Does India need a different rice ecosystem to harness the export advantages and manage the virtual water exports?

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The present study assessed the virtual water trade and comparative advantages in rice exports. It suggests realigning the Indian rice ecosystem based on the demand–supply gap, groundwater exploitation, productivity growth and untapped productivity potential. It also advocates the phased shifting of acreage under common (non-basmati) rice production to potential regions identified as suitable. The proposed shifting of cultivation will lead to achieving a sustainable rice ecosystem, conserving the natural resource base and reducing risk in terms of environmental and economic factors. Emerging practices such as dry direct-seeded rice, and the system of rice intensification could be effectively used for sustainable rice ecosystem in India.

Keywords: Comparative advantage, rice, sustainable cultivation, virtual water exports.

Background

THE role of virtual water trade (VWT) in managing global water-saving and ensuring food security is discussed by many researchers[1–4]. VWT has been progressively used as a concept to deliberate and analyse the water flows embodied in the commercial trade that results in the reallocation of water resources and rebalancing of water budgets[5,6]. Water stress is a local phenomenon sensitive to food production globally as agriculture occupies the largest consumption share of global freshwater resources[7,8]. India is facing second-generation challenges like the decline in groundwater, surface-water pollution, water-related stress and the adverse impact of trade patterns[9]. Studies in the Indian context demarcate that the country's virtual water exports have increased multifold in recent years[7,10]. This accentuates the need to contemplate how much virtual water we are exporting through the trade of food commodities, particularly when the Indian Government has targeted to double the agricultural exports to the tune of USD 60 billion to facilitate the mission of doubling farmers' income. This is critical from the perspective of the widespread depletion of groundwater resources in the country[11]. Considering this, the present study assessed the temporal variations in the export of virtual water for rice during the recent two decades. Findings from this study can help policymakers and water managers to develop an efficient conservation strategy for the available water resources in India and monitor VWT of the rice being exported.

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Material and methods

Relevant data for the study were extracted from multiple sources. Export and import data for rice were collected from the International Trade Centre (ITC) website, and its virtual water content was drawn from past studies[12]. The virtual water exported or imported was estimated by multiplying the trade volume with the virtual water content in rice. The quantity of virtual water export (VWE) and virtual water import (VWI) was calculated using the following equation:

$$\text{VWE or VWI} = \text{Traded volume (quantity)} \times \text{VWC of the traded product } (\text{m}^3).$$

Net water trade (NWT) was calculated by deducting virtual water imports from virtual water export.

$$\text{NWT} = \text{VWE} - \text{VWI}.$$

The purpose of NWT is to explore the virtual form of trade surplus and deficit of the traded commodities. The positive value denotes trade surplus, while the negative value demarcates the trade deficit.

Revealed comparative advantage of rice

Revealed comparative advantage (RCA) for rice was calculated as follows[13]:

$$\text{RCA}_{ij} = (X_{ij}/X_{wj})/(X_i/X_w),$$

Table 1. Mapping of agro-climatic zones based on rice surplus, sustainability and productivity potential

Parameters	Description	Categories
Rice surplus regions	The surplus production in rice was computed after meeting the local human consumption requirements. District-wise production data were collated from the Department of Agriculture and Farmers' Welfare, Government of India, while the district-level consumption was worked out using the monthly per capita consumption (quantity) with the district population. The surplus was estimated by deducting consumption from the district-level production.	(1) Deficit zone with <10% surplus. (2) Surplus zone with 10–50% surplus. (3) Major surplus zone with more than 50% surplus.
Groundwater exploitation[a]	District-wise data regarding the extent of groundwater exploitation (GE) were collected from the Central Ground Water Board, GoI for the year 2018.	(1) Safe zone: less than 70%. (2) Semi-critical zone: 0–90%. (3) Critical zone: more than 90%.
Growth in rice productivity	The recent growth in rice productivity during 2011–18 was examined to identify the potential regions. Higher growth was considered favourable to balance the rice output sacrificed from the overexploited regions.	(1) Negative productivity growth zone with less than 0% growth. (2) Average productivity growth zone exhibiting 0–1.20% growth. (3) High productivity growth zone witnessing more than 1.20% growth.
Untapped yield potential	The untapped productivity potential was calculated as follows: $$\text{Untapped productivity potential} = 100 - \left(\frac{\text{Best local} - \text{actual yield}}{\text{Actual yield}}\right) * 100$$ The best local yield was determined using the household-level data available in Situation Assessment Survey of Agricultural Households (2014). The best district yield of rice was estimated out for the top 10 percentile of households cultivating rice. The actual yield was the average yield for the remaining rice-cultivating households in the district.	(1) Low productivity potential zone: less than 15%. (2) Moderate productivity potential zone: 16–30%. (3) High productivity potential zone: above 31%.

