zhang, 1993), finally resulting in small fraction of water availability used by ET. The amount of irrigation water used to leach salt mainly depends on local irrigation technology and water management. In semi-humid and humid areas with relatively abundant precipitation, the application of irrigation events aims to regulate the unevenly distributed rainfall in a year. The small values of ET/Pe reflect the generally low water use efficiency of irrigation districts in China and indicate the significance of water saving measurements. For arid and semi-arid areas with relatively higher rainwater utilization, the improvement of drainage systems can effectively remove the accumulated salt from soil surface, further reducing the fraction of irrigation water used to alleviate soil salinization. For semi-humid and humid areas with enough precipitation, the judicious regulation of rainfall including the effective rainwater harvesting and reuse is expected as helpful way to improve water use efficiency. Reducing unproductive evapotranspiration through canal lining or drip irrigation is applicable to improve water use efficiency as well."

Reference:

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