



Comments on “Large-scale afforestation significantly increases permanent surface water in China's vegetation restoration regions” by Zeng, Y., Yang, X., Fang, N., & Shi, Z. (2020). *Agricultural and Forest Meteorology*, 290, 108001

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ABSTRACT

The paper “Large-scale afforestation significantly increases permanent surface water in China's vegetation restoration regions, *Agricultural and Forest Meteorology*, Volume 290, 15 August 2020, 108001” by Zeng et al. (2020) finds that northern China is greening up and that “vegetation cover is an important factor in controlling permanent water changes”. They suggest that afforestation partially caused the increase in surface water areas due to the “significant positive correlations between forest covers and surface water area”. The authors suggest that, except precipitation, “climatic factors were not the main factor influencing permanent water”. They attribute the increase in area of surface waterbody to the increase in dams, precipitation rise, and afforestation. This commentary aims at clarifying concepts of afforestation-water yield-river flow relations and offers an alternative explanation of the observed expansion of surface water areas in northern China. Using a simple water balance-based approach, we conduct a back-of-envelope calculation and show that afforestation and ‘greening up’ are not likely to cause an increase in water yield and surface water storage. We argue that the detected rise of permanent surface water changes in the study regions is a result of hydraulic infrastructure construction, urbanization, and increase in precipitation, perhaps not vegetation recovery from afforestation. We believe that large-scale afforestation is not likely to increase surface water resources in northern China as implied in Zeng et al (2020). Future process-based studies are needed to understand the sources of the local precipitation and the effects of revegetation on precipitation, soil improvement, and water yield.

1. Introduction

Zeng et al. (2020) presents a multi-year remote sensing based-study in northeastern China (NE) and the loess plateau (LP) areas to explore how afforestation activities in the past decades have influenced surface water resources in a large area (0.9 million km²) that is experiencing ‘the highest significant vegetation cover changes on the earth’. Multi-source remote sensing data and the Least Square Regression method were used to link seasonality and transition of surface water changes to climate, vegetation cover, and dam constructions. The authors found that annual maximum NDVI, permanent water surface area, precipitation, dam construction areas all significantly increased in the two study regions from 2000 to 2015. Thus, the authors concluded “...Large-scale afforestation significantly increases permanent surface water in China's

vegetation restoration regions” because “the statistical analysis results indicated that vegetation cover, especially forest coverage, was significantly positively correlated with permanent water change”. The authors suggest that the mechanism was that afforestation is likely to improve soil infiltration, thus “comprehensive forest hydrological effect significantly increased the regional permanent surface water in NE and LP and provided people with available water resources”. The paper suggests that the hydrologic role of forests is positive to provide more surface water and increased inflow to water bodies causes an increase in water storage in spite of the increase in evaporation loss from vegetation and reservoirs.

We found that the title of the paper is misleading and that conclusions on the role of vegetation restoration in influencing water resources are not supported by the data presented. We found that some

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Figure 1. Man-made check dams and fishing ponds are common watershed features in the Loess Plateau regions in northern China (credit to Xu et al., 2013).

assumptions used in the papers did not align with the basic principles of forest hydrology (i.e. water balances). Information presented may cause further confusions within the ecohydrology communities on the effects of vegetation on water cycles at the watershed scale. Most importantly, the implications presented may have consequences in local watershed management in the arid and semi-arid regions where water resource is extremely critical.

The objective of this commentary aims at clarifying concepts of afforestation-surface water relations. Using a simple water balance-based approach, we conduct a back-of-envelope calculation and show that afforestation and greening up are not likely to cause an increase in water yield and surface water storage. We show that some of the conclusions in Zeng et al. (2020) may not be accurate and further correctional studies are warranted. We offer alternatives to explain the observed increase in permanent surface water areas and decrease in seasonal surface water area using published literature and our data.

