Sonar Bangla Revisited: Groundwater development and agrarian change in Bangladesh and West Bengal since the 1970s

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List of abbreviations

ACIAR	Australian Centre for International Agricultural Research
APY	Area, Production and Yield
BADC	Bangladesh Agriculture Development Corporation
BARD	Bangladesh Academy for Rural Development
BMDA	Barind Multipurpose Development Authority
BRDB	Bangladesh Rural Development Board
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CACP	Commission for Agricultural Cost and Prices
CoP	Cost of Production
CV	Coefficient of Variations
DAE	Department of Agricultural Engineering
DTW	Deep Tube Wells
EPWPDA	East Pakistan Water and Power Development Authority
GoB	Government of Bangladesh
GoI	Government of India
GoWB	Government of West Bengal
HP	Horse Power
HYV	High Yielding Varieties
HTW	Hand-pump Tube Wells
IAAP	Intensive Agricultural Areas Programme
IADP	Integrated Area Development Programme
IDCOL	Infrastructure Development Company Limited
IHDS	Indian Human Development Survey
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
LLP	Low Lift Pumps
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MI	Minor Irrigation
MoU	Memorandum of Understanding
MSP	Minimum Support Price
MV	Modern Varieties
MWP	Master Water Plan
NABARD	National Bank for Agricultural and Rural Development
NSA	Net Sown Area
NSSO	National Sample Survey Organization
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyaan
PSPGP	Private Sector Power Generation Policy
RBI	Reserve Bank of India
STW	Shallow Tube Wells
SWID	State Water Investigation Directorate
TE	Total Efficiency
TFP	Total Factor Productivity
TOD	Time of the Day
WB-ADMI	West Bengal Accelerated Development of Minor Irrigation
WBSEDCL	West Bengal State Electricity Distribution Company Limited
WEM	Water Extraction Mechanisms

Executive Summary

Setting the context:

The study of agrarian change in the Bengal plains (present-day Bangladesh and West Bengal) has a long history spanning several centuries. In recent decades, the trajectory of agricultural growth in two countries – with the same agroecology, history and culture, but with two different policy settings, became a topic of intense interest among scholars of agrarian change. In the 1980s, West Bengal had registered higher agricultural growth rates than Bangladesh. However, since the mid-1990, it is clear that Bangladesh has experienced higher growth rates, while growth in West Bengal has slowed down and stagnated. In this report, we explore the trends in agricultural development since the 1990s and analyze the reasons for the same. We narrate our story through six interrelated themes.

Theme 1: Expansion in area, production and yield (APY) of *boro* paddy:

The entry point of our analysis is the rapid expansion in APY of summer *boro* paddy since the early 1980s. *Boro* paddy is sown in December/January and harvested in April/May. It is an entirely irrigated crop. *Boro* paddy was one of the main contributors to rapid agricultural growth in Bangladesh and West Bengal. APY of *boro* paddy grew rapidly till around the mid-1990s in West Bengal, and after that, it rose less sharply and has stagnated in recent years. In Bangladesh, APY of *boro* paddy continued to grow all throughout from the 1980s till the end 2000s and has started to slow down since 2011. Bangladesh cultivates *boro* paddy in 80% of the land where monsoon *aman* paddy is cultivated, showing that further expansion of the area in *boro* paddy is not feasible. On the other hand, West Bengal only cultivates *boro* paddy in 30% of the land on which it grows monsoon *aman* paddy, showing further expansion in the *boro* area is possible. The yield of *boro* paddy is higher in Bangladesh, and variability of yield is lower – both indicating more assured irrigation in Bangladesh than in West Bengal.

Theme 2: Groundwater irrigation

Expansion in APY of *boro* paddy was made possible through a rapid increase in groundwater irrigation, especially growth in the number of shallow tube wells (STWs) since the 1980s. However, expansion in the number of STWs stagnated in West Bengal by the mid-1990s and kept expanding in Bangladesh till 2010 or so. As a result, Bangladesh has an estimated ~1.5 million groundwater wells and tube wells in 2018-19, while there are no definitive estimates of the number of groundwater structures in West Bengal. However, we arrived at a tentative estimate of ~0.9 million groundwater structures in 2013-14 in West Bengal using various sources. Initial expansion in groundwater structures in West Bengal was attributed to land and institutional reforms and later slowdown to market reforms. In contrast, an increase in the number of STWs in Bangladesh happened as a direct result of market liberalization policies, including relaxation of well spacing norms and removal of restrictions on pump imports in 1987-88, following a major cyclone event.

