



Commentary

Coordinating red line policies with water consumption caps in China's drylands

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China's rapid economic growth over the past four decades has come at the cost of the environment, with increasing challenges related to natural resource depletion, in addition to genuine water scarcity in nearly one-third of the country [1]. As a result of extensive irrigation development, more than 50% of cropland is irrigated [2], and upland agricultural production is facilitated by rain harvesting, resulting in less water being available downstream. The impacts of climate change have compounded these environmental issues and further contributed to ecosystem degradation. Thus, China faces the challenge of balancing food, water, and ecological security, especially in China's drylands, which cover 6.6 million km² (70% of China) with 580 million people. Agricultural water withdrawal accounts for 95% of total water withdrawal in drylands [1], and dryland agricultural water consumption has resulted in large-scale aquifer depletion.

Recognizing this challenge, China has gradually evolved and developed a series of red line policies (RLPs) as part of the pathway to “ecological civilization” (Supp-1 online), where development respects the ecological carrying capacity. RLPs in China's drylands include arable land, water, and ecological red lines (Fig. S1 online). Typical measures under the RLP framework include cropland protection and reclamation, well-facilitated cropland, irrigation modernization, water-saving measures, conservative tillage, tree crop plantations, soil and water conservation on sloping lands, land terracing, afforestation, assisted natural regeneration, silviculture management, river channel and mountain rehabilitation, urban green space, wetland restoration, closed forest treatment, and afforestation and reforestation [3,4]. These measures lead to improvements in management practices for croplands and the restoration of vegetation cover (particularly forest, grasslands, shrublands, and agroforestry) with agricultural and ecological benefits, which further increase land productivity and soil carbon storage through reductions in erosion, increases in water infiltration of 40%–80% and increases in soil organic carbon of 28%–45% [5].

However, the implementation of RLPs in China's drylands has had nonanticipatory consequences because of the lack of effective coordination among them, which has imposed substantial pressure on water (Supp-2 online). Most measures for implementing RLPs have been promoted separately, failing to address competition for water demand and adapting to constantly changing socioeconomic conditions, resulting in a decline in dryland ecosystem services, limiting dryland development and endangering livelihoods. Agricultural activities do contribute to water scarcity but also suffer from it. China's drylands have undergone an unprecedented level of arable land reclamation [6,7] to increase production and compensate for cropland losses in other parts of the country. This has led to unprecedented levels of cropland expansion, particularly in Xinjiang (Supp-4.1 online). Although these efforts have stabilized the total cropland area of China, they have also substantially increased the intensity and overall volume of agricultural water consumption. This, in turn, has exacerbated regional ecosystem degradation [8]. Although large-scale ecological RLP measures have been successful in curbing land degradation and improving ecosystem services, they can exert excessive pressure on regional water resources [9]. The “Grain for Green” Program and the Natural Forest Protection Project, which return cropland to forest, for example, have had a positive impact on increasing the forest proportion, improving biodiversity and reducing soil erosion in the upper and middle reaches of the Yellow River Basin [1], and they have had a negative impact on freshwater storage by increasing evapotranspiration (ET) and reducing soil moisture by 1.5 mm over China's drylands [1]. Infrastructure has been central to RLPs, and some infrastructures have paradoxically exacerbated the challenges of water scarcity (Supp-4 online). Most measures for implementing RLPs (12 out of 14) increase ET (Table S2 online and Fig. 1), such as afforestation and terracing. Some measures have the potential to mitigate the water crisis, including irrigation modernization, the selection of drought-tolerant local species instead of water-intensive varieties, the regulation of vegetation density by thinning, and the adoption of water-saving measures. Water balance assessments revealed that the decrease was insufficient to offset

