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News & Views

Decadal water storage decrease driven by vegetation changes in the Yellow River Basin

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The Yellow River is the second largest river in China, and it is of paramount importance as it serves various hydro-ecological functions for its inhabitants and environment. It consumes 12% of the water in China, with annual runoff accounting for 2% of the whole country. For sustainable water resources management under climate change and land cover changes (mainly the vegetation change), it is essential to understand the terrestrial water storage change (WSC) and its major driving factors in the Yellow River Basin (YRB) [1].

The YRB, including the northeastern Tibet Plateau and the Loess Plateau, has suffered serious soil erosion issues due to the low vegetation coverage and summer rainstorms. Therefore, to address this serious environmental and ecological issue, The National Ecological Restoration Project—"Grain for Green Project" (GfGP)—has been implemented since 1999 to improve vegetation coverage in the region [2–4]. It is expected that revegetation not only has impacts on the soil structure [5], but also on the water cycle [6,7]. However, there are few reports that comprehensively investigate how revegetation influences catchment to regional water availability (referred as terrestrial water storage hereafter) in the YRB.

The large-scale WSC can be evaluated using the Gravity Recovery and Climate Experiment (GRACE) data which was launched in 2002. This has provided data regarding the monthly global land and terrestrial water storage change, by observing spatio-temporal variations in the Earth's gravity field. There have been several official GRACE datasets released by three different processing centers, including the GeoForschungsZentrum Potsdam (GFZ), the Center for Space Research at University of Texas, Austin (CSR), and the Jet Propulsion Laboratory (JPL). The main limitation with GRACE data is its coarse spatial resolution of 1.0°, which makes it difficult to use when evaluating local water resource changes.

In contrast, the simple water balance method can be used to evaluate WSC at a catchment scale when the three primary water balance components are available [8,9]. These components include precipitation, actual evapotranspiration (ET), and catchment runoff.

Precipitation and catchment runoff can be observed from surface measurements. However, large-scale ET are estimated using a variety of approaches [10]. Among them, the remotely sensed approaches attract more attention, since they can provide spatially and temporally explicit ET estimates. With the rapid development of remote sensing and other geospatial techniques, the high-resolution global ET products have now become available. These include a representative state-of-the-art ET product, the PML-V2, which is a coupled carbon-ET model. It has generated a 500 m, an 8-day ET and gross primary production data across global land surface for the period of 2002–2019 [11]. This model performs similarly or noticeably better than other products. Therefore, PML-V2 ET data can be used together with observed catchment precipitation and runoff to estimate WSC at annual and catchment scales.

The WSC has been investigated in China from regional to national scales (Table S1 online). Major studies carried out for WSC used the GRACE data and (or) hydrological models. Some studies have also attempted to understand the spatial and temporal dynamics of groundwater storage [12]. Other studies investigated trends of WSC caused by the climatic variations and human activities [13]. There have been extensive applications of using GRACE data and hydrological models to assess spatio-temporal changes in WSC. However, there are few studies investigating relationships between the catchment (and regional) variation of WSC and vegetation change. Here, we show the trend of WSC in the YRB from a small catchment to whole basin scales. This may help in gaining a better insight into the underlying hydro-ecological processes at different spatio-temporal scales at a river basin.

Fig. 1a–d summarizes the spatial pattern of trends in precipitation, LAI, ET and GRACE across the research area from 2003 to 2016. The time trend of precipitation is unevenly distributed. It is obvious that precipitation in the middle region of the study area has increased by 10 mm a^{-2} while precipitation in southern region has decreased by 8 mm a^{-2}. However, in most parts of the regions, the precipitation change is not significant ($P > 0.05$). The LAI in the upper Yellow River region has increased slightly, but the strong increase has taken place in its southeastern part, where the