2. Basic Forest-Water Relationships and Concepts of Surface Waters

The basic forest-water relationships have been well established around the world during the past century (Andreassian, 2004; Zhang et al., 2017). Deforestation generally increases river flows and afforestation or reforestation decreases it at the watershed scale (Bosch and Hewlett, 1982; Zhang et al., 2001; Brown et al., 2005). We know that planting trees and associated engineering measures for soil and water conservation in northern China are likely to increase ET (Feng et al., 2012; 2016; Schwarzel et al., 2020; Xie et al., 2016), and thus reduce total watershed water yield (Sun et al., 2006; Mu et al., 2007; Zhang et al., 2008) and sedimentation (Wang et al. 2016), and most likely to reduce soil water storage in the unsaturated zones (Yang et al., 2012; Yang et al., 2014; Wang et al., 2009; Jia et al., 2017; Liu et al., 2018; Zhang et al., 2019), and thus reduce groundwater and baseflow. These process-based studies using the water balance principles covered the regions in Zeng et al. (2020) (see Lv et al., 2013; Feng et al., 2012; 2016; Wang et al., 2019) have partially explained the dry up of the mighty Yellow River (Wang et al., 2016) and many rivers under both climatic and human impacts (i.e., deforestation and reforestation, irrigation) in northern China (Zheng et al., 2016). The vegetation-based ecological restoration - water yield relations in northern China are unequivocal and scientists have gradually reached consensus at the watershed level (Zhang et al., 2008; Wang et al., 2011; Feng et al., 2016), and also at regional scale (Li et al., 2018; Ge et al., 2020).

The forest hydrological literature defines water yield (WY) from a catchment is the residual of precipitation (P) and evapotranspiration

(ET), or the sum of streamflow (Q) and change in water storage (ΔS) in soils, aquifer, or stream channels (i.e., subsurface and surface water storage), as presented in the following balance equation (Hewlett, 1982; Sun et al., 2005). The following simple water balance model is used in our discussion on the effects of vegetation on WY. We use this water balance equation to discuss the likely impacts of P and human activities on WY, Q, and ΔS . We separate ΔS into surface ($\Delta S1$) and subsurface water storage ($\Delta S2$).

$$WY = \Delta S1 + \Delta S2 + Q = P - ET \quad (1)$$

2.1. Surface water areas and water yield

Zeng et al. (2020) appeared to use 'permanent surface water areas' (PSWA) as an surrogate of water yield and suggest the hydrological effects of vegetation on WY is controversial. The "controversial" issues and/or the "challenges of uncertainty" for regional water resources mentioned in the paper were the impacts of afforestation on WY, rather than ΔS or PSWA. However, most literature on the effects of re-vegetation on water yield in the Loess Plateau region showed that converting farmlands to forests or shrubs results in an increase ET and thus a decrease in recharge to deep soil layers and consequently water yield and water supply (Yang et al., 2012; Yang et al., 2014; Feng et al., 2012; 2016).

We agree with Zeng et al. that the change in PSWA is related to WY, but $\Delta S1$ is a better term to represent PSWA. Any discussion on the effect of afforestation on water bodies (PSWA) should start with $\Delta S1$. To our best knowledge, the variation of PSWA on Loess Plateau is dominantly controlled by water infrastructures, mainly by the check dams (Figure 1; Xu et al., 2013). Check dams have been widely used for soil conservation as an engineering approach on the Loess Plateau. For instance, in the Yanhe watershed on the Loess Plateau with an area of 7,725 km², there are over 6,572 check dams (Xu et al., 2013). The numerous check dams have significantly increased PSWA and reduced flow down streams. Indeed, the authors also found that "from 2000 to 2015, the permanent water in the reservoirs in NE and LP increased by 350.4 km² and 86.8 km², accounting for 50% and 73% of the increase of permanent water, respectively." However, they mistakenly state "newly built dams contributed 43% in NE and 25% in LP to the increase in permanent water" in the Abstract, thus perhaps underestimating the influences of dams and reservoirs on PSWA.