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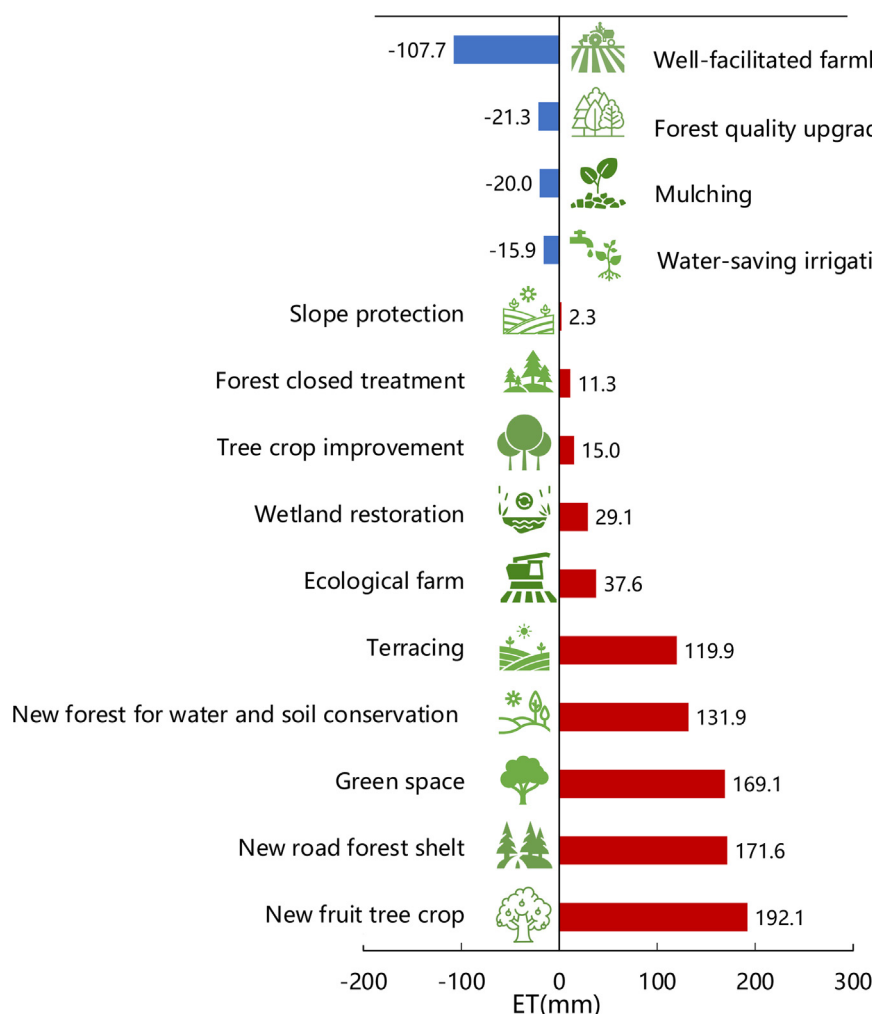


Fig. 1. Averaged ET changes induced by implementing RLP measures in five example watersheds.

the increase in water consumption, and water scarcity was exacerbated during the 2010–2019 period, including challenges in meeting the minimum environmental flow requirements (MEFRs) for all sample watersheds (Table S3, Supp-2 online). The RLPs underscore a clear recognition of environmental vulnerabilities, but their guidelines and implementation plans lack coordination among measures and/or activities, failing to adequately address the essential issues of water scarcity in China's drylands [4]. Therefore, if adaptation and resilience-building efforts for implementing RLPs are not well targeted and fail to consider potentially competing demands and trade-offs among various users and sectors, they may exacerbate water scarcity threats and challenges. These issues are particularly acute in China's drylands [10].

In the coming decades, China will continue to implement RLP measures, including irrigation modernization, conservative tillage, tree crop plantations, terracing, afforestation, urban green space and wetland restoration, which will cause 5%–24% of land cover changes (Supp-1&2 online). These changes intensify water competition among RLP measures and exacerbate water scarcity in China's drylands. Consequently, RLPs implemented for better ecosystem restoration provide contradictory trends regarding whether progress in achieving desirable objectives is being made. One of the reasons is that the interventions of RLPs have a marked sectoral scope and have not been planned in an inte-

grated manner that considers water constraints and ecosystem trade-offs.

