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The interprovincial green water flow in China and its tele-connected effects on socio-economy

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Abstract: Green water (terrestrial evapotranspiration), flowing from source regions and precipitates downwind via moisture recycling, generates surface water resources and sustains socio-economy in sink regions. However, unlike blue water, there has been limited assessment of green water flows and their tele-connected effects on socio-economy. This study used the moisture tracking dataset of 2008-2017 to quantify interprovincial green water flows in China and their socio-economic contributions. Results reveal a complex flow network where green water of each province reciprocally exchanges with each other. Despite self-recycling, green water from source provinces mainly forms precipitation in neighboring provinces, with average interprovincial flow directions from west to east and south to north. About 56% of total green water exported from 31 provinces retains at home and contributes 43% of precipitation in China. Our assessments show that green water from source provinces embodies substantial socio-economic values for downwind provinces with regionally varying importance. Western provinces are the largest contributors to surface water

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resources while southwestern and central provinces embody the highest GDP, population, and food production. About 40% surface water resources, 45% GDP, 46% population, and 50% food production of China are supported by green water from 31 provinces. There is an overall increase in embodied socio-economic value of green water flow from source to sink provinces, suggesting that less developed provinces effectively support the higher socio-economic status of developed provinces through green water supply. The results emphasize the substantial tele-connected socio-economic values of green water and the need to incorporate it for a more comprehensive and effective water resources management.

1 Introduction

Terrestrial moisture recycling is a crucial process of the water cycle, whereby water evaporates from land into the atmosphere, travels with prevailing winds, and eventually falls back to the land as precipitation (Keys and Wang-Erlandsson, 2018; van der Ent et al., 2010; Zemp et al., 2014). Terrestrial evapotranspiration (i.e., green water (Falkenmark and Rockström, 2006)), which includes evaporation and transpiration from land and vegetation, contributes to over half of the global precipitation on land (Rockström et al., 2023; Theeuwen et al., 2023; Tuinenburg et al., 2020). Green water flows from upwind source regions to generate precipitation and supply water resources for the social development of downwind sink regions through moisture recycling (Schyns et al., 2019; Wang-Erlandsson et al., 2022). Analogous to the upstream and downstream connection via blue water (referring to surface water and groundwater (Gleeson et al., 2020)) flow within a watershed, the upwind source and downwind sink regions are connected via green water flow within the evaporationshed (i.e., downwind regions receiving precipitation from a specific location's evaporation (Ent and Savenije, 2013)). Changes in both blue and green water flow directly impact water resources availability, thereby influencing regional water security and human societies (Keys et al., 2019).

The blue and green water flows provide a mechanism through which changes in ecohydrological and societal processes in upstream/upwind regions may affect the supply of water resources, and thus ecological and societal systems of downwind/downstream regions. Due to upstream water withdrawal and dams, global total blue water flow into oceans and internal sinks has decreased by 3.5% in 2002 (Döll et al., 2009). The decline in water availability exacerbated water stress in downstream

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of transboundary river basins (Munia et al., 2016). Moreover, upstream vegetation restoration, soil and water conservation practices reduced water yield to downstream, as already happened in the Yellow River (Wang et al., 2017; Zhou et al., 2015b). Numerous studies have investigated the causal linkage of blue water flow between upstream and downstream regions, yet research into the linkage of green water flow from upwind to downwind regions and their impacts remains inadequate.

Unlike blue water flow primarily shaped by terrain and regulated by human activities (e.g., reservoir, transfer) with specific routes, green water flow originating from evapotranspiration to precipitation in downwind sink regions is transported by atmospheric air movement in a pervasive manner (Schyns et al., 2019). This establishes a spatial linkage between source and sink regions for green water flow through the moisture recycling process, similar as blue water flow does through the surface hydrological process. Therefore, evapotranspiration changes associated with land cover changes in source regions are likely to impact not only downstream rivers via blue water flow but also downwind precipitation via green water flow (Keys et al., 2012), with further implications on socio-economic development (Wang-Erlandsson et al., 2018). For example, vegetation greening reduced blue water but increased downwind water availability globally through green water (Cui et al., 2022). Reduction in green water in Amazon decreased downwind precipitation in the United States (Lawrence and Vandecar, 2015), and reduction in key green water source regions could decrease potential crop yields in five global key food-producing regions (Bagley et al., 2012).

Source regions supply water resources to support the socio-economic development of sink regions through both blue and green water flows. Existing research has extensively assessed the socio-economic value of blue water, e.g., the population dependency on runoff (Green et al., 2015; Viviroli et al., 2020), while seldom considering tele-connected effects of green water on the socio-economy. In fact, green water is also closely tied to human society because green water traveling from source regions precipitates, forms surface water resources, and ultimately sustains socio-economic activities, livelihoods, and ecosystems in sink regions (Aragão, 2012; Keys and Wang-Erlandsson, 2018; O'Connor et al., 2021). These contributions should be quantified and recognized as the value of green water to socio-economy, which expands the scope of water management and water security maintenance (Keys et al., 2017; Rockström et al., 2023). Emerging moisture tracking technologies offer feasible ways to quantify green water flow across regions at large scale (Keys et al., 2019; Li et al.,

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2023; Theeuwen et al., 2023) and pave the way for assessing the socio-economic value of green water.

Recent studies analyzed green water flows at the national or regional scale to identify the source and sink areas of specific regions, like the Tibetan Plateau (Zhang et al., 2024) and Europe (Pranindita et al., 2022). However, green water flows from different regions are interlinked because different regions could become sources and sinks of each other, especially for large countries like China. Such green water transfer at a sub-national scale effectively forms a complex green water flow network, and highlights the mutual dependency of green water and its socio-economic contributions across different regions. Yet, the interprovincial green water flows in China and their socio-economic contributions remain unquantified.

In this study, we used a high-quality moisture trajectory dataset from the UTrack model to quantify and visualize the interprovincial network of green water flows within China. We next combined socio-economic statistical data to evaluate socio-economic values embodied in green water flow for economic production, population and food production. Our study aims to reveal the transboundary green water flows within China and their tele-connected effects on the socio-economy. By incorporating green water flow into water resources, this study extends water resources management beyond blue water toward a more complete understanding of the water cycle and its socio-economic implications, which is beneficial to assess and optimize regional water security.

2 Data and Methods

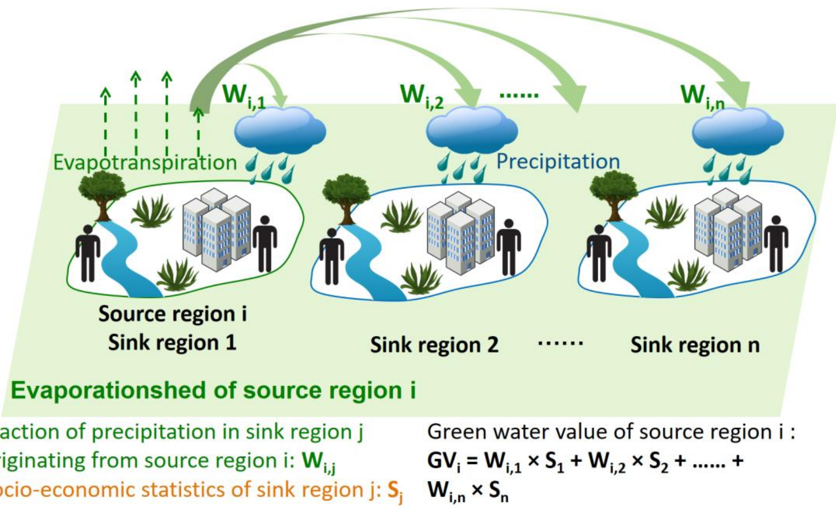

Figure 1. Conceptual figure of green water flows from source to sink regions and their association with socio-economy.

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This study used the moisture trajectory dataset generated by the Lagrangian moisture tracking model "UTrack-atmospheric-moisture" driven by ERA5 reanalysis data (Tuinenburg et al., 2020). The dataset provides monthly moisture flows at the global scale with a spatial resolution of 0.5° for 2008-2017, expressed as the fractions of evaporation from a source grid allocated to precipitation at a sink grid. The detailed processing of the moisture trajectory dataset can be found in Li et al. (2023), and here we focus on the quantification of interprovincial moisture flows and resultant precipitation. The fractions from the moisture trajectory were first multiplied by ERA5 evapotranspiration (ET) to obtain monthly precipitation at a given sink grid contributed by green water from all source grids. Repeating the calculation for all grids within a sink province and summing them up yielded the total precipitation contribution by green water. We next employed zonal statistics with sum method to estimate precipitation contribution in sink province by each of its source provinces, and the results were converted to relative contribution (i.e., the fraction of precipitation in sink province *j* originating from green water of a source province *i*, denoted as W_{ij}) rather than absolute contribution to reduce the uncertainty in the latter. The fractions W_{ij} multiplied by precipitation of sink province restore the absolute precipitation contribution. Finally, the interprovincial green water flows in China can be obtained after estimating each province individually.