[a]Groundwater extraction in a particular area reflects the state of the existing groundwater resources. Groundwater development for irrigation is planned in a manner that the stage of groundwater extraction should not exceed 70% at any time after implementation of the project. Thus, the study has set the critical limit of 70% to indicate the criticality of groundwater resources across agro-climatic zones.

where X_{ij} is the ith country's export of commodity j, X_{wj} the world export of commodity j, X_i the total exports of country i and X_w is the total world export.

RCA value lies between 0 and ∞. An ith country is said to have a comparative advantage in the production of the jth commodity (rice), if the RCA value exceeds one.

Kernel density estimation

The relationship between a random variable's outcomes and probability is known as its probability density. The probability density function (PDF) may be used to determine the likelihood that a random variable is continuous. The probability distribution depicts how PDF for a random variable appears throughout the whole domain. A probability is provided for a certain value by a mathematical function known as a kernel with the condition that the sum of probabilities must equal one. The kernel efficiently smoothens or interpolates the probabilities throughout the possible outcomes. The parameter that controls the scope or window of observations from the data sample contributes to estimating the likelihood for a given sample, referred to as a smoothing parameter (bandwidth). The kernel function is used to control the contribution of samples in the dataset towards estimating the probability[14]. The kernel function is defined as follows:

$$f(x) = \frac{1}{n}\sum_{i=1}^{n}(K_h(x - x_i)) = \frac{1}{nh}\sum_{i=1}^{n}\left(K\left(\frac{x - x_i}{h}\right)\right),$$

where h is bandwidth, n the number of data points and K is the kernel function.

Mapping of agro-climatic zones based on the rice surplus, sustainability and productivity potential

This study was conducted at the agro-climatic zone (ACZ) level as delineated by the Planning Commission, Government of India[15]. It identified four parameters for the sustainability mapping of rice (Table 1).

Trade advantages of Indian rice

VWT embodies the application of absolute advantage, while the comparative advantage integrates the technology and agro-climatic attributes reflected in the actual trade patterns. Rice has emerged as the most important export-oriented