Since 2013, China has promoted national territory spatial planning (NTSP) to integrate plans for main functional areas, land use, urban–rural development, water resource development, irrigation plans, and ecological environment protection. However, issues such as serious resource space mismatch, inefficient use of resources, land degradation, environmental pollution and regional development imbalance still exist, partially because there are no mandatory constraints on the resource carrying capacity and territorial suitability.

Water is a key limiting factor in shaping drylands. Water shortages tend to occur together with food insecurity and malnutrition [11], with over 1.5 billion people and 17% of global food crop production located in basins most vulnerable to fresh water stress and shortages [12]. The exposure of fresh water to human-induced agricultural and urban pressures has also degraded river biodiversity. Water regulation is the primary service of dryland ecosystems and has a cascading effect on all dryland livelihoods [1]. Therefore, limiting water consumption is critical for addressing the challenges of water scarcity and can serve as a leverage and mandatory constraint to coordinate RLPs. Measures aimed at improving agricultural production and water use efficiency, as well as restoring ecosystems as part of implementing RLPs, need to be

carefully considered in trade-offs and positioned within agreed-upon limits of water consumption (Supp-4 online). Appropriate measures need to be taken to control or reduce water consumption by human activities to achieve the total constraint of the water consumption cap (WCC) (Supp-3 online) or the boundary value of the local safe operating space, but only limited measures are available for reducing agricultural, landscape, industrial and domestic water consumption.

Determining the total water consumption cap. The WCC can serve as leverage for coordinating and constraining RLPs (Table S4 online). The WCC is the upper limit of water consumption for human activities and is constrained by the environmental flow requirement (Supp-3&5 online). Water consumption is a lever within the nexus of water for humans, the environment flows and natural ecosystems in drylands, with an increase in any one implying a decrease in the other two (Fig. S3 online). Reductions in anthropogenic water consumption through less water for irrigation and water-saving measures such as mulching can increase water discharge into rivers, and the resulting increase in environmental flow can in turn dilute more pollutants and improve water quality. Pollution control through agricultural nonpoint control and wastewater treatment mitigates pollution-related water scarcity, which increases the amount of water available for humans. Ecosystem protection and restoration primarily affect natural ET, leading to changes in environmental flows or water availability for humans. Therefore, the measures and actions taken by RLPs need to be carefully evaluated, and the nexus of water for humans, environmental flow and natural ecosystems should be fully considered. The WCCs for the current and target years are, for example, $76.0 \times 10^6 \text{ m}^3$ and $69.6 \times 10^6 \text{ m}^3$ for the Shichuan River, respec-

tively (Table S4 online and Fig. 2). The WCC is constantly revised with changes in precipitation due to climate changes and natural ET due to ecological restoration and protection in watersheds. Alternatively, the diversion of water from water-abundant basins to China's drylands could be an effective measure to increase WCC and alleviate water shortages in agriculture and cities at the receiving ends while reducing the impact on ecosystems. One such example is the Hanjiang-to-Weihe River Water Diversion Project and the Bailongjiang Water Diversion Project.

The basic principle of adopting the WCC as the leverage of coordinating RLPs in China's drylands is that the total water consumption of human activities should be below the sustainable level of water consumption, whereas the activities implemented should maximize their impacts to increase water use efficiency, improve water quality, and enhance biodiversity. Indicators were designed to implement RLPs for water (Table S1 online), including binding indicators for water withdrawal (use), water use efficiency and water quality, but these indicators are insufficient, especially in drylands where irrigation agriculture is the main water consumer. Adding consumption use as an indicator can improve the design of intervention measures and the monitoring of their outcomes [4].

