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Analysis

Inter-district rice water productivity differences in Bangladesh: An empirical exploration and implications

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ABSTRACT

While the bulk of research on crop water productivity (WP) focuses on static cross-section analysis, this research provides a spatio-temporal perspective. It estimates rice crop WP for 21 Bangladesh districts for 37 years; explores WP variations among districts; and investigates causality involving WP, intensification and technological variables; and groundwater irrigation and depth. It breaks new grounds by probing these significant but unexplored issues.

Technological diffusion was the key factor explaining inter-district WP differences. The impact of agricultural intensification on *rabi* (dry season) and *kharif* (wet season) crop WPs was positive and negative respectively. Dummy variables typifying policy transition negatively impacted on WPs for both *kharif* and overall crops. While *rabi* and *kharif* rice WPs grew with time, overall crop WP recorded the strongest growth. *Rabi* and overall WPs were lower in salinity- and drought-prone districts covering 33% of Bangladesh's net cropped area (NCA). In 90% of Bangladesh's NCA districts, technological diffusion caused WP. Causality existed between groundwater irrigation and depth in 60% NCA. Despite significant potential to increase WP, increasing dependence on groundwater appears unsustainable. Widespread diffusion of HYVs in the *kharif* season, and development of salinity and drought-tolerant rice varieties could go a long way in sustaining rice WP.

1. Introduction and Background

Literature on agricultural development has long neglected the measurement and explanation of productivity of a fundamental and, in many cases limiting, input — water. This stands in sharp contrast to the voluminous research on land and labor productivity in agriculture. It has long been recognized that with a growing population in Bangladesh and a dwindling supply of arable land per capita, there is very little prospect for expanding food production by bringing in more land under cultivation. The only way forward is to augment the productivity per hectare of cultivated land. In their influential work, Hayami and Ruttan (1985) espoused internal land-augmentation as opposed to external land-augmentation as a way of overcoming severe constraints on the supply of arable land per capita. The former refers to a situation where qualitative improvement in land input takes place, for instance, through irrigation while the latter refers to a situation where cultivation is based on the extensive margin.

In the densely populated and land-scarce countries of South Asia, internal land augmentation has taken the form of increasing reliance on groundwater irrigation. In no other part of the world does people's livelihood depend so much on groundwater as it does in South Asia. As Shah (2007) reports, 55–60 and 60–65% of the respective populations in India and Pakistan depend on groundwater for their livelihoods. Given the high and increasing dependency on groundwater irrigation stated in Section 1.1, this figure for Bangladesh is likely to be at least as high as that of Pakistan. In contrast, the corresponding figure for China is in the 20–25% range.

First, the world pays more attention now than in the past to letting the market forces and the private sector operate. Many countries in the Third World (including Bangladesh) adopted structural reform programs, which were essentially institutional reforms that embodied a set of policies propelled by the IMF and the World Bank. These policies had the explicit aim of opening up the Third World countries to world market competition so as to: (1) promote their exports, and (2) restrain domestic expenditure in order to create a better climate for investment and enhance economic growth (Messkoub, 1992, p. 198). In many countries, structural adjustment policies permeate every aspect of the economy (Rahman, 1992).

Second, the depletion and degradation of land and water resources due to agricultural intensification seem amply clear. This is a global as well as a South Asian phenomenon (Alauddin and Hossain, 2001; Prescott–Allen, 2001; Shah, 2009). The adverse impact of intensive

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agriculture on soil quality in parts of Bangladesh is well documented (see, for example, Ali et al., 1997). In south-eastern Nigeria, farm-level data suggested that about nine percent of the soil in irrigated land has been degraded to the extent that it is no longer suitable for arable agriculture (Urama, 2005, p.199).

Therefore, the focus of technological innovations must shift from just land-augmentation to environment-saving by considering environment as factor of production (Alauddin, 2004; Alauddin and Quiggin, 2008). This paper focuses on the water-saving perspective of agricultural development, implying a higher crop yield/m^3 of water use (Barker and Levine, 2012, p.2).

The bulk of the research on crop water productivity (WP) available thus far has focused almost exclusively on static cross-sectional analyses. They have measured WP at different locations at a point of time precluding the possibility of examining any time trends. Ahmad et al. (2004) estimated rice and wheat WPs in the Rechna-Doab basin in the Pakistan Punjab. They employed remote sensing and Surface Energy-based Algorithm (SEBAL) modeling for evapotranspiration (ET) estimation. Cai and Sharma (2010) measured water productivity in the Indo-Gangetic basin using a range of methods including remote sensing, census and weather data. Mahajan et al. (2009) measured water productivity and yield of rice according to time of transplanting in the Indian Punjab. On the whole, measurement of water productivity as has been done by Ahmad et al. (2004) and Mahajan et al. (2009) is possible for a micro-level study. It is rather too laborious, cumbersome, and data-intensive to investigate crop water productivity for a larger geographical entity such as a country or regions within a country, let alone over time.

Vaidyanathan and Sivasubramaniyan (2004) measured changes in water demand for crop production for 13 Indian states between 1966–68 and 1991–93 employing consumptive water-use (CWU). CWU for a particular crop refers to the amount of water that a crop transpires during its course of growth and the amount of water that evaporates from the bare surface on which the crop grows (Amarasinghe et al., 2007; Vaidyanathan and Sivasubramaniyan, 2004).