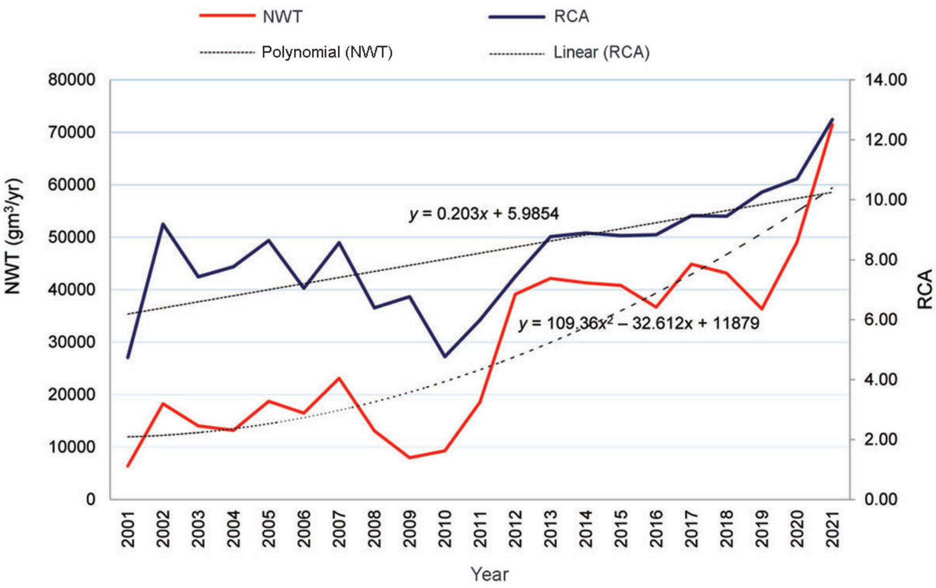

Figure 1. Trends in revealed compartive advantage (RCA) and net water trade (NWT) of rice.

Table 2. Delineation of favourable zones for rice cultivation

Agro-climatic zone	Demand–supply gap of rice	Groundwater extraction for irrigation	Growth of rice productivity	Productivity potential	Remarks
Western Himalayan	–	+	++	+	Inadequate surplus
Eastern Himalayan	+	=	++	++	Partially favourable
Lower Gangetic Plains	+	–	++	+	Unsustainable, semi-critical in GE
Middle Gangetic Plains	–	+	++	++	Sustainable with inadequate surplus
Upper Gangetic Plains	+	=	++	++	Largely favourable
Trans Gangetic Plains	++	--	++	++	Unsustainable, critical in GE
Eastern Plateau and Hills	+	+	++	++	Favourable, high growth potential
Central Plateau and Hills	–	+	++	++	Sustainable with inadequate surplus
Western Plateau and Hills	–	–	++	++	Inadequate surplus
Southern Plateau and Hills	–	–	+	++	Unsustainable, semi-critical in GE
East Coast Plains and Hills	–	+	++	++	Inadequate surplus
West Coast Plains and Ghat	+	+	+	++	Favourable
Gujarat Plains and Hills	–	+	++	++	Inadequate surplus
Western Dry	–	–	++	++	Inadequate surplus
Island region	–	+	++	++	Inadequate surplus

Note: Demand–supply gap: ++ denotes major surplus region; +, surplus region; –, deficit region.
Groundwater extraction: + denotes safe region; =, balanced region; –, semi-critical region; --, critical region.
Growth in rice productivity: ++, high productivity growth; +, average productivity growth.
Untapped productivity potential: ++, high productivity potential; +, moderate productivity potential.

commodity with an established comparative advantage in exports. Concomitantly, it is the principal crop through which India exports the bulk of its virtual water (Figure 1). About 60% of the cultivated rice area in India is irrigated, and more than 50% of the total water in irrigation is used in rice cultivation. Substantial export advantage indicated in higher values of rice RCA designates that the country must maintain its comparative advantage built historically in rice exports. This derives us to the strong foundation that India needs to adopt an alternative ‘regional crop planning’ for rice, meeting the twin objectives of water sustainability and harnessing export advantages.

Delineation of sustainable rice zones

The framework outlines specific strategies for shifting the cultivation of rice from areas facing water sustainability concerns to favourable ACZs based on demand–supply gap of rice, groundwater extraction for irrigation, rice productivity growth and rice productivity potential across various ACZs (Table 2). The Trans-Gangetic Plains (TGP), emerges as the exclusive surplus zone in terms of the production–consumption gap owing to its significant contribution to the rice production basket of the country (Figure 2 *a*). Nonetheless, it is also a critical zone for groundwater extraction.