In addition, confusion between Permanent Surface Water Area (PSWA) and Seasonal Surface Water Area (SSWA) used in Zeng et al. (2020) might also contribute misunderstanding the role of vegetation on water yield. In contrast to PSWA, SSWA is controlled by the seasonal flows such as baseflow, thus is heavily impacted by

Table 1

Modeled effects of afforestation and precipitation change on water yield (WY = Q + ΔS) in Northeast (NE) and Loess Plateau (LP) in northern China. P = Precipitation (Data from Zeng et al. (2020)), and PET = Potential evapotranspiration (data from Lv et al., 2013).

Scenario	Sites	P (mm) (First period)	P (mm) (Second period)	PET (mm)	ET (mm) (first period)	WY (mm) (first period)	ΔET (mm)	ΔWY (mm)	ΔWY/WY
Afforestation only	NE	375	375	700	294	81	51	-51	-62%
	LP	425	425	800	334	91	39	-39	-42%
Precipitation + Afforestation	NE	375	575	700	294	81	170	30	39%
	LP	425	525	800	334	91	118	-18	-20%

Note: First period and Second period mean 'before' and 'after' afforestation, respectively.

afforestation. Interestingly, the decreasing trend of seasonal surface water area (SSWA) in both LP and NE (Figure 3 in Zeng et al., 2020) supports our hypothesis, that afforestation increases water loss through ET, and decreases baseflow and surface water areas in dry seasons and overall annual WY.

Thus, we argue that afforestation (i.e., planting trees) does not have direct physical consequences to PSWA that is mostly controlled by topography and stream channel morphology in natural watersheds. The increase of PSWA is mostly a result of increased hydraulic infrastructures or urbanization that increases impervious surface and stormflow due to decrease in ET. However, the decrease in seasonal surface area (SSWA) is very likely an indicator of water balance change and SSWA is a better variable for quantifying the impact of afforestation on runoff. The data from Zeng et al. (2020) suggest that there was a significant decrease in SSWA in LP, suggesting a possible decrease in water yield and seasonal inflow into surface water storages. We argue that the increase in PSWA does not mean an increase in ΔS at the regional scale. The increase in PSWA or change in water storage change in some areas (e.g., upstreams) may imply a decrease in water yield and water storage change in other areas (e.g., downstreams). We explain this mechanism further using a modeling approach presented in 2.3.

2.2. Processes to explain changes in surface water areas

"Correlations do not equal to causations". This statement in empirical statistical research applies to the results in Zeng et al. (2020). The analysis by Zeng et al. (2020) with Partial-Least Squares Regression (PLSR) showed that the increase in forest areas and greening as indicated by NDVI and EVI had a small but significant influence on PSWA. We argue that these correlations may be statistically correct but lack physical basis, and collinearity may exist between NDVI and precipitation that is strong enough to give the erroneous results. In arid and semi-arid regions, NDVI and ecosystem productivity is rather responsive to water availability (i.e., precipitation) (Xie et al., 2005).

As explained earlier, an increase in vegetation generally reduces river flow and does not necessarily elevate surface water areas unless substantial water storage is increased. Zeng et al. (2020) tried to make connections between ecological restoration and PSWA change. However, they attributed most of the observed increase in PSWA to hydrological effects of dams and other engineering measures, but ignored the largest impacts of vegetation restoration on water yield. Their discussion about the likely impacts of afforestation mostly focuses on soil infiltration, subsurface flow, and potential groundwater recharge, but little on the largest hydrological flux in the arid regions, ecosystem water use (i.e., ET) – the fundamental process in affecting surface water resource. The authors did not explain why urbanization and afforestation has the same directional effects on PSWA. Urbanization often increases in built-up areas and impervious surface areas thus decreases in NDVI and ET (Hao et al., 2015) and afforestation increases in NDVI and ET as discussed earlier. In addition, the authors did not mention the role of climatic change of increase in precipitation in influencing PSWA, and its potential effects on NDVI, EVI and forests covers. The increase of precipitation, either by global climate change or/and vegetation feedbacks (Li et al., 2018), must have large positive impacts on WY and

PSWA but little quantitative discussion was provided in the paper. Thus, the authors fail to explain the mechanistic connections between vegetation restoration and increase in PSWA. We believe that one has to use a water balance approach to fully explain the hydrological processes involved in the observed phenomena of rising surface water area under a changing environment in northern China.