Green water from upwind source provinces flows downwind and generates precipitation to sustain socio-economic activities in sink provinces. Consequently, precipitation, surface water resources, and socio-economic factors such as economy, population, and food production in sink provinces rely on green water exported from source provinces. If we assume all socio-economic activities in sink province *j* are sustained by precipitation which constitutes surface water resources and recharges groundwater, socio-economic statistics of sink province *j* can be partitioned to source provinces by their share of precipitation contribution (W_{ij}). Therefore, multiplying socio-economic statistics from China Statistical Yearbook (2008-2017) in sink province *j* (S_j) by W_{ij} yielded the socio-economic value of green water from source province *i* (Fig. 1). The total socio-economic value of green water of source province *i* (GV_i) can be obtained by summing its contributions to all sink provinces, as equation (1):

$$GV_i = \sum_{j=1}^{n} (W_{i,j} \times S_j) \quad (1)$$

Where S_j is the average socio-economic value of 2008-2017 (i.e., surface water resources, GDP, population, and food production) at sink province *j*, n is the number of

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sink provinces.

Due to the different socio-economic development statuses, the same amount of green water may produce different socio-economic values between source and sink provinces. This means green water flow also involves changes in embodied socio-economic value from source to sink provinces. Since Eq. 1 shows socio-economic values of green water when consumed in sink provinces, we estimate socio-economic values if green water was retained and consumed in source provinces. We utilized water productivity in source province (WP_i) to quantify socio-economic values of green water if retained in source province without interprovincial transfer (GV_i') (Eq. 2).

$$GV_i' = \sum_{j=1}^{n} (W_{i,j} \times WU_j \times WP_i) \quad (2)$$

Where WU_j is water use in sink province j, WP_i is water productivity in source province i. (i.e., economic output, population, and food production per unit water use).

The changes in the socio-economic value of green water flow (ΔGV_i) from source province i to its sink provinces can be estimated by Eq. 3.

$$\Delta GV_i = GV_i - GV_i' \quad (3)$$

$\sum_{i=1}^{n} \Delta \mathrm{GV}_i$ is the net change in socio-economic values of all interprovincial green water flows in China.

Due to data limitations, we estimated the socio-economic value of green water in terms of surface water resources, GDP, population and food production for 31 provinces in mainland China, without Hong Kong, Macau and Taiwan. GDP was adjusted to constant prices in the year 2020 to eliminate the effects of inflation.

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3 Results

3.1 The interprovincial green water flows in China

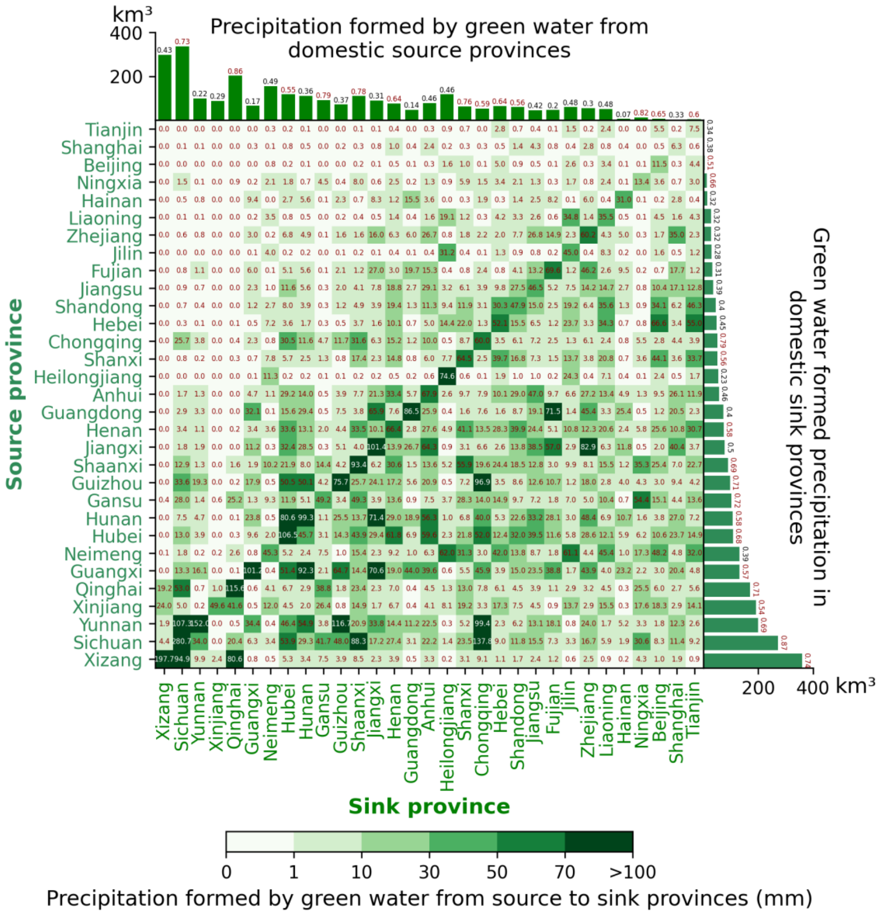

Figure 2. Interprovincial green water flows in China. Heat map denotes precipitation in sink province generated by green water from a source province (mm). The right bar shows domestic precipitation (km^3) formed by green water from each source province, and annotations represent fractions of green water formed precipitation within China to total exported green water. The top bar shows precipitation in each sink province formed by green water from domestic source provinces (km^3), and annotations represent fractions of precipitation generated by green water from domestic source provinces to total precipitation.

Green water exported from a source province forms precipitation in different sink provinces in China, and precipitation in a sink province originates from green water in different source provinces. Therefore, different provinces in China, acting either as

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sources or sinks, are interconnected through moisture recycling and established an interprovincial network (Fig. 2). For instance, green water from Xizang, the largest exporter in China, not only precipitates locally (198 mm) but also contributes to precipitation in other 30 provinces with varying extents (0.2 to 95 mm). Simultaneously, Xizang imports green water from 31 provinces (including itself) to form its own precipitation, especially from Xinjiang (24 mm) and Qinghai (19 mm).

The green water of each source province, apart from being retained locally, predominantly flows and generates precipitation in neighboring provinces. The precipitation recycling rate (PRR), defined as the ratio of precipitation generated by local green water to total precipitation, reflects how much green water of each source province contributes to its own precipitation. In most provinces, PRR is higher than the percentage of precipitation formed by green water from other provinces, suggesting the important role of self-recycling. Among provinces, Xizang has the highest PRR of 34.5%, followed by Qinghai 34.1%, Sichuan 29.7% (Fig. A1). Apart from local recycling, green water flows generate significant precipitation in neighboring provinces. For example, green water from Sichuan forms high precipitation in neighboring provinces such as Chongqing (138 mm), far surpassing other distant sink provinces (< 88 mm).

Green water from source provinces of China contributes to precipitation both within and outside of China, depending on the spatial extent of its evaporationshed and volume of green water. We defined the domestic precipitation ratio (short for DPR hereafter) as the ratio of green water that formed precipitation in China to the total green water export of each province to represent their relative importance to China's precipitation (right bar on Fig 2). Xizang's green water produces the largest domestic precipitation (360 km^3) with a high DPR of 0.74 because Xizang is located in the western China under the influence of prevailing westerlies, making its evaporationshed extend eastward to cover a large territory of China, and generate more precipitation within China. In contrast, green water from coastal or border provinces with most of their evaporationshed laid outside China generates less domestic precipitation but more outside the country, such as Fujian (DPR 0.31) and Heilongjiang (DPR 0.23) near the coast or border. While some inland provinces have a high DPR because their evaporationsheds overlap with mainland China, the low green water volume limits their domestic precipitation contribution (e.g., Gansu and Ningxia with DPR of 0.72 and 0.66, respectively) (Fig. A3).

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Furthermore, precipitation in sink provinces originates from green water of both domestic and foreign sources. Sichuan (337 km^3), Xizang (298 km^3), and Qinghai (203 km^3) are the top 3 provinces importing the largest volume of green water from domestic sources due to the large ET from themselves and neighboring provinces. To quantify the relative importance of domestic sources, we defined the domestic source ratio (DSR) in each province as the sum of precipitation contribution from domestic sources divided by total precipitation (top bar of Fig 2). DSR is related to precipitationshed (i.e., upwind region contributing evaporation to a specific location's precipitation (Keys et al., 2014)) of each province and the included domestic green water exporters. The highest DSR found in Qinghai (0.86) and Ningxia (0.82) is because their precipitationsheds include large domestic green water exporters like Xinjiang and Xizang which supply considerable green water traveling eastward. Conversely, Hainan (0.07) and Guangdong (0.14) in coastal areas have lower DSR because their precipitationsheds are primarily located in oceans and other countries due to the influence of the summer monsoon (Cai et al., 2010).