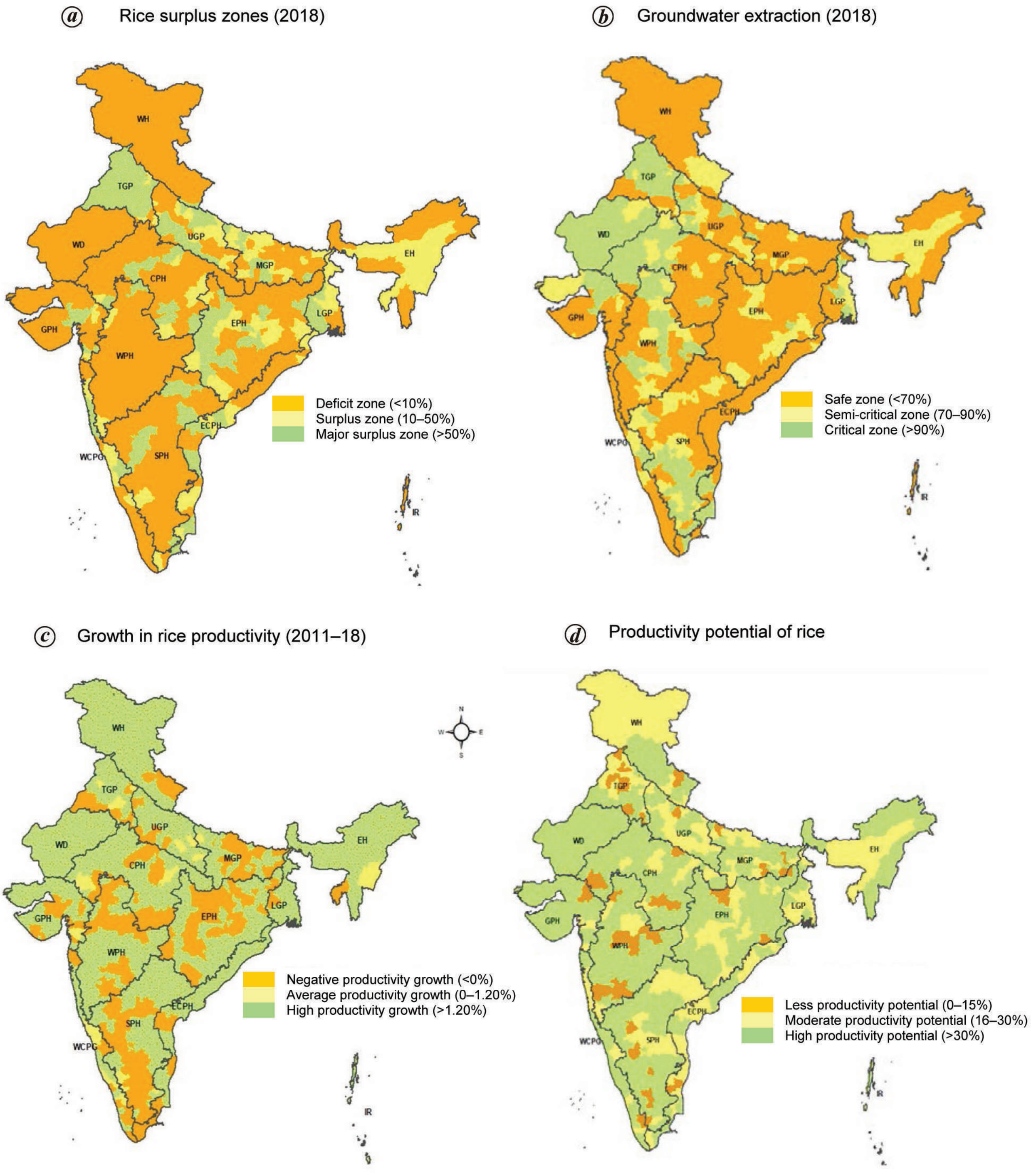

Figure 2. Mapping of agro-climatic zones based on rice surplus, sustainability and productivity potential.

India produces two types of rice – common rice and superfine rice (basmati rice). Basmati rice is grown mainly for export purposes and requires specific agro-climatic conditions in the upper TGP. Policies and measures like power subsidies for agriculture and assured minimum support prices play a major role in rice-skewed cropping patterns. The sustainability threats in TGP necessitate the adoption of a water-sustainable cropping pattern.