2.3. Scenario Water Balance Modeling to Explain Water Yield and Surface Water Area Dynamics

Both climate change and afforestation can affect water yield and surface water storage. We designed a simulation to demonstrate that water yield decreases with an increase in forest covers that causes an increase in ET, but this decrease can be masked by an increase in precipitation. We used precipitation change data from Zeng et al. (2020) and potential ET data of the two regions (NE and LP) reported in our previous studies in Lv et al. (2013). By combining the water balance equation (Equation 1) with an ET model (Equation 2) that is sensitive to both precipitation and vegetation, change in WY can be estimated by:

$$WY = P - ET = P - \frac{1 + W \frac{PET}{P}}{1 + W \frac{PET}{P} + \frac{P}{PET}} P \quad (2)$$

Change in WY or ET is estimated by the Zhang et al. (2001) model that has been widely used in the study region (Sun et al., 2006; Lv et al., 2012). W is an empirical parameter that reflects the effects of vegetation on ET. We used 0.5 and 2.0 for 'before' and 'after' afforestation, respectively according to Sun et al. (2006) and Lv et al. (2012).

This simple exercise suggests that the 'Afforestation only' scenario alone increases ET and thus reduces WY in both NE and LP regions by 42–62% (Table 1). However, under the 'Precipitation + afforestation' scenario with an increase in precipitation from 375 to 575 mm or 27%, water yield in NE is projected to increase by 39% in spite of the large increase in ET. In contrast, with an increase in 425 mm to 525 mm or 24% in precipitation, the LP region still shows a decrease in annual water yield by 20% as a result of increase in ET of 334 mm due to afforestation that overwhelms the increase in precipitation.

It is safe to say that an increase in WY means an increase in $Q + \Delta S$, such as the case for NE under the increase in precipitation. Similarly, a decrease in water yield (WY) generally means a decrease in $Q + \Delta S$, and unlikely results in an increase in surface water storage (ΔS_1) under natural conditions. However, engineering structures such as dams and fishing ponds built by humans can increase surface water storage (ΔS_1) in certain part of a watershed at the expense of reducing discharge (Q) down streams. In another word, these ponds built for temporary or permanent water storages altered the spatial distributions of ΔS at a watershed or landscape level. Under such a scenario, subsurface water storage (ΔS_2) such as soil moisture on hillslope uplands and groundwater may still decreased as reported in many literature (Yang et al., 2012; Yang et al., 2014; Wang et al., 2009; Jia et al., 2017; Lv et al., 2019). This mechanism may explain the observed increase in PSWA in both NE and LP regions and also the decrease in SSWA for LP as reported in Zeng et al. (2020).

3. Conclusions

We argue that the paper by Zeng et al. (2020) does not offer robust data to support the conclusions that afforestation increases surface water areas in northern China. The interpretations of the statistical casual relations between rise of forest cover and surface ponding areas are erroneous resulting in misleading implications. The research method by Zeng et al. (2020) is not able to separate the true role of vegetation in influencing surface water resources from climate, dam constructions, and activities not related to afforestation.

Using a water balance approach and literature, we offer alternatives to explain the data presented in Zheng et al. (2020). We show that afforestation is not likely to increase in water resources in northern China. The reported increase in area of permanent surface water body in Zeng et al. (2020) was most likely caused by the recent dam constructions for water supply, regional increase in precipitation, and urbanization, not by the increase in forest covers and ‘greening up’. The increase in surface water storage is likely to increase water loss through surface water evaporation and further stress water supply down streams. Evaluating the benefits of such hydraulic structure need to consider at a watershed scale. Future studies need to examine all the water balance components including subsurface water storage at a watershed scale to fully understand the impacts of environmental changes (i.e., dam and pond building, climate change and variability, reforestation and afforestation, urbanization) on watershed hydrology (e.g., downstream – upstream relations) and water resources. In addition, future process-based studies are needed to understand the sources of the local precipitation and the effects of revegetation on precipitation, soil improvement, ET, and water yield.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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