3.2 Direction of interprovincial green water flows in China

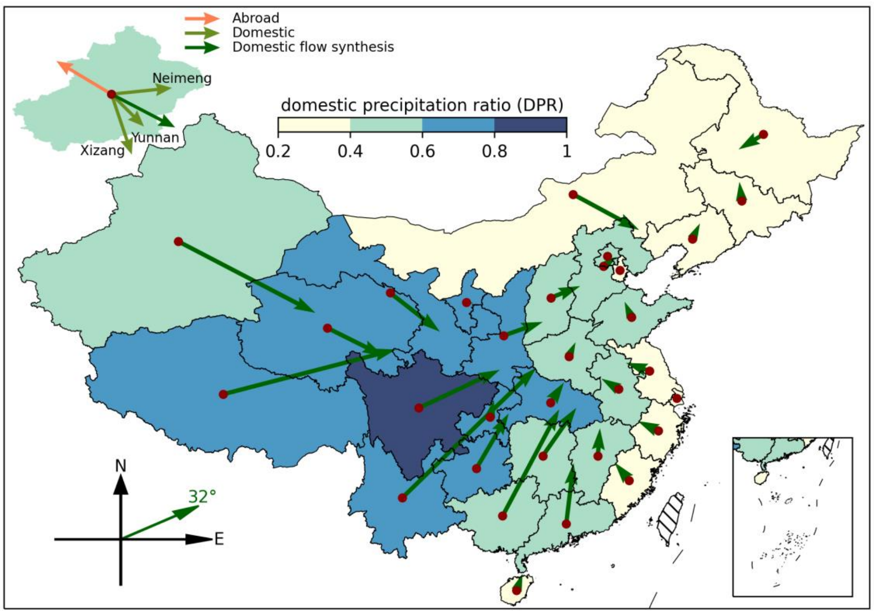

Figure 3. Direction of green water flows from each source province. Green arrows indicate the average direction of green water flow from each source province. The length of arrows shows the amount of precipitation formed by green water. Red points are geometric centers of each province. The colors on map represent fractions of green water formed precipitation within China in each source province (DPR). The upper left corner is a schematic diagram for green water flows from

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Xinjiang. The lower left corner is the composite flow direction of interprovincial green water of all provinces.

The direction of green water flows can be represented by a vector starting from a source to sink province determined by their geometric centers and with its length denoting flow magnitude. Since green water flows have multiple destinations, each flow points to different sink provinces, and even outside of China. For each source province, all of their domestic green water flow vectors can be averaged to a composite to represent their net direction and magnitude, which are mainly determined by atmospheric wind conditions, source location and green water volume (Fig. 3).

The dominant direction of green water flow from most western and central provinces is eastward because of the prevailing westerlies. The exported green water generated precipitation along the movement to eastern coast of China, making their evaporationsheds cover large area of China and with a higher DSR. Moreover, these provinces produce a greater amount of domestic precipitation than other provinces due to their large volume of green water, as indicated by the longer arrows.

The green water from eastern provinces mainly goes to the northwest primarily attributed to the East Asian Monsoon (southeast monsoon) (Cai et al., 2010; Yihui, 1993). However, a significant portion of green water forms precipitation outside of China (not included in the interprovincial green water analysis), resulting in a lower DPR.

The green water from southern provinces is also affected by the Indian Ocean Monsoon (southwest monsoon), which drives green water flowing northeastward. With a substantial volume of green water, these southern provinces contribute significantly to domestic precipitation with long arrows.

The northern provinces are influenced by westerly winds and winter monsoon from Siberia (Sun et al., 2012), causing predominantly southeastward flow of green water. However, evaporationsheds of these provinces mainly cover the Pacific Ocean, resulting in a relatively low DPR despite their substantial volume of exported green water.

The average direction of all interprovincial green water flows in China is at 32° northeastward (32° north off the east direction), suggesting green water within China overall is transported to the north and east directions owning to combined effects of monsoons and westerly.

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3.3 Socio-economic effects of interprovincial green water flows

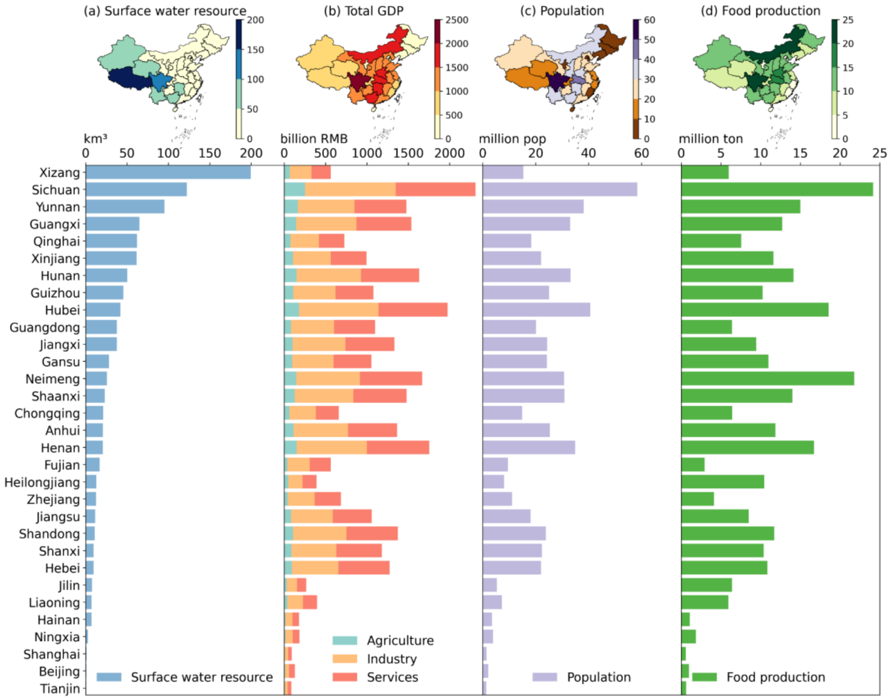

Figure 4. The tele-connected effects of green water flow from source provinces on surface water resources, GDP, population, and food production (average value of 2008-2017) in sink provinces of China.

Source provinces export green water and bring precipitation to sink provinces through the moisture recycling process, contributing to surface water resources and supporting the socio-economic development of downwind sink provinces (Fig. 4). The reliance on green water supply from source provinces for socio-economic activities of sink provinces indicates a tele-connection between source and sink provinces. It implies that the green water and socio-economy are intertwined through the interprovincial green water flow network.

Our assessment of contribution of green water to surface water resources indicates that green water from western provinces generates the highest volume of surface water resources. Xizang (200 km^3), Sichuan (122 km^3), and Yunnan (95 km^3) are the top 3 contributors of surface water resources, making up to 46%, 50%, and 51% of their own total surface water resources, respectively (Table. A1). They also correspond to the top contributors to domestic precipitation, owing to the close linkage between precipitation and surface water resources. Although southern and eastern provinces are rich in surface water resources due to the wet climate, most of their green water contributes to

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surface water resources outside of China or to the ocean since they are situated downwind of prevailing westerlies and proximate to the coast (e.g., Guangdong). In total, green water exported from 31 provinces together contributes 43% and 40% of precipitation and surface water resources in China (Table. A1).

The GDP, population, and food production embodied in green water export from source provinces are shown in Fig 5b-d, which reflects how much socio-economy of downwind sink provinces is supported by green water of source provinces. Overall, the contribution of green water to selected socio-economic statistics shows similar rankings because food production and agriculture GDP (R = 0.79), population and total GDP (R = 0.85) are correlated (Fig. A5).

Sectoral GDP embodied in green water from source provinces is highly related to the industrial structure in sink provinces. The industry and service sector GDP values embodied in green water across provinces are relatively comparable, whereas agricultural GDP values are lower due to the small contribution of agricultural output to total GDP (Fig. A2).

Green water from southwest and central provinces (e.g., Sichuan, Hubei, Henan) embodies the most GDP, population, and food production, because of the large economic volume of these provinces and neighboring regions, as well as the high DPR. Specifically, green water from Sichuan supports the highest GDP (2312 billion RMB), population (58 million people), and food production (24 million tons) (Table. A2), because Sichuan has high GDP, population and food production (Fig. A2). Also, green water from Sichuan contributes significantly to precipitation in Sichuan (30%) and 87% of its green water generated domestic precipitation. These factors together make green water in provinces like Sichuan embody the highest socio-economic values.