The WCC approach accounts for not only the needs of environmental flow and natural ecosystems (mostly in terms of green water consumption) but also the impact of human activities on the water cycle in a watershed. The WCC can be further allocated to administrative units or sectors in the watershed by weighing consumption and water resource requirements between upstream and downstream areas and between left banks and right banks to determine the total water consumption of each administrative

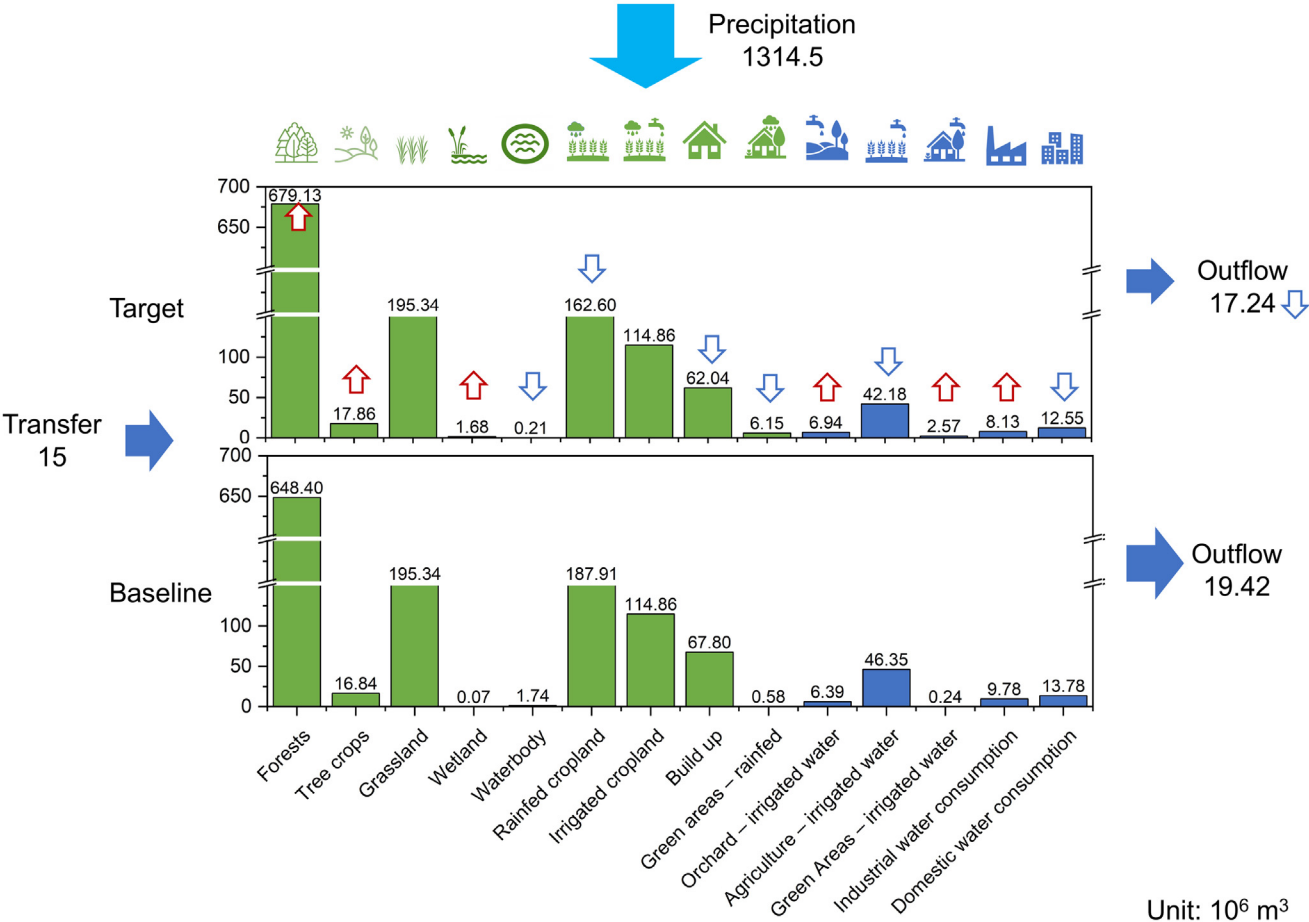


Fig. 2. Baseline and target year water balance in the Shichuan watershed; the colors indicate blue or green water.

unit, which quantifies the sustainable water consumption caps for all stakeholders in the watershed.