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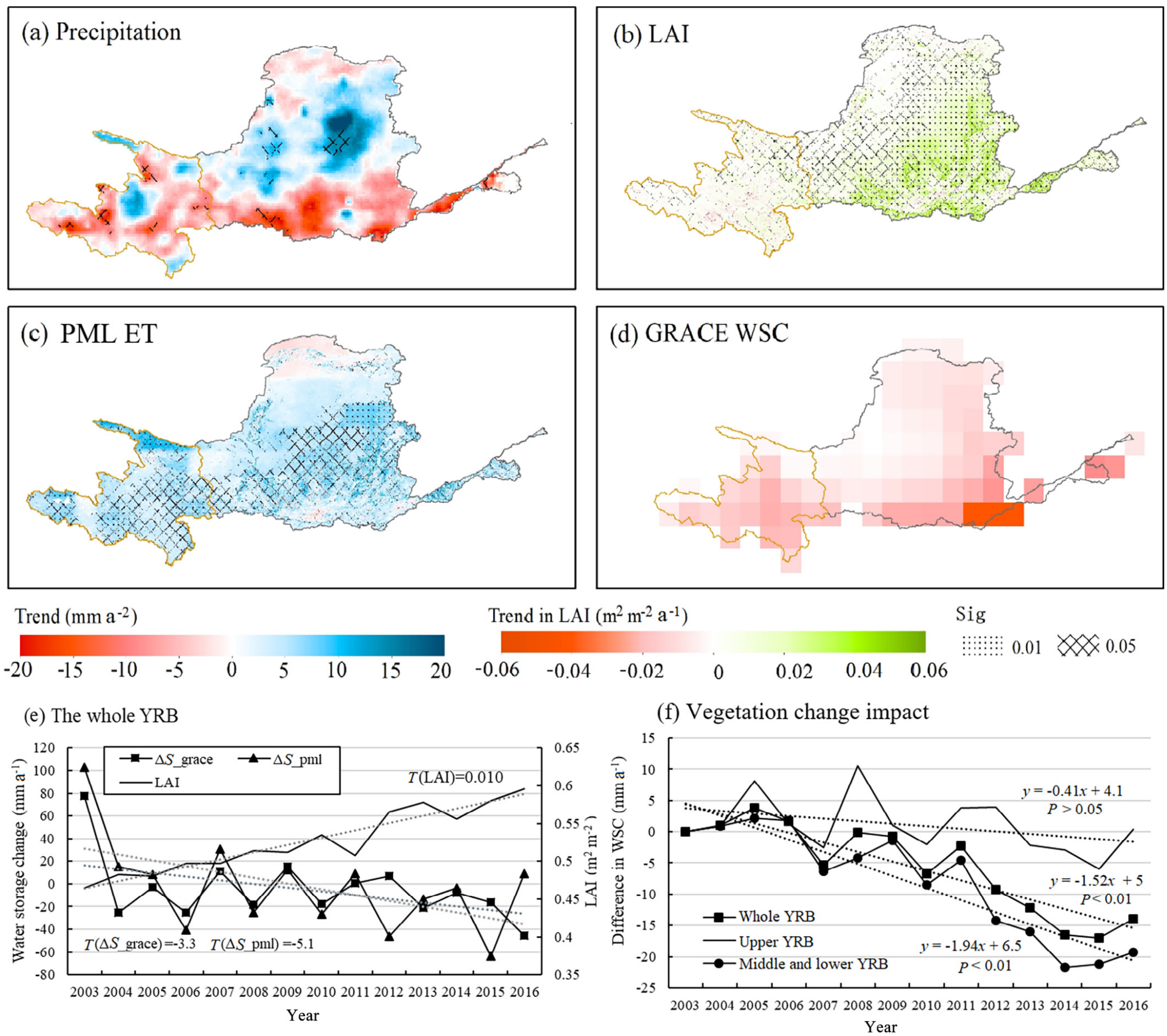

Fig. 1. Water storage change driven by vegetation change in YRB. Annual trends in precipitation (a), leaf area index (LAI) (b), actual evapotranspiration (ET) obtained from the PML-V2 model (c), and water storage change (WSC) obtained from GRACE satellite data for YRB from the period of 2003–2016 (d). (e) Annual variation of water storage and LAI summarized for the whole YRB. (f) Impact of vegetation cover change on WSC, isolated using two modelling experiments: dynamics minus static (see Methods in Supplementary materials online). The upper YRB is delineated by an orange line.

increase in LAI is up to 0.03 $m^2\ m^{-2}\ a^{-1}$ ($P < 0.01$). The trend in ET is positive almost everywhere in the basin, except for some places in the north. In summary, the LAI and ET have increased over the periods from 2003 to 2016. While precipitation showed mixed trends, decreasing in the south, but increasing in the middle reach; the GRACE WSC decreased.

Water storage change obtained from GRACE can be compared with those calculated by the water balance equation (ET is obtained from PML-ET) in the whole YRB (Fig. 1e). The WSC trends obtained from the two approaches (PML named ΔS_pml and GRACE named ΔS_grace) are both negative from 2003 to 2016. For the whole YRB, the trend in ΔS_pml is −5.1 mm a^{-2}, which is close to −3.3 mm a^{-2} in ΔS_grace. The correlation coefficient between ΔS_grace and ΔS_pml is 0.69 ($P < 0.01$). Furthermore, there exists a good overall agreement between ΔS_grace and ΔS_pml in nine small catchments in the YRB (Figs. S1 and S2 online).

The WSC driven by vegetation cover change (ΔS_v) can be isolated using the difference of two modelling experiments (dynamic–static, see Methods in Supplementary materials online). The ΔS_v has decreased across different parts of the YRB (Fig. 1f). Among them, the ΔS_v in the upper YRB decreased slightly by 0.41 mm a^{-2}. The ΔS_v in middle and lower YRB significantly ($P < 0.01$) decreased by 1.94 mm a^{-2}. As a result, the ΔS_v significantly ($P < 0.01$) reduced by 1.52 mm a^{-2} for the whole YRB. It is observed that the decrease in ΔS_v was higher from 2010 to 2016 than from 2003 to 2009 in the middle and lower YRB. Therefore, it is evident that WSC driven by vegetation cover change occurred mainly in the middle and lower reaches of the YRB in 2010–2016.