Provinces exported large volume of green water and with high DPR do not necessarily embody more socio-economic values if sink provinces importing their green water are less developed. Xizang is the highest green water exporter and the largest contributor of surface water resources (200 km^3) but ranks low in embodied GDP (561 billion RMB, 23rd), population (15 million, 20th), and food production (5.97 million ton, 23rd) because provinces importing most of its green water, such as Xizang and Qinghai, have low rankings in GDP (31st, 30th), population (31st and 30th), and food production (30th and 29th).

Green water from highly developed provinces (e.g., southeastern China) may not necessarily embody high socio-economic value if they have low DPR. For example,

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Guangdong ranks 1st in GDP and population and 17th in food production, but with a small fraction of green water contributed to domestic precipitation (DPR 0.4). The limited domestic precipitation contribution results in low rankings of socio-economic value (14th for GDP, 17th for population, and 21st for food production) embodied in green water of Guangdong.

4 Discussion

This study quantified the interprovincial green water flows in China using the moisture recycling framework and a moisture tracking model. The green water flow is established by the transport of evaporated moisture by atmospheric winds from a source province to precipitate in a sink province. The transferred green water exchanges among multiple provinces and creates an interprovincial flow network. The location of the source province and its flow direction largely determine to what extent green water formed precipitation retains within China. In our estimation, roughly 43% of green water forms precipitation in China, similar to 44% of PRR identified by Rockström et al. (2023). The average direction of all inter-provincial green water flows in China is from southwest to northeast, consistent with findings by Xie et al. (2024).

Since green water from source provinces contributes to water resources and supports socio-economy of downwind sink provinces, various socio-economic activities of downwind sink provinces including economy, population, and food production are tele-connected to source provinces. This highlights the critical role of green water in sustaining the socio-economy and implies substantial socio-economic values embodied in interprovincial green water flows. When green water travels from source and sink provinces with different levels of socio-economic development, the socio-economic values embodied in the same amount of green water will change.

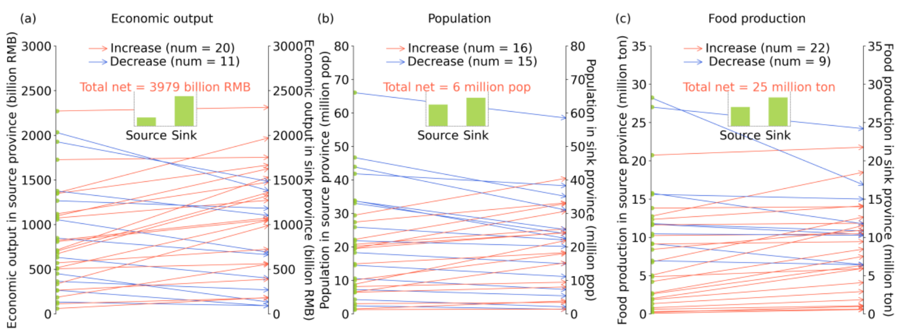

Figure 5. The economic output (a), population (b) and food production (c) value embodied in green water flow and their changes from source to sink provinces. Thin arrows of different colors represent the socio-economic value increase (in red) or decrease (in blue) from source to sink

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provinces. Green bars represent the sum socio-economic value in China's 31 provinces.

The water resources generated by green water, either locally or remotely, affects the socio-economic development of province receiving green water. We investigated how the socio-economic value associated with green water flow would change when transferring from source to sink provinces. We found that the embodied economic output value, population and food production increased for 20, 16 and 22 out of 31 source provinces, with increases of 3979 billion RMB for GDP, 6 million pop for population, and 25 million ton for food production from source to sink provinces (Fig. 5). This indicates that green water tends to flow from less to more developed provinces, with per unit of green water supporting more economic production and population. The largest economic output value increases of green water are found in Guangxi (+826 billion RMB, 54%). Xinjiang has the most added value in population (+13 million pop, 59%) and food production (+7 million ton, 60%) because their green water flows to more developed provinces (Fig. A4). In contrast, decreased socio-economic values of green water flow are also observed. Shandong, Shaanxi, and Henan have the largest reduction in green water values for the economy (-659 billion RMB, 48%), population (-13 million pop, 42%) and food production (-12 million ton, 72%) (Fig. A4) because their green water flows to provinces with lower socio-economic values.

The change in socio-economic value of green water flow reflects the regional disparity in socio-economic statuses between source and sink provinces. The exported green water from more than half of source provinces in China has increased socio-economic values when reaching sink provinces. This shows that green water from less developed provinces effectively supports the higher level socio-economic status of developed provinces through the interprovincial flow network. Therefore, these provinces are vitally important green water providers to developed areas. Such a tele-connected effect of green water and socio-economy implies that changing land use in the source provinces that affect evapotranspiration is likely to influence water resources availability, and socio-economic development in the sink provinces (Dias et al., 2015; Weng et al., 2018). Hence, it is imperative to account for "invisible" green water flow and its cascade effect in large-scale water resources management.

Green water flow can fill the gap in land-atmosphere feedback in the traditional water resources management framework (Keys et al., 2017). Typically, water resources management only considers blue water changes while neglecting green water flow, even though the latter may compensate the former (Hoek van Dijke et al., 2022). Human activities such as irrigation (Su et al., 2021), afforestation (Li et al., 2018) and reservoir

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construction (Biemans et al., 2011; Veldkamp et al., 2017) in upstream regions may markedly change blue water accessibility in downstream regions. Meanwhile, the resulting changes of ET in upstream regions (McDermid et al., 2023; Qin, 2021; Shao et al., 2019) might offset the decline of water resources in downstream by moisture recycling. Similarly, increased vegetation coverage intercepts more rainfall, reducing runoff and consequently diminishing water resources availability (Sun et al., 2006; Zhou et al., 2015a), but the rise of ET may compensate local and downwind water availability through increased green water flows (Wang et al., 2023; Zhang et al., 2021). Therefore, green water stands as one of essential paths of climatic and hydrological interactions among different regions, providing a new angle for integrated regional resources management (Keys et al., 2018; te Wierik et al., 2021). Comprehensive impact assessment of regional water security and optimization would benefit from combining both blue and green water flows (Schyns et al., 2019) by which upstream/upwind regions affect regional water resources availability (Creed et al., 2019).

With the recognition of tele-connected green water flows, maintaining regional water security requires both rational utilization of local water resources and appropriate land management in the upwind source regions. However, similar to blue water, resources management across administrative boundaries has always been challenging due to conflicting interests among different regions (Rockström et al., 2023). The diverse strategies developed to enhance regional coordination of blue water management serve as reference for green water management, such as the inter-basin water transfer or downstream beneficiaries paying upstream providers for clean water services (Farley and Costanza, 2010; Pissarra et al., 2021; Sheng and Webber, 2021). However, unlike blue water resources with well-established accounting and valuation methods, green water monitoring and valuation are challenging. Green water from a specific region flows to multiple regions, and the received green water can subsequently reevaporate and flow to other regions. This interconnected network and cascade complicate the quantification of how much green water from a source region contributes to human activities in sink regions. More importantly, it is difficult to measure green water flow through observations as those measurements made by hydrologic stations for blue water (Hu et al., 2023; Sheng and Webber, 2021). This study utilized a dataset from a moisture tracking model to construct an interprovincial green water flow within China, which offers valuable insights for understanding the

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quantity of green water flow. Our attempts to quantify the socio-economy embodied in green water flow fill the gap in green water value assessment and provide reference for green water management.

Due to complex dynamics of the green water flow and limitations of the moisture tracking model, there are still major uncertainties in data and methods of this study. First, ET and precipitation datasets that drive the tracking model affect the quantity of green water flow. The resulting moisture trajectory data only represent the climatologically average moisture trajectories and ET (Li et al., 2023), neglecting the inter-annual variability in green water flow, e.g., those induced by the influence of extreme weather events or ENSO (Zhao and Zhou, 2021). Moreover, simplifications and assumptions introduced in the moisture tracking model also add uncertainty (Tuinenburg and Staal, 2020). Secondly, the socio-economic value assessment of green water in this study only considers green water flows within China, excluding flows moving abroad and to the ocean that may embody socio-economic value beyond territory of mainland China. We mainly attribute socio-economic values to green water and formed precipitation, because precipitation is the ultimate water source of a region (i.e., surface and groundwater). Strictly speaking, such attribution is not precise because socio-economy also utilizes stream flows from upstream areas which deserve separate attention. Nevertheless, our assessment serves as a useful first step to demonstrate the importance of the tele-connected green water flow in addition to blue water.