TGP comprising the states of Punjab and Haryana and contributing to almost 15% of rice production in India, has been globally identified as the water-stress hot spot[16]. Excessive groundwater extraction in many blocks of Punjab and Haryana has been reported (Figure 2 *b*). The provision of free power in Punjab has led to massive depletion of the water table, as cropping patterns have leaned towards paddy. As a result, the water table is going down at an alarming rate

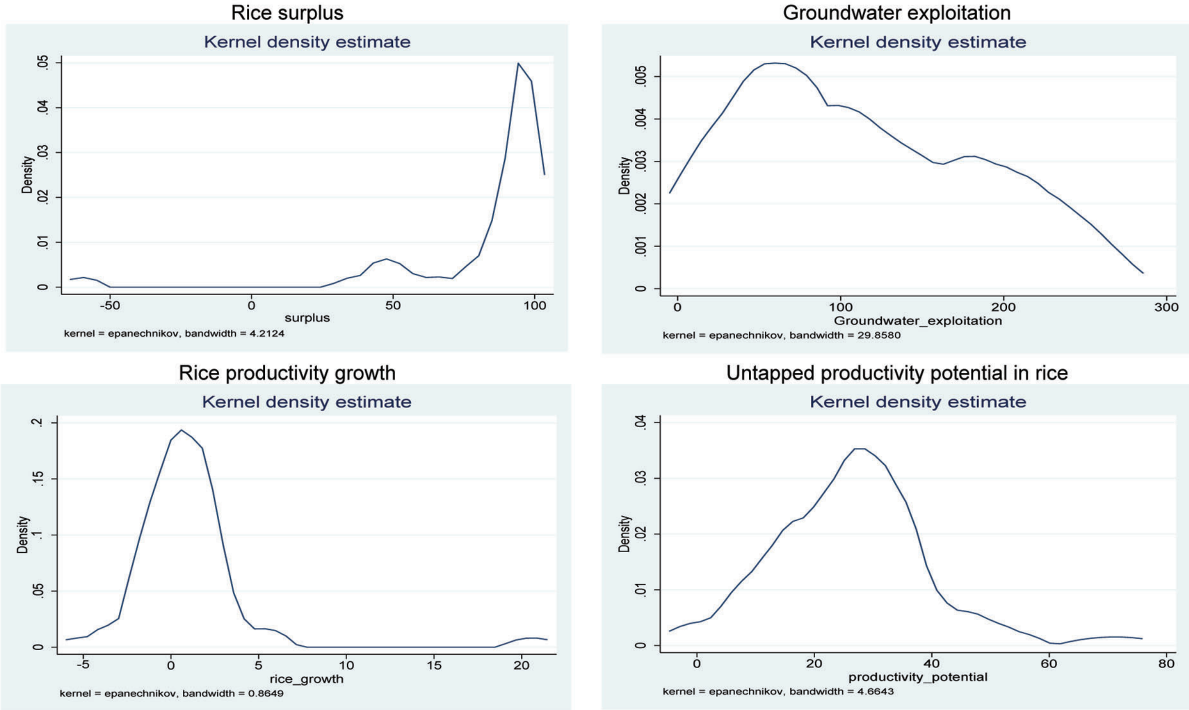

Figure 3. Kernel density distribution for selected parameters in the Trans Gangetic Plains.

(70 cm per year during 2008–12), and 80% of the blocks are overexploited[17]. Shifting the major chunk of non-basmati rice production to potential ACZs, namely Eastern Himalayan (EH), Upper Gangetic Plains (UGP), Eastern Plateau and Hills, and West Coast Plains and Ghat, from areas identified as unsustainable due to emerging environmental concerns, i.e., Lower Gangetic Plains (LGP), Trans Gangetic Plains (TGP), Western Plateau and Hills (WPH), could help India prevent an impending water crisis[18]. Many ACZs, particularly EH, LGP, East Coast Plains and Hills (ECPH), and Middle Gangetic Plains (MGP), have revealed high rice productivity growth during 2011–18, while pockets in TGP and UGP have witnessed negative productivity growth (Figure 2 *c*). Technological fatigue, along with the sluggish input intensification, is contributing to this decline in rice yield growth in recent years[19]. Therefore, the projected rice demand for domestic consumption and exports can be met by increasing rice yields in negative productivity regions while maintaining current rice yields in the high-yielding regions, as there is limited scope to bring additional land into cultivation.