Theme 3: Informal groundwater markets and energy irrigation nexus

A large majority of farmers (up to 2/3rd) in both West Bengal and Bangladesh get access to groundwater irrigation through informal markets for irrigation services (we refer to them as groundwater markets for the sake of brevity). A lot has been written on the functioning of these markets, including claims and counterclaims on the exploitative nature of these markets. Of interest to our storyline is the impact of electricity tariffs and diesel prices on the functioning of these informal markets. High flat tariffs in West Bengal promoted relatively competitive water markets. Low diesel prices and low diesel price to paddy price ratio also made groundwater markets beneficial in Bangladesh. However, the nature of water markets changed in West Bengal following the metering of electric pumps starting in 2007, which led to further demand for electrification. However, there were policy-related entry barriers to electrification, which the government of West Bengal removed in 2011. As a result, there was rapid electrification of agricultural wells and tubewells between 2011 to 2019, and over 200,000 new agricultural pumps were electrified. Yet, despite lower irrigation costs, such rapid electrification of pumpsets did not usher in high growth in water-intensive crops like *boro*, possibly due to rising costs of other inputs (e.g., labour, electricity costs) and stagnant paddy prices in the absence of government-led procurement. There is not much literature in Bangladesh on impact of energy prices on groundwater markets.

Theme 4: Rising cost of cultivation and crop diversification

The rising price of diesel, and other inputs, including labour, started making *boro* cultivation unprofitable in both West Bengal and Bangladesh. This resulted in declining trends in APY of *boro* in recent years and a move towards diversification away from paddy. Crop diversification is more apparent in West Bengal than in Bangladesh, but some amount of diversification away from paddy is happening in Bangladesh too. In West Bengal, diversification has been towards rainfed crops like oilseeds, while in Bangladesh, farmers have diversified to irrigated crops like maize. Diversification has been promoted amidst concerns around the long-term sustainability of groundwater irrigation. Yet, in the Indian context, this has led to a paradox where relatively water abundant states like West Bengal reduced their area under water-intensive crops, while states like Punjab and Haryana, with acute groundwater depletion, still grow rice.

Theme 5: Groundwater depletion and climate change

While the area under water-intensive *boro* paddy stagnated in West Bengal since the mid-2000s, there seems to be a trend towards declining water tables in the state in the last ten years. This trend is also observed in Bangladesh, where the area under *boro* paddy has not expanded since 2010-11. Could long term changes in rainfall and temperatures be the reason for the decline in groundwater levels? Due to higher temperatures and more erratic precipitation, increased evapotranspiration may affect effective recharge. Still, more work is needed to understand the exact nature of the change in groundwater recharge due to climate change, and it was beyond the scope of this report.

Theme 6: Public policies and policy discourses on water-energy and food:

West Bengal started experiencing a slowdown in *boro* cultivation in the mid-1990s. This slowdown was preceded by popular policy discourses on groundwater depletion, even though in the 1990s, there was no concrete evidence of a long-term secular decline in groundwater levels. In Bangladesh, the policy discourse was around the need for achieving national food self-sufficiency, and as such, there was a supportive environment for intensive groundwater use for irrigation. These differences in public discourses also find reflection in formal policy-making processes. In Bangladesh, throughout the 1980s till 2010s, water, energy and food policies were framed to make groundwater irrigation more accessible to farmers. In West Bengal, policies since the mid-1990s focused on restricting access to groundwater for farmers.

Two storylines with groundwater irrigation as the binding theme:

The first storyline is that of high growth. During this period, West Bengal (early 1980s to mid-1990s) and Bangladesh (early 1980s to the end of 2010s) saw a rapid rise in APY of *boro* paddy, supported by water, energy and food policies that encouraged intensive groundwater use. The second storyline is for West Bengal (from the mid-1990s onwards) and Bangladesh (from the early 2010s). Both started experiencing stagnation in the APY of *boro* paddy, which can be attributed to the unfavourable cost of production and output price ratios, partly associated with restrictions on groundwater irrigation. Farmers are trying to diversify away from paddy, yet paddy remains critical from a food security perspective, and diversification brings in its own sets of challenges including marketing infrastructure. Diversification away from paddy also means that relatively water-abundant West Bengal cannot emerge as the rice basket of India, while water-scarce Punjab continues to produce the bulk of rice for national consumption. Both storylines suggest that rise and fall in agricultural growth is intricately tied with trajectory of groundwater irrigation.