5 Conclusion

This study quantified the interprovincial green water flows in China and its tele-connected effects on the socio-economy. The green water exchanges among different regions effectively form a complex flow network and embody socio-economic values. The interprovincial green water in China flows primarily from west to east and to a less extent from south to north, influenced by the co-control of westerlies and monsoon. Western provinces have significant contributions to precipitation and surface water resources in China, while southwestern and central provinces embody the most socio-economic values in terms of GDP, population and food production. Green water flowing from less developed regions supports substantial socio-economic values in more affluent regions, due to disparity in socio-economic development between source and sink regions. Given the embodied socio-economic benefits of green water, regional water resources management should consider water flow beyond blue water to integrate green water for a more comprehensive and effective management of resources and security. Our study provides a reference for understanding the "invisible" green water flow and its tele-connected benefits.

Data and code availability

The moisture trajectory dataset is available at https://doi.pangaea.de/10.1594/PANGAEA.912710 (Tuinenburg et al., 2020). The evapotranspiration data from ERA5 reanalysis dataset is available at https://cds.climate.copernicus.eu/#!/search?text=ERA5. The socio-economic statistics data is available from China Statistical Yearbook (https://data.stats.gov.cn/index.htm).

The Python codes used in this study are available at GitHub (https://github.com/sangshan-ss/GW-China).

Author contributions

YL and SS conceived the study and performed data analysis. SS and YL wrote the manuscript with contributions from CCH, SSZ and HQL.

Competing interests

We declare no conflict of interest of this work.

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References

Aragão, L. E. O. C.: The rainforest's water pump, Nature, 489, 217–218, https://doi.org/10.1038/nature11485, 2012.

Bagley, J. E., Desai, A. R., Dirmeyer, P. A., and Foley, J. A.: Effects of land cover change on moisture availability and potential crop yield in the world's breadbaskets, Environ. Res. Lett., 7, 014009, https://doi.org/10.1088/1748-9326/7/1/014009, 2012.

Biemans, H., Haddeland, I., Kabat, P., Ludwig, F., Hutjes, R. W. A., Heinke, J., Bloh, W. von, and Gerten, D.: Impact of reservoirs on river discharge and irrigation water supply during the 20th century, Water Resources Research, 47, https://doi.org/10.1029/2009WR008929, 2011.

Cai, Y., Tan, L., Cheng, H., An, Z., Edwards, R. L., Kelly, M. J., Kong, X., and Wang, X.: The variation of summer monsoon precipitation in central China since the last deglaciation, Earth and Planetary Science Letters, 291, 21–31, https://doi.org/10.1016/j.epsl.2009.12.039, 2010.

Creed, I. F., Jones, J. A., Archer, E., Claassen, M., Ellison, D., McNulty, S. G., van Noordwijk, M., Vira, B., Wei, X., Bishop, K., Blanco, J. A., Gush, M., Gyawali, D., Jobbágy, E., Lara, A., Little, C., Martin-Ortega, J., Mukherji, A., Murdiyarso, D., Pol, P. O., Sullivan, C. A., and Xu, J.: Managing Forests for Both Downstream and Downwind Water, Front. For. Glob. Change, 2, https://doi.org/10.3389/ffgc.2019.00064, 2019.

https://doi.org/10.5194/egusphere-2024-1420
Preprint. Discussion started: 22 May 2024

Cui, J., Lian, X., Huntingford, C., Gimeno, L., Wang, T., Ding, J., He, M., Xu, H., Chen, A., Gentine, P., and Piao, S.: Global water availability boosted by vegetation-driven changes in atmospheric moisture transport, Nat. Geosci., 15, 982–988, https://doi.org/10.1038/s41561-022-01061-7, 2022.

Dias, L. C. P., Macedo, M. N., Costa, M. H., Coe, M. T., and Neill, C.: Effects of land cover change on evapotranspiration and streamflow of small catchments in the Upper Xingu River Basin, Central Brazil, Journal of Hydrology: Regional Studies, 4, 108–122, https://doi.org/10.1016/j.ejrh.2015.05.010, 2015.

Döll, P., Fiedler, K., and Zhang, J.: Global-scale analysis of river flow alterations due to water withdrawals and reservoirs, Hydrology and Earth System Sciences, 13, 2413–2432, https://doi.org/10.5194/hess-13-2413-2009, 2009.

Ent, R. J. van der and Savenije, H. H. G.: Oceanic sources of continental precipitation and the correlation with sea surface temperature, Water Resources Research, 49, 3993–4004, https://doi.org/10.1002/wrcr.20296, 2013.

van der Ent, R. J., Savenije, H. H. G., Schaefli, B., and Steele-Dunne, S. C.: Origin and fate of atmospheric moisture over continents, Water Resources Research, 46, https://doi.org/10.1029/2010WR009127, 2010.

Falkenmark, M. and Rockström, J.: The New Blue and Green Water Paradigm: Breaking New Ground for Water Resources Planning and Management, Journal of Water Resources Planning and Management, 132, 129–132, https://doi.org/10.1061/(ASCE)0733-9496(2006)132:3(129), 2006.

Farley, J. and Costanza, R.: Payments for ecosystem services: From local to global, Ecological Economics, 69, 2060–2068, https://doi.org/10.1016/j.ecolecon.2010.06.010, 2010.

Gleeson, T., Wang-Erlandsson, L., Zipper, S. C., Porkka, M., Jaramillo, F., Gerten, D., Fetzer, I., Cornell, S. E., Piemontese, L., Gordon, L. J., Rockström, J., Oki, T., Sivapalan, M., Wada, Y., Brauman, K. A., Flörke, M., Bierkens, M. F. P., Lehner, B., Keys, P., Kummu, M., Wagener, T., Dadson, S., Troy, T. J., Steffen, W., Falkenmark, M., and Famiglietti, J. S.: The Water Planetary Boundary: Interrogation and Revision, One Earth, 2, 223–234, https://doi.org/10.1016/j.oneear.2020.02.009, 2020.

Green, P. A., Vörösmarty, C. J., Harrison, I., Farrell, T., Sáenz, L., and Fekete, B. M.: Freshwater ecosystem services supporting humans: Pivoting from water crisis to water solutions, Global Environmental Change, 34, 108–118, https://doi.org/10.1016/j.gloenvcha.2015.06.007, 2015.

Hoek van Dijke, A. J., Herold, M., Mallick, K., Benedict, I., Machwitz, M., Schlerf, M., Pranindita, A., Theeuwen, J. J. E., Bastin, J.-F., and Teuling, A. J.: Shifts in regional water availability due to global tree restoration, Nat. Geosci., 15, 363–368, https://doi.org/10.1038/s41561-022-00935-0, 2022.

Hu, H., Tian, G., Wu, Z., and Xia, Q.: Cross-regional ecological compensation under the composite index of water quality and quantity: A case study of the Yellow River Basin, Environmental Research, 238, 117152, https://doi.org/10.1016/j.envres.2023.117152, 2023.

Keys, P. W. and Wang-Erlandsson, L.: On the social dynamics of moisture recycling, Earth System Dynamics, 9, 829–847, https://doi.org/10.5194/esd-9-829-2018, 2018.

Keys, P. W., van der Ent, R. J., Gordon, L. J., Hoff, H., Nikoli, R., and Savenije,

https://doi.org/10.5194/egusphere-2024-1420
Preprint. Discussion started: 22 May 2024

H. H. G.: Analyzing precipitationsheds to understand the vulnerability of rainfall dependent regions, Biogeosciences, 9, 733–746, https://doi.org/10.5194/bg-9-733-2012, 2012.

Keys, P. W., Barnes, E. A., van der Ent, R. J., and Gordon, L. J.: Variability of moisture recycling using a precipitationshed framework, Hydrology and Earth System Sciences, 18, 3937–3950, https://doi.org/10.5194/hess-18-3937-2014, 2014.

Keys, P. W., Wang-Erlandsson, L., Gordon, L. J., Galaz, V., and Ebbesson, J.: Approaching moisture recycling governance, Global Environmental Change, 45, 15–23, https://doi.org/10.1016/j.gloenvcha.2017.04.007, 2017.

Keys, P. W., Wang-Erlandsson, L., and Gordon, L. J.: Megacity precipitationsheds reveal tele-connected water security challenges, PLOS ONE, 13, e0194311, https://doi.org/10.1371/journal.pone.0194311, 2018.

Keys, P. W., Porkka, M., Wang-Erlandsson, L., Fetzer, I., Gleeson, T., and Gordon, L. J.: Invisible water security: Moisture recycling and water resilience, Water Security, 8, 100046, https://doi.org/10.1016/j.wasec.2019.100046, 2019.

Lawrence, D. and Vandecar, K.: Effects of tropical deforestation on climate and agriculture, Nature Clim Change, 5, 27–36, https://doi.org/10.1038/nclimate2430, 2015.

Li, Y., Piao, S., Li, L. Z. X., Chen, A., Wang, X., Ciais, P., Huang, L., Lian, X., Peng, S., Zeng, Z., Wang, K., and Zhou, L.: Divergent hydrological response to large-scale afforestation and vegetation greening in China, Science Advances, 4, eaar4182, https://doi.org/10.1126/sciadv.aar4182, 2018.