Overall, the water storage change in the YRB decreased from 2003 to 2016. The WSC in the southern YRB (middle and lower reaches) decreased more than that of other regions. Decrease in precipitation and increase in the leaf area index and ET are the major reasons for the decline in water storage at the YRB.

At the YRB, the environmental conditions have largely improved in the last two decades due to the GfGP. Vegetation coverage in the Loess Plateau increased from 31.6% in 1999 to 59.6% in 2013 [14]. This effectively controlled soil erosion in the region [15]. The change in vegetation conditions can lead to noticeable water storage change, with the impacts being distinct. In the upper YRB, the vegetation change does not play a major role in controlling water storage change. In the middle and lower YRB, vegetation change plays a major role in controlling WSC. It is clear that the serious decreasing water storage change occurred mainly in the middle and lower reaches of the YRB.

Vegetation types have different contributions to decrease in WS between the upper, middle, and lower YRB. In the upper YRB, the most important contributor to the decrease in water storage is cropland, followed by forest, grassland and others. However, in the middle and lower YRB, the most important contributor is forest, followed by cropland, shrubland, grassland and others (Fig. S3 online). This is because the GfGP has resulted in large expansion of forest area in the Loess Plateau (the middle and lower reaches), which resulted in a strong increase in LAI (Fig. 1b).

In summary, the water storage change decreased in the YRB from 2003 to 2016, especially in its southeastern region. A large increase in the leaf area index of the forest and cropland regions in the Loess Plateau is the biggest contributing factor for the increase in ET and decrease of terrestrial water storage. The changes in land cover types have resulted in 1.2 $km^3\ a^{-1}$ decrease in terrestrial water storage in the YRB. This has an alarming implication on regional water resources. For sustainable water use management, more ecohydrological investigations are required on topics of ecological balance and hydrological consequences.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.scib.2020.07.020.

References

[1] Alley WM, Healy RW, LaBaugh JW, et al. Hydrology -flow and storage in groundwater systems. Science 2002;296:1985–90.
[2] Wang QF, Zheng H, Zhu XJ, et al. Primary estimation of Chinese terrestrial carbon sequestration during 2001–2010. Sci Bull 2015;60:577–90.
[3] Yao YT, Piao SL, Wang T. Future biomass carbon sequestration capacity of Chinese forests. Sci Bull 2018;63:1108–17.
[4] Zhang Y, Peng C, Li W, et al. Multiple afforestation programs accelerate the greenness in the 'Three North' region of China from 1982 to 2013. Ecol Indicat 2016;61:404–12.
[5] Lin M, Biswas A, Bennett EM. Spatio-temporal dynamics of groundwater storage changes in the Yellow River Basin. J Environ Manag 2019;235:84–95.
[6] Wang D, Hejazi M. Quantifying the relative contribution of the climate and direct human impacts on mean annual streamflow in the contiguous United States. Water Resour Res 2011;47:W00J12.
[7] Xie X, Cui Y. Development and test of SWAT for modeling hydrological processes in irrigation districts with paddy rice. J Hydrol 2011;396:61–71.
[8] Lv M, Ma Z, Yuan X, et al. Water budget closure based on GRACE measurements and reconstructed evapotranspiration using GLDAS and water use data for two large densely-populated mid-latitude basins. J Hydrol 2017;547:585–99.
[9] Sheffield J, Ferguson CR, Troy TJ, et al. Closing the terrestrial water budget from satellite remote sensing. Geophys Res Lett 2009;36:L07403.
[10] Sheffield J, Wood EF, Munoz-Arriola F. Long-term regional estimates of evapotranspiration for Mexico based on downscaled ISCCP data. J Hydrometeorol 2010;11:253–75.
[11] Zhang Y, Kong D, Gan R, et al. Coupled estimation of 500 m and 8-day resolution global evapotranspiration and gross primary production in 2002–2017. Remote Sens Environ 2019;222:165–82.
[12] Yao C, Luo Z, Wang H, et al. GRACE-derived terrestrial water storage changes in the inter-basin region and its possible influencing factors: a case study of the Sichuan Basin, China. Remote Sens 2016;8:444.
[13] Huang ZW, Tang QH, Lo MH, et al. The influence of groundwater representation on hydrological simulation and its assessment using satellite-based water storage variation. Hydrol Proc 2019;33:1218–30.
[14] Chen Y, Wang K, Lin Y, et al. Balancing green and grain trade. Nat Geosci 2015;8:739–41.
[15] Zhang B, He C, Burnham M, et al. Evaluating the coupling effects of climate aridity and vegetation restoration on soil erosion over the Loess Plateau in China. Sci Total Environ 2016;539:436–49.

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