Economic Analysis and Policy 44 (2014) 51–64

Contents lists available at ScienceDirect

Economic Analysis and Policy

journal homepage: www.elsevier.com/locate/eap

Full length article

Four decades of rice water productivity in Bangladesh: A spatio-temporal analysis of district level panel data

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ARTICLE INFO

Article history:
Available online 3 March 2014

Keywords:
Consumptive water use
Water productivity
Agro-ecological zones
Groundwater dependency
Fossil fuel
Sustainability

ABSTRACT

The bulk of the water productivity (WP) literature has focused on static cross-sectional analysis with inadequate attention given to long-term, time series analysis, either at the country level or at a lower level of aggregation (e.g., district). The present study fills this gap by analyzing WP in Bangladesh using panel data of 21 districts over 37 years (1968–2004) divided into three phases. It estimated levels of, and trends in, WPs of one irrigated rice (*rabi*) crop, and two mainly rain-fed (*kharif*) rice crops, with occasional supplementary irrigation. Also examined were WPs for rice crops in irrigated and rain-fed ecosystems.

The findings indicated that WP levels in Bangladesh were significantly lower than that by global standards. Overall, WP growth rates varied significantly among districts and between phases with no consistent pattern emerging. On the whole, WPs trended upwards while differing widely among districts and between phases, seasons, ecosystems and areas differentiated by physiographic characteristics. The 1980s represented a period of stagnation. Drought-prone areas grew faster while salinity-prone areas grew slower *vis-à-vis* non-drought and non-saline areas. In the Ganges-dependent area, WP grew faster than that in the non-Ganges-dependent area. Rice production in Bangladesh represented a highly groundwater-dependent and fossil fuel-using process with significant environmental implications suggesting that WP growth may be unsustainable. Sustaining WP growth required a range of market and non-market-based policy options.

1. Introduction

Water is the critical input in the process of intensification of agriculture in densely populated parts of the world, especially South Asia (Shah, 2009; Shah et al., 2003) over the last half century. Given that water could be a limiting factor for crop production and, therefore, food security, measuring water productivity (WP) assumes critical importance. It is surprising then that the literature on agricultural development has focused extensively on land productivity (see e.g., Hayami and Ruttan, 1985) or total factor productivity (see e.g., Heady et al., 2010; Rahman and Salim, 2013) and there has been contrastingly inadequate attention paid to measuring agricultural WP. Molden (2007, pp. 11–12) differentiated between physical and economic water scarcity. The former refers to inadequate investment in water or a shortage of human capacity

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http://dx.doi.org/10.1016/j.eap.2014.02.005
0313-5926/

to satisfy demand for water while the latter is primarily due to insufficient water supplies to meet all demands, including environmental flows.

The South Asian country of Bangladesh suffers particularly from significant water resource and production issues which are predicted to grow steadily worse (WARPO, 2002) with an associated dearth of empirical research to help address the problems. While Bangladesh's water scarcity is primarily economic in nature, some parts, such as Nawabganj (#13), Naogaon (#11) and Rajshahi (#12) in the northwest may be approaching physical water scarcity. Furthermore, the quality of groundwater contaminated with arsenic is a critical issue in many parts of Bangladesh and the adjoining areas of the Indian state of West Bengal (Chakraborti et al., 2002). De Vries et al. (2008, p. 1) found that reduction in water quality due to pollution, water-borne diseases and disease vectors was a major concern related to environmental degradation.

The focus of agricultural development in Bangladesh has shifted from a process of external (extensive margin) to internal (intensive margin) land augmentation (Hayami and Ruttan, 1985). The overall process seems consistent with Boserup's (Boserup, 1965; 1981) views that (1) rising population pressure led to the intensification of farming methods in order to increase food production to support extra population; (2) the pressure to change agricultural output by modifying farming techniques was primarily demand-driven.