Li, Y., Xu, R., Yang, K., Liu, Y., Wang, S., Zhou, S., Yang, Z., Feng, X., He, C., Xu, Z., and Zhao, W.: Contribution of Tibetan Plateau ecosystems to local and remote precipitation through moisture recycling, Global Change Biology, 29, 702–718, https://doi.org/10.1111/gcb.16495, 2023.

McDermid, S., Nocco, M., Lawston-Parker, P., Keune, J., Pokhrel, Y., Jain, M., Jägermeyr, J., Brocca, L., Massari, C., Jones, A. D., Vahmani, P., Thiery, W., Yao, Y., Bell, A., Chen, L., Dorigo, W., Hanasaki, N., Jasechko, S., Lo, M.-H., Mahmood, R., Mishra, V., Mueller, N. D., Niyogi, D., Rabin, S. S., Sloat, L., Wada, Y., Zappa, L., Chen, F., Cook, B. I., Kim, H., Lombardozzi, D., Polcher, J., Ryu, D., Santanello, J., Satoh, Y., Seneviratne, S., Singh, D., and Yokohata, T.: Irrigation in the Earth system, Nat Rev Earth Environ, https://doi.org/10.1038/s43017-023-00438-5, 2023.

Munia, H., Guillaume, J. H. A., Mirumachi, N., Porkka, M., Wada, Y., and Kummu, M.: Water stress in global transboundary river basins: significance of upstream water use on downstream stress, Environ. Res. Lett., 11, 014002, https://doi.org/10.1088/1748-9326/11/1/014002, 2016.

O'Connor, J. C., Dekker, S. C., Staal, A., Tuinenburg, O. A., Rebel, K. T., and Santos, M. J.: Forests buffer against variations in precipitation, Global Change Biology, 27, 4686–4696, https://doi.org/10.1111/gcb.15763, 2021.

Pissarra, T. C. T., Sanches Fernandes, L. F., and Pacheco, F. A. L.: Production of clean water in agriculture headwater catchments: A model based on the payment for environmental services, Science of The Total Environment, 785, 147331, https://doi.org/10.1016/j.scitotenv.2021.147331, 2021.

Pranindita, A., Wang-Erlandsson, L., Fetzer, I., and Teuling, A. J.: Moisture recycling and the potential role of forests as moisture source during European heatwaves, Clim Dyn, 58, 609–624, https://doi.org/10.1007/s00382-021-05921-7, 2022.

Qin, Y.: Global competing water uses for food and energy, Environ. Res. Lett., 16, 064091, https://doi.org/10.1088/1748-9326/ac06fa, 2021.

Rockström, J., Mazzucato, M., Andersen, L. S., Fahrländer, S. F., and Gerten, D.: Why we need a new economics of water as a common good, Nature, 615, 794–797, https://doi.org/10.1038/d41586-023-00800-z, 2023.

Schyns, J. F., Hoekstra, A. Y., Booij, M. J., Hogeboom, R. J., and Mekonnen, M. M.: Limits to the world's green water resources for food, feed, fiber, timber, and bioenergy, Proceedings of the National Academy of Sciences, 116, 4893–4898, https://doi.org/10.1073/pnas.1817380116, 2019.

Shao, R., Zhang, B., Su, T., Long, B., Cheng, L., Xue, Y., and Yang, W.: Estimating the Increase in Regional Evaporative Water Consumption as a Result of Vegetation Restoration Over the Loess Plateau, China, Journal of Geophysical Research: Atmospheres, 124, 11783–11802, https://doi.org/10.1029/2019JD031295, 2019.

Sheng, J. and Webber, M.: Incentive coordination for transboundary water pollution control: The case of the middle route of China's South-North water Transfer Project, Journal of Hydrology, 598, 125705, https://doi.org/10.1016/j.jhydrol.2020.125705, 2021.

Su, Y., Li, X., Feng, M., Nian, Y., Huang, L., Xie, T., Zhang, K., Chen, F., Huang, W., Chen, J., and Chen, F.: High agricultural water consumption led to the continued shrinkage of the Aral Sea during 1992–2015, Science of The Total Environment, 777, 145993, https://doi.org/10.1016/j.scitotenv.2021.145993, 2021.

Sun, G., Zhou, G., Zhang, Z., Wei, X., McNulty, S. G., and Vose, J. M.: Potential water yield reduction due to forestation across China, Journal of Hydrology, 328, 548–558, https://doi.org/10.1016/j.jhydrol.2005.12.013, 2006.

Sun, Y., Clemens, S. C., Morrill, C., Lin, X., Wang, X., and An, Z.: Influence of Atlantic meridional overturning circulation on the East Asian winter monsoon, Nature Geosci, 5, 46–49, https://doi.org/10.1038/ngeo1326, 2012.

Theeuwen, J. J. E., Staal, A., Tuinenburg, O. A., Hamelers, B. V. M., and Dekker, S. C.: Local moisture recycling across the globe, Hydrology and Earth System Sciences, 27, 1457–1476, https://doi.org/10.5194/hess-27-1457-2023, 2023.

Tuinenburg, O. A. and Staal, A.: Tracking the global flows of atmospheric moisture and associated uncertainties, Hydrology and Earth System Sciences, 24, 2419–2435, https://doi.org/10.5194/hess-24-2419-2020, 2020.

Tuinenburg, O. A., Theeuwen, J. J. E., and Staal, A.: High-resolution global atmospheric moisture connections from evaporation to precipitation, Earth System Science Data, 12, 3177–3188, https://doi.org/10.5194/essd-12-3177-2020, 2020.

Veldkamp, T. I. E., Wada, Y., Aerts, J. C. J. H., Döll, P., Gosling, S. N., Liu, J., Masaki, Y., Oki, T., Ostberg, S., Pokhrel, Y., Satoh, Y., Kim, H., and Ward, P. J.: Water scarcity hotspots travel downstream due to human interventions in the 20th and 21st century, Nat Commun, 8, 15697, https://doi.org/10.1038/ncomms15697, 2017.

Viviroli, D., Kummu, M., Meybeck, M., Kallio, M., and Wada, Y.: Increasing dependence of lowland populations on mountain water resources, Nat Sustain, 3, 917–928, https://doi.org/10.1038/s41893-020-0559-9, 2020.

Wang, S., Fu, B., Liang, W., Liu, Y., and Wang, Y.: Driving forces of changes in the water and sediment relationship in the Yellow River, Science of The Total

Environment, 576, 453–461, https://doi.org/10.1016/j.scitotenv.2016.10.124, 2017.

Wang, X., Zhang, Z., Zhang, B., Tian, L., Tian, J., Arnault, J., Kunstmann, H., and He, C.: Quantifying the Impact of Land Use and Land Cover Change on Moisture Recycling With Convection-Permitting WRF-Tagging Modeling in the Agro-Pastoral Ecotone of Northern China, Journal of Geophysical Research: Atmospheres, 128, e2022JD038421, https://doi.org/10.1029/2022JD038421, 2023.

Wang-Erlandsson, L., Fetzer, I., Keys, P. W., van der Ent, R. J., Savenije, H. H. G., and Gordon, L. J.: Remote land use impacts on river flows through atmospheric teleconnections, Hydrology and Earth System Sciences, 22, 4311–4328, https://doi.org/10.5194/hess-22-4311-2018, 2018.

Wang-Erlandsson, L., Tobian, A., van der Ent, R. J., Fetzer, I., te Wierik, S., Porkka, M., Staal, A., Jaramillo, F., Dahlmann, H., Singh, C., Greve, P., Gerten, D., Keys, P. W., Gleeson, T., Cornell, S. E., Steffen, W., Bai, X., and Rockström, J.: A planetary boundary for green water, Nat Rev Earth Environ, 3, 380–392, https://doi.org/10.1038/s43017-022-00287-8, 2022.

Weng, W., Luedeke, M. K. B., Zemp, D. C., Lakes, T., and Kropp, J. P.: Aerial and surface rivers: downwind impacts on water availability from land use changes in Amazonia, Hydrology and Earth System Sciences, 22, 911–927, https://doi.org/10.5194/hess-22-911-2018, 2018.

te Wierik, S. A., Cammeraat, E. L. H., Gupta, J., and Artzy-Randrup, Y. A.: Reviewing the Impact of Land Use and Land-Use Change on Moisture Recycling and Precipitation Patterns, Water Resources Research, 57, e2020WR029234, https://doi.org/10.1029/2020WR029234, 2021.

