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Water Footprint of Paddy Cultivation: Concepts and Approaches for Estimation

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Abstract

The water footprint quantifies the total volume of freshwater used directly and indirectly in the production of agricultural commodities. It encompasses water consumed (evaporated or incorporated into a product) and polluted during production processes. Understanding water footprints in agriculture is crucial for addressing water scarcity concerns and promoting sustainable resource management. It helps identify inefficient water usage, assesses the environmental impact of agricultural practices, and guides the development of water-efficient strategies. By optimizing water use, we can enhance productivity, mitigate environmental degradation, and contribute to long-term resilience in agricultural systems amidst increasing water challenges.

Introduction

India has 18% of the world's population and has 4% of the world's freshwater, out of which 80% is used in agriculture. Water is a finite and essential resource, and its sustainable management is very critical in agriculture. Paddy is one of the largest water consumers globally, and India is the second largest producer and consumer of paddy in the world. Water footprint is a valuable approach to quantify the total amount of water used throughout the production of crops or livestock. Understanding the water footprint of paddy production and consumption is essential to ensure sustainable agricultural practices and effective water resource allocation, provides insights into the local demand for water resources, and is crucial for ensuring food security and water sustainability. It also has global implications due to India's rice exports and the indirect export of a substantial amount of virtual water (the volume of water required to produce a food product but is currently not contained within the product). Hence, managing the water footprint in agriculture is crucial for sustainable food production, as it helps conserve limited water resources and minimize environmental impacts.

Components of water footprint

There are three main components of a water footprint- blue water footprint, green water footprint, and grey water footprint. Blue water footprint refers to the volume of surface and groundwater consumed (or polluted) during the production of a product or service that includes water that is withdrawn from rivers, lakes, and aquifers and may not be returned to the same source. Green water footprint represents the volume of rainwater that is consumed (or polluted) during the growth of crops or forests, and it accounts for the portion of precipitation that evaporates or transpires by plants. Grey water footprint is the amount of freshwater required to dilute pollutants (primarily chemicals and contaminants) to meet water quality standards which reflects the environmental impact associated with pollution.

Concepts in water footprint

Estimating water demand for paddy cultivation involves calculating total water demand, which comprises several components like soil saturation, standing water layer, percolation, and crop evaporative demand. The total water demand is calculated for each time, typically five days, by summing these components. Water availability is determined by factors such as effective rainfall, residual water level, and delayed soil saturation. If total water demand exceeds available water, the deficit is met by irrigation water supply, known as irrigation water demand. The distinction between water footprint (actual water lost from the catchment) and percolation (water seeping into the ground and not lost) is essential as water footprint is a real loss, and percolation is beneficial as it recharges groundwater and maintains the water table, contributing to overall catchment productivity. The internal water footprint of rice consumption refers to the amount of water used within a country to produce rice for its consumption. The external water footprint of rice consumption pertains to the water used in the countries from which rice is imported for national consumption; it is directly related to the water footprint in paddy consumption and encompasses the total volume of water used in the production, processing, and transportation of rice both within a country and in countries from which rice is imported.