Restraining agricultural water consumption. From both the global and watershed perspectives, agriculture is the sector with the highest water consumption [13]. It is essential to limit the total agricultural water consumption to ensure the WCC of the watershed. However, current water-saving measures are insufficient to meet the excessive expectations of alleviating water scarcity. More measures need to be taken, such as adjusting the planting structure, fallowing, and crop rotation, or ensuring food security through interbasin water transfer (Supp-5 online).

There are many methods for ensuring agricultural water consumption within the upper limit of the water allocated to agriculture. By optimizing cropping structures, the world could feed an additional 825 million people, while the consumption of rainwater and irrigation water in agriculture could be reduced by 14% and 12%, respectively [14]. Promoting water-saving technologies such as mulching can reduce water consumption by 10%–30% (Supp-5 online). The simple method is to fallow cropland, particularly less productive irrigated cropland. However, fallowing cropland will reduce crop production and threaten local food security if no other remedial measures are taken to improve productivity. Shifting to higher-value, water-saving crops through cropping pattern adjustments is encouraged to decrease water consumption; this shift requires careful coordination between farmers and water managers, which is supported by economic incentive policies. Additionally, the effectiveness of both irrigation modernization and well-facilitated cropland to reduce ET must be carefully evaluated and managed, as they do not necessarily save water from a watershed perspective if no WCC is implemented (Supp-4&5 online).

Adoption of local species for ecological restoration. With ecological restoration, the consumption of green water resources has an increasing impact on water resources, exceeding the green water planetary boundaries [15]. Owing to the dry climate, all kinds of artificial green landscapes in drylands need additional water for maintenance, which significantly increases ET, further exacerbating regional water resource tension and restricting the sustainable development of drylands. Thus, in 2021, the government issued guidelines to halt the expansion of urban green land and artificial water surface landscapes in arid regions and encourage the use of native species. When planning ecological restoration activities, measures for vegetation improvement should fully consider water resource constraints. The proposed activities can include (i) the restoration of degraded and monoculture forests with native species; (ii) the natural regeneration of native species on site, which involves identifying target trees for retention, the selective cutting of competing vegetation to favor the diverse regeneration of mixed-species clusters, habitat protection, and target tree management; and (iii) afforestation, which involves planting and managing diverse mixed species and ecologically stable forests in priority areas, for example, through forest quality upgrades (Supp-5 online).

Overall, China has established RLPs as part of the pathway to “ecological civilization”, where development respects ecological carrying capacities. However, evidence indicates that RLPs have increased water consumption (Supp-2 online), causing reductions in environmental flows, exceedances of the ecosystem carrying

capacities of water, the loss of hydrological connectivity with floodplains and wetlands, and threats to biodiversity, mainly due to the lack of coordination among RLPs. Therefore, the WCC has been proposed to address the challenges of water scarcity and serve as leverage to coordinate RLPs and NTSPs in China’s drylands not only for the present but also for the future, which is a new emphasis compared with the previous focus on water withdrawal and water use efficiency indicators [4]. The WCC should be implemented for the watershed overall and for the agricultural sector in particular. The employed strategy should involve taking appropriate management measures to control or reduce water consumption related to human activities to constrain the total water consumption for agriculture and for all land types. Some effective measures are recommended to reduce water consumption.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (41991232 and W2412015).

Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scib.2025.02.021>.

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