Xie, D., Zhang, Y., Zhang, M., Tian, Y., Cao, Y., Mei, Y., Liu, S., and Zhong, D.: Hydrological impacts of vegetation cover change in China through terrestrial moisture recycling, Science of The Total Environment, 915, 170015, https://doi.org/10.1016/j.scitotenv.2024.170015, 2024.

Yihui, D.: Monsoons over China, Springer Science & Business Media, 440 pp., 1993.

Zemp, D. C., Schleussner, C.-F., Barbosa, H. M. J., van der Ent, R. J., Donges, J. F., Heinke, J., Sampaio, G., and Rammig, A.: On the importance of cascading moisture recycling in South America, Atmospheric Chemistry and Physics, 14, 13337–13359, https://doi.org/10.5194/acp-14-13337-2014, 2014.

Zhang, B., Tian, L., Zhao, X., and Wu, P.: Feedbacks between vegetation restoration and local precipitation over the Loess Plateau in China, Sci. China Earth Sci., 64, 920–931, https://doi.org/10.1007/s11430-020-9751-8, 2021.

Zhang, C., Zhang, X., Tang, Q., Chen, D., Huang, J., Wu, S., and Liu, Y.: Quantifying precipitation moisture contributed by different atmospheric circulations across the Tibetan Plateau, Journal of Hydrology, 628, 130517, https://doi.org/10.1016/j.jhydrol.2023.130517, 2024.

Zhao, Y. and Zhou, T.: Interannual Variability of Precipitation Recycle Ratio Over the Tibetan Plateau, Journal of Geophysical Research: Atmospheres, 126, e2020JD033733, https://doi.org/10.1029/2020JD033733, 2021.

Zhou, G., Wei, X., Chen, X., Zhou, P., Liu, X., Xiao, Y., Sun, G., Scott, D. F., Zhou, S., Han, L., and Su, Y.: Global pattern for the effect of climate and land cover on water yield, Nat Commun, 6, 5918, https://doi.org/10.1038/ncomms6918, 2015a.

https://doi.org/10.5194/egusphere-2024-1420
Preprint. Discussion started: 22 May 2024

Zhou, Y., Huang, H. Q., Nanson, G. C., Huang, C., and Liu, G.: Progradation of the Yellow (Huanghe) River delta in response to the implementation of a basin-scale water regulation program, Geomorphology, 243, 65–74, https://doi.org/10.1016/j.geomorph.2015.04.023, 2015b.

Appendix A

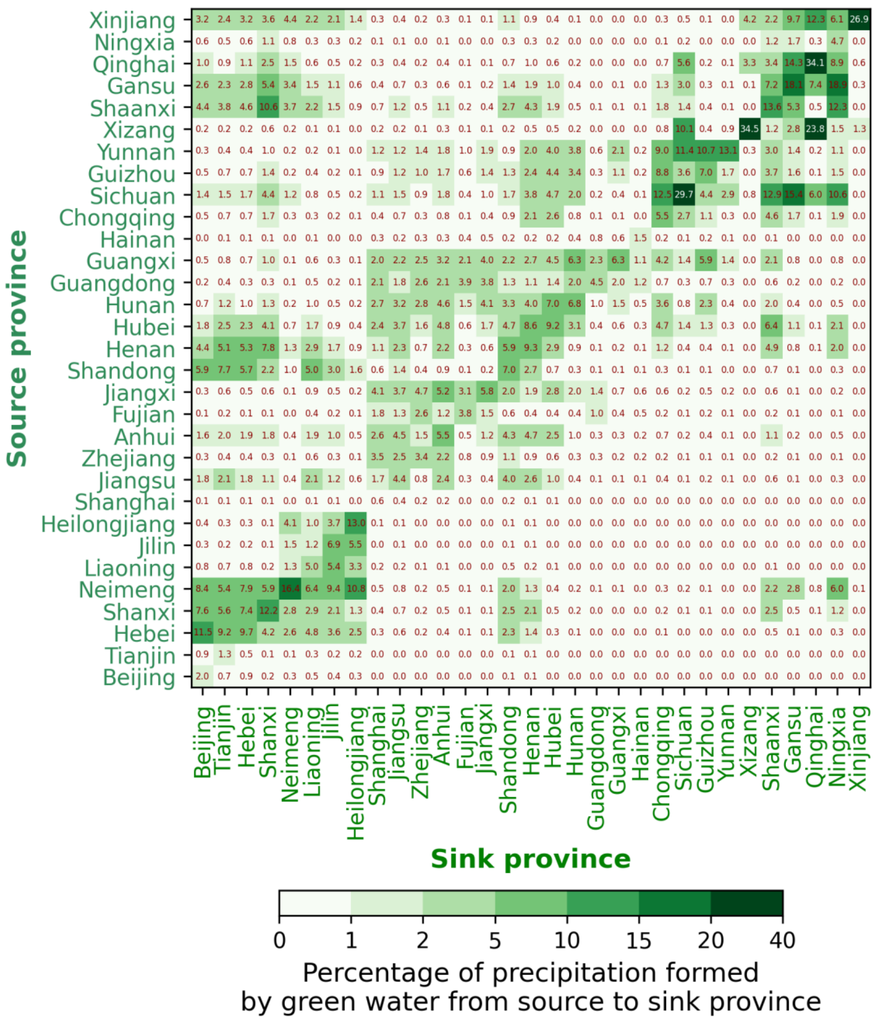

Figure A1. Green water flow from a source province to precipitation in sink province. Red annotations represent the percentage of precipitation from certain source province to the total precipitation in certain sink province.

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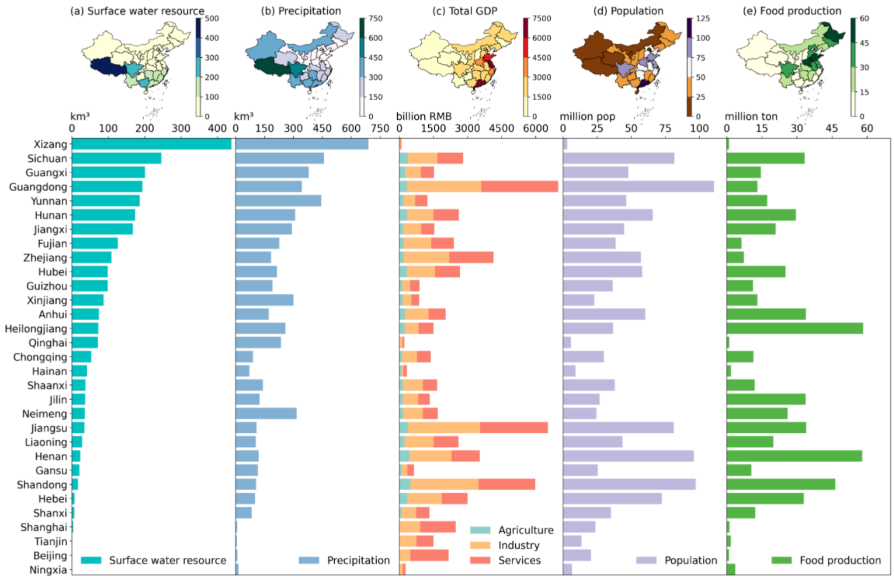

Figure A2. Surface water resource (a), precipitation (b), GDP (c), population (d) and food production (e) in each province.

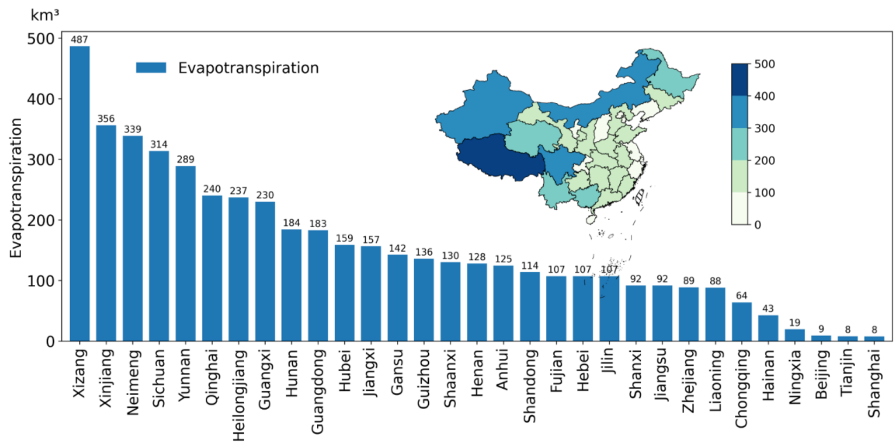

Figure A3. Evapotranspiration in each province.