A range of innovations collectively referred to as the green revolution led to agricultural intensification. The high yielding varieties (HYVs) of rice and wheat in South Asia spread to areas with pre-existing and well-developed irrigation infrastructure primarily dependent on surface water (Raj, 1970). However, subsequent diffusion of the HYV technology became increasingly dependent on groundwater irrigation (Alauddin and Quiggin, 2008; Alauddin and Sharma, 2013) relative to other parts of the world, such as China (Shah, 2007). Groundwater as a source of irrigation has covered nearly 75% of the total irrigated area in Bangladesh in recent years compared to minimal coverage at the beginning of the green revolution in the late 1960s (Alauddin and Tisdell, 1991; Alauddin and Tisdell, 1995; BBS, 2012). Private initiative, small irrigation systems based on low-lift pumps (surface water), and shallow and deep tube wells (groundwater) drawn from streams and groundwater have proliferated. After initial rapid growth, low-lift pump irrigation has slowed significantly since the 1990s due to limited access to reliable surface water sources. This has led to the development of groundwater structures in places previously served by surface water (WARPO, 2002, p. 11).

However, this average percentage of groundwater usage for Bangladesh as a whole has masked significant inter-district variations. For example, usage ranged from more than 95% in the northern districts of Bogra (#8 and #9) and Dinajpur (#1–3), and the central district of Tangail (#37) to minimal or none in the southern districts of Barisal (#24, #28–30) and Patuakhali (#31, 32) (Table 1 and Fig. 1). Furthermore, around 80% of the gross area irrigated in Bangladesh was allocated to rice.

Of particular importance is the focus on the relative performance of the eight (greater) districts (Barisal, Faridpur, Jessore, Khulna, Kushtia, Pabna, Patuakhali and Rajshahi) that constitute the Ganges-dependent area (GDA) accounting for more than a third of Bangladesh's net cropped area (NCA, Fig. 1 and Table 1) *vis-à-vis* the non-Ganges-dependent area (NGDA). This research is part of the International Water Management Institute-Indo-Gangetic Basin (IWMI-IGB) project, and analysis of WP levels and trends was an integral part of this project.

The driest and most severe drought-prone districts are located in the GDA (BBS, 1999). This region, characterized by high climatic variability, is likely to experience even greater climatic variability in coming decades. By 2050, the dry season (November–May) water deficit (deficit of rainfall over evapotranspiration) is expected to rise to 445 mm from 343 mm in 2000 and 372 mm in 2025. The wet season (June–October) water surplus (surplus of rainfall over evapotranspiration) is expected to increase to 1221 mm in 2050 from 980 mm in 2000 and 1072 mm in 2025 (WARPO, 2002, p. 13).

Although some drought and salinity-prone districts lie outside the GDA (Table 1), the most severe salinity-prone areas, as with most drought-prone areas, are located in this area. This paper is organized as follows: Section 2 provides a brief review of the relevant literature. Section 3 discusses the materials and method used in the study. Section 4 presents the results for the estimated levels of, and trends in, WPs of one irrigated rice (*rabi*) crop, and two mainly rain-fed (*kharif*) rice crops: combination of *aus* (early monsoon) and *aman* (monsoon–late autumn). It also presents levels of and trends in WPs for rice crops in irrigated and rain-fed ecosystems. Results of Pearson correlation between WP in the irrigated ecosystem and overall WP and *kharif* WP are also presented. Implications and policy options are discussed in Section 5 and Section 6 respectively, and Section 7 provides a brief conclusion.

2. Brief review of literature

Molden (1997) represented the first major research on water productivity. Subsequent research (e.g., Ahmad et al., 2004; Barker et al., 2003; Cai and Rosegrant, 2003; Molden et al., 2003); (Molden and Sakthivadivel, 1999) measured water accounts and crop water productivity on different scales. Cai and Sharma (2010) concentrated on the Indo-Gangetic Basin that included parts of Bangladesh, India, Nepal and Pakistan, while Mahajan et al. (2009) and Jalota et al. (2009) focused exclusively on the Indian Punjab. Cai et al. (2011) measured crop water productivity in ten major river basins, including the Indo-Gangetic, Mekong, Nile and Yellow River basins.

The bulk of the literature on crop WP has concentrated on static cross-section analysis and used aggregate data with occasional micro-level evidence (Molden et al., 2007), even though different scenarios were considered between two points in time such as 2000 and 2025 (Cai and Rosegrant, 2003; Rosegrant et al., 2002). Despite this growth in the literature on WP,