Approaches for estimating water footprint

LCI (Life Cycle Inventory) methods are used to quantify the inputs and outputs of resources and environmental impacts associated with a product or process throughout its life cycle. These methods focus on data collection and quantification, providing the necessary information for subsequent life cycle assessments. LCI methods include the Hoekstra approach for calculating the water footprint of a product or process, which considers green, blue, and grey water as well as the location, quality, scarcity, and timing of water use. This approach has been widely used in academic research and adopted by organizations such as the Water Footprint Network and the Global Water Footprint Standard. Still, the approach may oversimplify the complex relationships between water use and environmental and social impacts and may not be suitable for all types of products and processes. Another example is the Milà I Canals method, which assesses the impacts of freshwater usage on a life cycle basis, considers water use at the level of a river basin, and categorizes water into blue and green water. These LCI methods play a crucial role in providing the data needed for further analysis and assessment. LCIA (Life Cycle Impact Assessment) methods are used to evaluate the potential environmental impacts of a product or process based on the data collected in the LCI phase on various impact categories such as climate change, water use, land use, etc. The LCIA methods include the eco-scarcity method, which assesses the impacts of water use on the environment based on the distance-to-target principle, focussing on the total input of freshwater abstracted for production or consumption and categorizes water scarcity into six levels and assigns eco-factors accordingly. The Milà i Canals LCIA approach examines two primary pathways through which freshwater use affects supply: freshwater ecosystem impact (FEI) and freshwater depletion. It uses a water stress indicator to assess FEI, categorizing river basins based on their exploitation levels. Still, it has limitations in capturing extreme seasonal variations and is constrained to river basin applications. Another example is the Pfister method (blue water), which considers both mid-point and end-point characterization factors for assessing the environmental impacts of freshwater consumption and ranks the severity of water scarcity in watersheds. It employs the Water Stress Index (WSI) to indicate water consumption impacts in relation to scarcity, accounting for monthly and annual precipitation variability, and focuses on Human Health, Ecosystem Quality, and Depletion of Freshwater Resources as end-point impact categories. These LCI and LCIA methods help quantify the water footprint of products and provide a framework for evaluating the potential environmental impacts of products and processes, aiding in sustainable water management and decision-making.

Water footprint for paddy cultivation

The analysis of the water footprint of rice across various agroclimatic zones (ACZs) in India revealed a significant spatial variation in the water footprint of rice cultivation and that traditional rice cultivation practices in 80 ACZs were found to rely more on green water than blue water. Eastern, Central, and Coastal zones of Western India were identified as sustainable for rice cultivation due to their lower water footprint. For instance, the water footprint of rice production in the high altitude and hilly zone of Tamil Nadu was found to be 1,030 m^3/t, which is significantly lower than the Central Maharashtra Plateau, where it was 13,515 m^3/t. In contrast, in the arid and semi-arid zones, particularly in states like Madhya Pradesh, Rajasthan, and Maharashtra, higher water footprints were exhibited. In these zones, over 50% of sub-districts have either overexploited or critically scarce groundwater resources, posing a threat to food security. Crop diversification away from water-intensive crops like paddy, especially in water-scarce regions, can reduce the overall water footprint of agriculture, and by focusing on zones with lower water footprints and promoting water-saving technologies such as direct seeded rice and laser land leveling, the agricultural sector can enhance its resilience to water scarcity and contribute to sustainable food production.

Virtual water content and international trade

India's approach to managing its water resources concerning agriculture and livestock products has been under scrutiny, so it’s important to consider water availability in exporting countries and compare the virtual water required to import products with self-production. India's trade partnerships with other countries can be categorized into four categories based on water savings or losses: mutually beneficial, partially beneficial, unsustainable, and pressured. Importing products from countries with lower virtual water content than India leads to mutual benefit while importing from water-scarce countries could result in unsustainable practices. Hence, this classification will help India to amend its trade relations.

Virtual water content (VWC) can be calculated based on the water footprint of a product, considering both its direct and indirect water use, and virtual water flow between countries can be determined by multiplying trade data with the associated VWC of the crop or animal in the exporting country calculated. Analysis reveals that while importing products from Africa leads to global water losses, importing from South America results in the most virtual water savings. While considering the long-term average virtual water imports by India, crop products consume the most significant portion, followed by industrial and livestock products.

Conclusion

Balancing economic benefits with responsible water management is crucial for long-term prosperity, food security, and environmental sustainability in India. Prospects for managing the water footprint of rice production in India will be promising if we prioritize the adoption of water-efficient technologies like precision irrigation and data-driven approaches, supported by technological advancements in remote sensing and data analytics and improving our ability to estimate water footprints accurately. Multi-stakeholder collaboration among government bodies, research institutions, farmers, and the private sector will be crucial for driving innovation and promoting sustainable practices. Government policies, incentives for sustainable water management practices, and public awareness campaigns can encourage farmers to reduce their water footprints and garner support for sustainable water management practices in rice cultivation.