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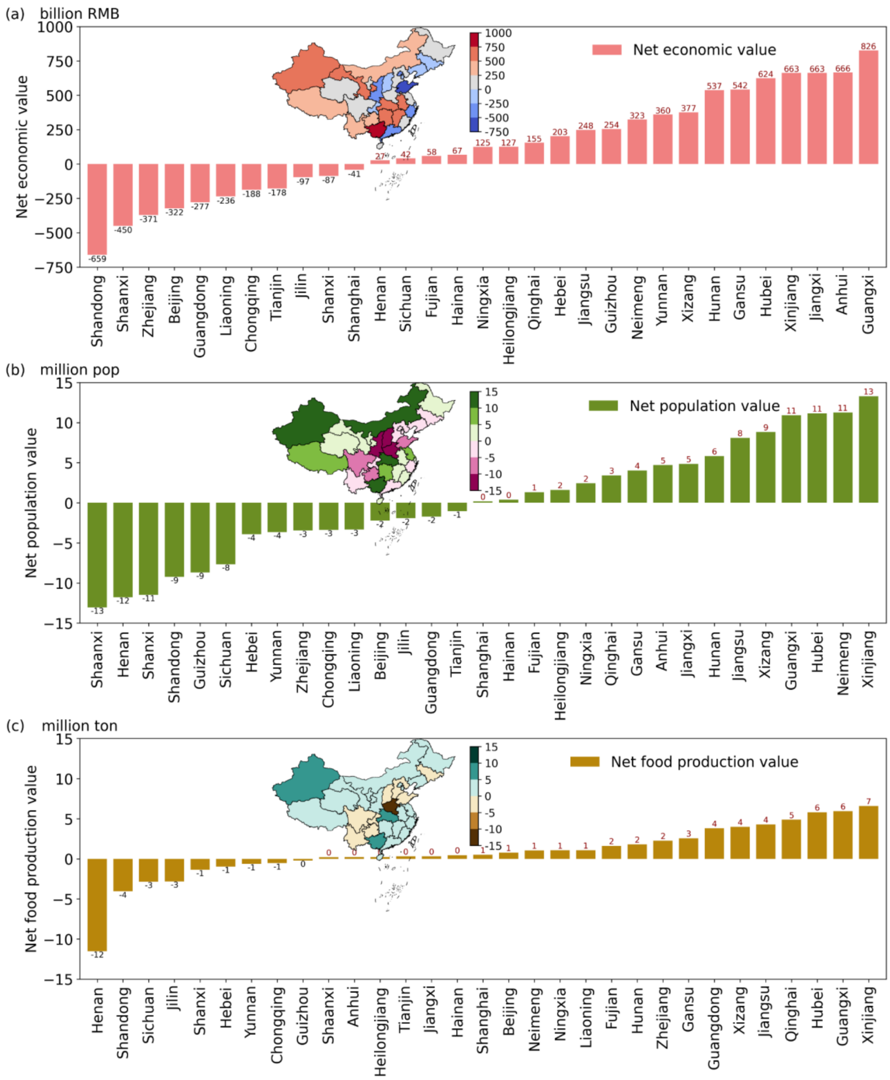

Figure A4. Net economic output (a), population (b), food production (c) value of green water flow in each province. Negative values represent these socio-economic values of water resource formed by green water increase by flowing from source to sink provinces. Positive values represent these socio-economic values of water resource formed by green water decrease by flowing.

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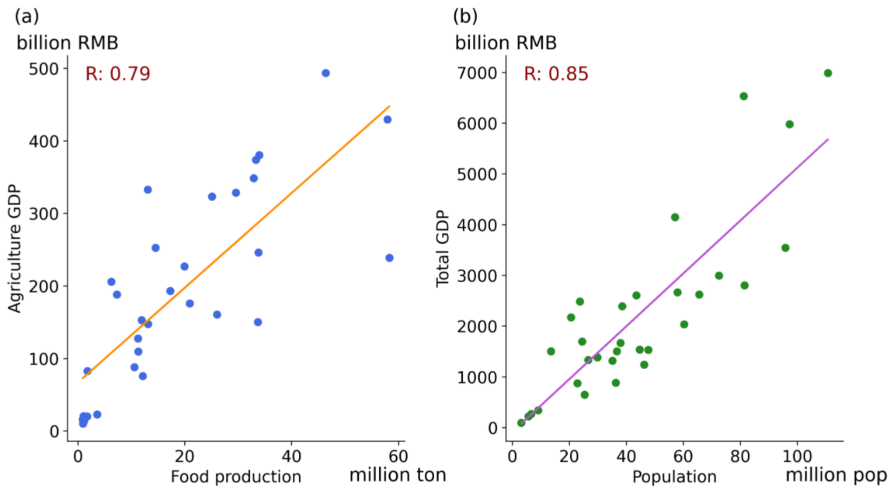

Figure A5. Pearson correlation coefficient between agricultural GDP and food production (a), population and total GDP (b).

Table A1. Surface water resource compare.

Province	Local surface water resource (km^3)	Surface water resource formed by green water (km^3)	Ratio (%)
Beijing	1.05	0.86	82.11
Tianjin	1.18	0.54	45.74
Hebei	6.95	9.38	135.11
Shanxi	6.71	9.58	142.79
Neimeng	35.15	25.62	72.90
Liaoning	28.15	7.07	25.11
Jilin	36.20	7.54	20.83
Heilongjiang	72.21	12.82	17.75
Shanghai	3.38	1.06	31.33
Jiangsu	34.19	11.56	33.82
Zhejiang	109.17	12.62	11.56
Anhui	73.84	20.80	28.16
Fujian	126.26	16.85	13.35
Jiangxi	167.52	37.66	22.48
Shandong	16.34	10.87	66.51
Henan	22.97	20.50	89.24
Hubei	98.63	41.98	42.57
Hunan	173.62	50.20	28.91
Guangdong	193.81	37.66	19.43

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Guangxi	200.68	64.81	32.30
Hainan	41.40	6.99	16.90
Chongqing	53.23	20.99	39.43
Sichuan	245.73	122.16	49.71
Guizhou	98.49	45.43	46.12
Yunnan	185.99	95.34	51.26
Xizang	438.59	199.51	45.49
Shaanxi	37.43	23.00	61.44
Gansu	20.83	28.10	134.94
Qinghai	71.55	61.90	86.50
Ningxia	0.76	2.92	384.55
Xinjiang	87.11	61.45	70.54
Total	2689.11	1067.76	39.71

Table A2. The tele-connected effect values of green water flow on GDP, population, and food production.

Province	Total GDP (Billion RMB)	Agriculture GDP (Billion RMB)	Industry GDP (Billion RMB)	Service GDP (Billion RMB)	Population (Million pop)	Food production (Million ton)
Beijing	128.92	8.09	51.70	69.13	2.05	0.97
Tianjin	86.79	5.16	37.11	44.53	1.33	0.61
Hebei	1274.16	91.69	562.13	620.34	22.00	10.82
Shanxi	1180.10	88.42	542.78	548.91	22.36	10.35
Neimeng	1669.22	146.90	768.35	753.97	30.77	21.78
Liaoning	397.02	38.00	187.78	171.24	7.23	5.92
Jilin	266.65	30.92	123.63	112.09	5.34	6.37
Heilongjiang	389.73	48.85	173.17	167.71	8.04	10.45
Shanghai	90.33	5.73	41.93	42.67	1.41	0.57
Jiangsu	1056.16	80.80	506.93	468.43	18.13	8.50
Zhejiang	685.00	44.54	323.18	317.29	11.08	4.11
Anhui	1365.58	111.59	659.27	594.72	25.42	11.85
Fujian	562.60	38.98	268.58	255.04	9.46	2.93
Jiangxi	1331.84	102.18	637.82	591.84	24.34	9.43
Shandong	1373.26	106.37	645.66	621.23	23.85	11.72
Henan	1753.29	150.86	848.59	753.84	34.94	16.74
Hubei	1975.71	180.31	958.26	837.13	40.57	18.56
Hunan	1630.74	147.89	780.74	702.11	33.20	14.13
Guangdong	1099.02	82.01	522.65	494.36	20.09	6.38
Guangxi	1537.63	144.55	727.78	665.30	33.06	12.70
Hainan	179.27	14.56	83.86	80.85	3.42	1.05

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Chongqing	660.08	64.18	319.49	276.41	14.92	6.40
Sichuan	2312.68	250.83	1098.37	963.49	58.39	24.16
Guizhou	1076.17	108.05	510.34	457.78	25.05	10.25
Yunnan	1478.03	164.39	685.76	627.88	38.21	14.98
Xizang	560.89	65.71	262.50	232.67	15.32	5.97
Shaanxi	1478.25	126.34	711.26	640.65	30.87	14.00
Gansu	1054.50	98.16	499.48	456.87	24.22	10.96
Qinghai	724.98	74.47	344.49	306.02	18.30	7.56
Ningxia	183.81	15.82	87.14	80.86	3.88	1.85
Xinjiang	995.82	106.22	456.23	433.37	22.03	11.60