Notably, several pockets in ECH, ECPH, LGP and EH have demonstrated high productivity potential (Figure 2 *d*). However, the potential of more than half of these areas is still untapped. These areas can be successfully used to shift rice cultivation from the regions facing serious concerns associated with severe deterioration of natural resources because of long-term intensive rice cultivation. Shifting the major chunk of rice production to India's central and eastern regions while diversifying the rice-growing areas in the rice-growing regions of TGP could help the country prevent an impending water crisis[20]. Further, the irrigation water productivity (IWP) in TGP is relatively low, reflecting inefficient irrigation despite 100% irrigation coverage (Figure 3). In contrast, the eastern and central regions have recorded higher IWP though they had substantially lesser irrigation coverage[21]. Therefore, appropriate policy measures are required to promote paddy cultivation in suitable areas and reduce the area under paddy in TGP.

This study suggests that basmati rice grown mainly for export, requires specific agro-climatic conditions available in UGP. So, farmers may continue to produce them. In contrast, the non-basmati varieties can be shifted to other suitable regions while considering a sustainable environment and ecological concerns. The eastern states such as Odisha, West Bengal, Bihar, and Chhattisgarh receive 1000–1500 mm rainfall is favourable for rice cultivation (Figure 4). Concurrently, in most of these regions, the air temperature lies between 27°C and 30°C, suitable for rice cultivation. However, several parts of the proposed location for shifting, particularly Bihar and Odisha, are highly susceptible to floods. Flash floods leading to the complete submergence of rice plants for 10–15 days are one of the major constraints for rice production, mainly in rainfed lowland areas. Moreover, among the suggested areas for the proposed shift, states of eastern India occupy one of the largest drought-prone ecologies in the world.

Dry directed-seeded rice (DDSR) is an alternative rice establishment method that reduces the water required to produce the crop[22]. Rice is generally grown without standing