CWU, as estimated by Vaidyanathan and Sivasubramaniyan (2004), used mean annual rainfall and ET; but this masked significant interregional and seasonal variations of rainfall within a state, and growth periods of crops. Amarasinghe et al. (2007) improved the Vaidyanathan and Sivasubramaniyan (2004) assessment of CWU in two important ways. First, they used average monthly rainfall and district-level ET. Second, they used crop coefficients (defined as the ratio of potential to actual ET, Pidwirny, 2006) corresponding to the four different periods of crop growth (initial, development, middle and late), and the crop calendar for different crops for four different regions to estimate CWU for India.

1.1. Overview of Changes in Bangladesh Agriculture

High yielding variety (HYV) rice has spearheaded the green revolution of the late 1960s in Bangladesh (Alauddin and Tisdell, 1991). Rice production consumes much more fresh water than any other crop of comparable value and duration (Allen et al., 1998; BARC, 2001). Almost all *rabi* (November–March) rice areas are currently allocated to HYVs while *kharif* (April–October) rice also has a significant component of HYVs for most districts. Bangladesh agriculture is characterized by the pre-eminent position of rice in its cropping pattern. Nearly 80% of the gross cropped area is allocated to rice (BBS, 2012).

Over time, Bangladesh has become increasingly dependent on groundwater irrigation for agricultural crop production. From next to nothing at the beginning of the green revolution in the late 1960s and early 1970s, groundwater is now the pre-eminent source of irrigation (BBS, 2012). However, there are significant inter-district variations. Fig. 1 illustrates the locations of the 64 (smaller) districts with their respective numbers.

Information contained in various issues of Yearbook of Agricultural Statistics of Bangladesh (BBS, 2008), suggests that the (greater) districts of Bogra (#8, 9), Dinajpur (#1–3), Jessore (#20–23), Kushtia (#17–19), Pabna (#14 and #16), Rajshahi (#11–13 and #15), and Rangpur (#4–7 and #10) located in the northern and western zones, and the (greater) districts of Jamalpur (#33 and #36), Mymensingh (#34 and #38), and Tangail (#37) in the central region are characterized by groundwater dependency of more than 85% of the gross irrigated area. The combined net cropped area (NCA) of these greater districts accounts for half of Bangladesh's total NCA. This phenomenon has drastically shifted the ground–surface water relativities in irrigation from almost nil to nearly all, in some cases. Three standout (greater) districts are Bogra, Tangail and Dinajpur with about 15% of Bangladesh's net cropped area, where groundwater irrigation is respectively 54, 34 and 24 times as important as surface water irrigation.

Increasing dependence on groundwater extraction has led to significant lowering of groundwater tables. The maximum groundwater depth is significantly positively correlated with the incidence of groundwater irrigation, as measured by the percentage of groundwater-irrigated area in gross area irrigated for almost all districts. This is especially so for the (greater) districts of Dhaka, Mymensingh, Tangail, Bogra, Pabna and Rajshahi, and Jessore and Kushtia.

Changes in the five yearly average maximum groundwater depths between the early 1970s and the early 2000s in selected regions of Bangladesh (CEGIS, see Section 3.1) suggest that Dhaka, which includes mostly the city area, has suffered the greatest increase in the maximum groundwater depth (by 42 m). This seems consistent with the finding that groundwater table in Bangladesh's capital city, Dhaka, has declined by an average of 1 m/year over the last three decades (Zahid and Ahmed, 2006, p.40). However, this phenomenon may not be entirely related to agricultural activities but due to a dramatic increase in Dhaka city's population from just under 1.68 million in 1974 (BBS, 1984, p.44) to 14.54 million in 2011 (http://www.citypopulation.de/php/bangladesh-dhaka.php).

Greater risk of drought combined with increasing extraction of groundwater resources can exacerbate the impact of drought on crop yield. Information limitations preclude the possibility of an in-depth analysis of the effect of drought on crop productivity. Karim and Iqbal (1997) provide an estimate of loss of crop yield of transplanted *aman* (*kharif*) rice due to drought in all three stages of the crop production process (panicle initiation, heading to milk, and milk to maturity) that approximately correspond to the 7th, 8–9th and 10–12th ten-day growth periods respectively in the present study. Karim and Iqbal (1997, p.75) further report that the impact of the loss is particularly severe during the milk-to-maturity stage.

There are also significant spatial variations to the effect of drought. Given the higher incidence of drought in the northern district of Rajshahi and western districts of Jessore and Kushtia, these are more adversely affected than the central district of Dhaka and the eastern districts of Comilla or Sylhet. Furthermore, the duration of the drought is much longer (13 days each) for Jessore and Rajshahi compared to eight and four days respectively for Comilla and Sylhet. Drought-stress-affected yield is only 43 and 38% respectively of the no-drought-stress yield. The eight (greater) districts (Barisal, Faridpur, Kushtia, Jessore, Khulna, Pabna, Patuakhali and Rajshahi), located in the Ganges basin (with about 38% Bangladesh's NCA) are characterized by high climatic variability. Some of these districts are susceptible to severe droughts while others are susceptible to salinity. This area is likely to experience even greater climatic variability in coming decades. By 2050, the dry season (November–May) water deficit will rise to 24.6% from 9.4% in 2025. On the other hand, the wet season (June–October) water surplus will increase to 29.7% from 8.85% over the same period (WARPO, 2002, p.13).

Bangladesh's public policy stance pertaining to agriculture, especially in relation to pricing of key agricultural inputs such as irrigation, chemical fertilizers and pesticides has changed significantly since the 1980s