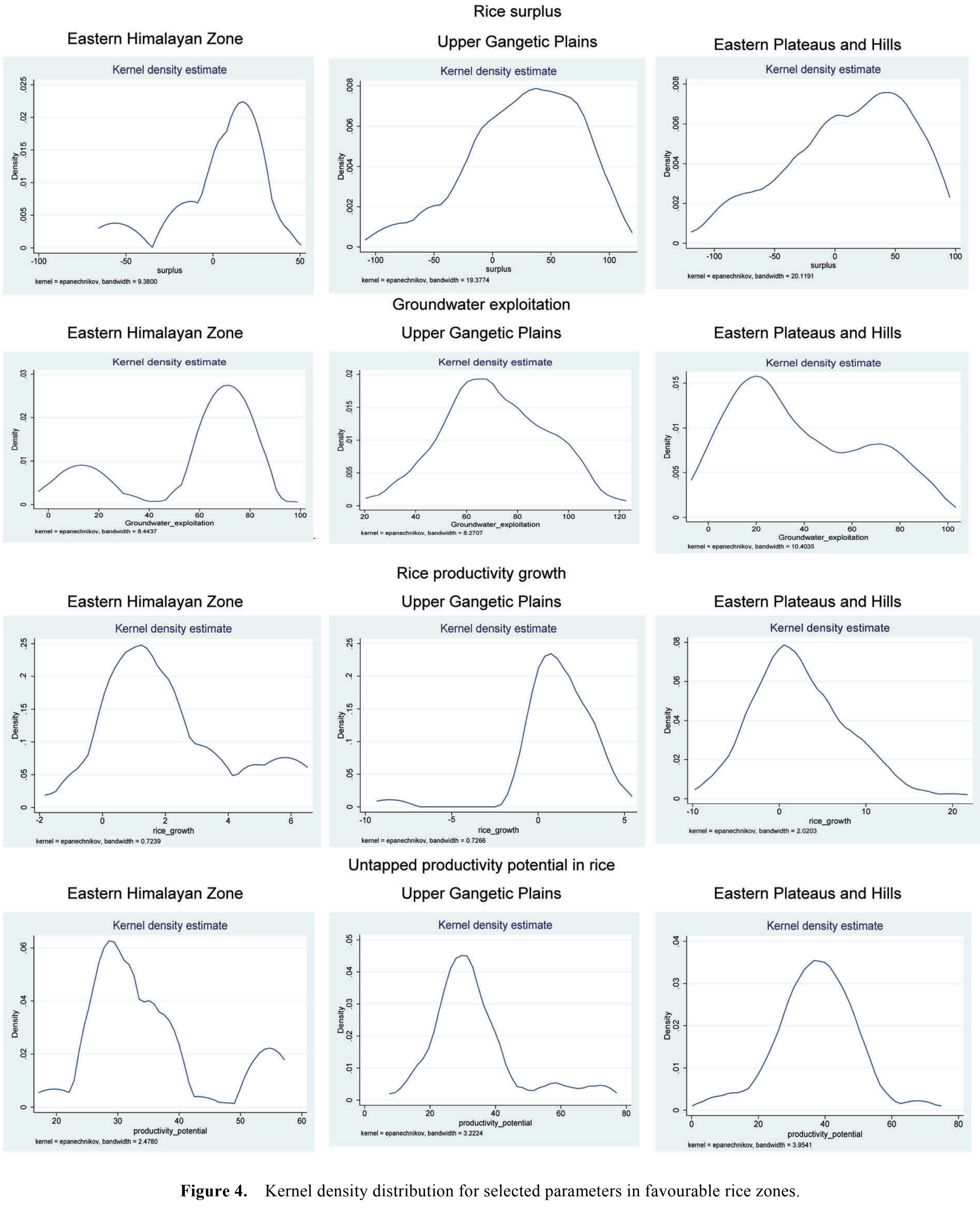

Figure 4. Kernel density distribution for selected parameters in favourable rice zones.

water, and water savings of 35–57% compared to traditional rice cultivation methods have been reported across North East India[23]. DDSR has been demonstrated to be effective across eastern India[24]. Similarly, the system of rice intensification (SRI) is a promising resource-saving method of growing rice under irrigated or rainfed conditions. Studies in several countries have shown a significant increase in rice yield, with substantial savings in seeds (80–90%), water (25–50%), and cost (10–20%) compared to conventional methods[25]. For illustration, paddy yields with SRI were higher by 32% than conventional paddy cultivation[26], net returns were higher by 67% and labour input was 8% less in West Bengal. Further, there is an opportunity to increase the total cropping area through strategic research in rice fallows. However, including the second crop in rice fallows is a great challenge as the post-rainy season often confronts a series of abiotic and biotic stresses[27].

Conclusion

This study helped delineate the critical ACZs in terms of rice surplus, groundwater resources, and productivity potential in rice to develop a strategic framework that focuses on shifting rice cultivation from water-stressed regions to favourable ACZs for managing virtual water exports. Shifting the major chunk of non-basmati rice production to potential ACZs, namely EH, UGP, and EPH, from areas identified as non-suitable keeping the emerging environmental concerns, i.e. LGP, TGP and WPH, could help India prevent an impending water crisis. Therefore, to mitigate these effects, apart from basmati rice grown primarily for export purposes, the non-basmati varieties can be shifted to other suitable regions while considering productivity and sustainability. Emerging practices such as DDSR, SRI, and alternate wetting and drying (AWD) techniques are notable mechanisms that could be effectively used for this proposed shifting. The suggested areas often face climate aberrations in terms of intermittent rainfall, enhanced flash flooding and periodic drought, adversely affecting the cultivated crop. Crop diversification along with required logistic support towards environment-friendly crops like pulses, millets, vegetables, and fruits would help the transition. Climate financing under the National Adaptation Fund for Climate Change can be used more effectively to reduce the emissions and vulnerability. Appropriate groundwater exploitation fees should be fixed to reinforce the status of groundwater, especially in critical regions. Investments should be encouraged to improve farming practices with better technologies to increase productivity on a sustainable basis.

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