1. Introduction

The study of agrarian change in Bangladesh and West Bengal has a long history spanning several centuries. Fertile plains, rich peasant tradition, and a history of high agricultural growth in *Mughal* and *Nawabi* Bengal (before 1770) and from 1770 to 1860 (during company *Raj*)(Bose, 1999), earned the land the name of "*Sonar Bangla*" (*sona* is gold in *Bangla*). The permanent settlement and *zamindari* system of 1793 by the British East India Company initially spurred growth by bringing in more fallow land under the plough. As a result, the population grew rapidly to supply surplus labour. However, soon growth from bringing additional fallow land under plough was exhausted, requiring shifts to intensification, which unfortunately did not happen. In the next century (1860 till the 1970s), Bengal came to be known as the land of poverty, famine, and high population growth. Lack of water control, including flood control and groundwater irrigation, was identified as the main impediment to intensification (Boyce, 1987). The consensus at that time was that groundwater irrigation and flood control needed cooperative action and investments. However, a regressive agrarian structure with absentee landlords hindered such cooperation (Bandyopadhyay, 2003; Boyce, 1987).

The trajectory of agricultural growth in two countries[i] – with similar agro-ecology, history and culture, but with different policy settings, became a topic of intense interest among scholars of agrarian change (Banerjee. et al., 2002; Boyce, 1987). A book comparing the agricultural transition in Bangladesh and West Bengal from the 1970s to the mid-1990s was published in 1999 and is the starting point of this analysis (Bose, 1999). Several authors in the book concluded that in the 1980s, West Bengal had higher agricultural growth rates than Bangladesh, which they attributed to land and institutional reforms in West Bengal in the 1970s (Banerjee et al., 2002; Bardhan & Mookherjee, 2012; Gazdar & Sengupta, 1999; Rogaly et al., 1999). However, several others (Fujita et al., 2003; Harriss, 1993; Palmer-Jones, 1999; Sawant & Achuthan, 1995) questioned the role of land and related institutional reforms, and instead emphasized the role of farmer-led groundwater irrigation and explained higher agricultural growth in West Bengal due to intensive groundwater irrigation supported by favourable policies like electrification and cheap diesel prices. Since the mid-1990s, Bangladesh has experienced higher agricultural growth rates than West Bengal, yet reasons for this reversal are not widely documented. This report fills a critical knowledge gap by analyzing trends in agrarian growth (with a focus on paddy) in West Bengal and Bangladesh since the 1990s and provides some hypotheses for divergence in growth.

Our analysis shows that both Bangladesh and West Bengal have followed similar trajectories of growth in area and production of paddy followed by a period of stagnation, even though the exact nature and duration of periods of high and low growth (and stagnation) varies. West Bengal experienced high agricultural growth from the early 1980s to the mid-1990s and Bangladesh from the mid-1980s to the end of 2010s – both driven by rapid expansion in area under *boro* paddy (Hossain, 2009; Palmer Jones, 1992; Palmer-Jones, 1992; Rawal, 2011; Ray & Ghosh, 2016; Saha & Swaminathan, 1994). During this period, both West Bengal and Bangladesh saw a rapid rise in the area, production and yield (APY) of *boro*[ii] paddy, supported by appropriate policies in water, energy and agricultural sectors that encouraged intensive groundwater use. Both these regions then experienced stagnation in APY of *boro* paddy, which we argue in this report, was due to unfavourable input- output price ratios, again brought about by a series of policy decisions in the water, energy and agricultural sectors. In recent years, declining groundwater tables have caused policy concerns in both places (Kirby et al., 2015; Malakar et al., 2021).

In this report, we weave together six interrelated themes to explain the differences in trajectories of agricultural growth (measured through APY of *boro* paddy) in Bangladesh and West Bengal. The report is organized into eight sections. Section 2 looks at trends in the APY of paddy, focusing on irrigated *boro* paddy. Section 3 discusses trends in groundwater irrigation given the centrality of groundwater in the expansion of *boro* paddy. Section 4 documents the functioning of informal groundwater services markets. These informal markets have been instrumental in spreading irrigation access to those who did not have the means to invest in water extraction mechanisms (WEMs) like tubewells and pumps. Section 5 discusses the slowdown in growth in APY of *boro* paddy and the current trend towards diversification away from paddy in both locations. Diversification is explained in terms of unfavourable input-output price ratio of growing paddy, which partly stems from restrictive groundwater policies emanating from concerns around groundwater over-exploitation. Section 6 looks at recent trends in declines in groundwater levels at a time when expansion in area under water-intensive *boro* paddy has stopped, leading to the hypothesis that climate change may be implicated in explaining recent declines. Section 7 explains the trends in agriculture and groundwater use through the lens of water, energy and food policies. Section 8 concludes by using these six themes to construct two storylines – one of growth and another of stagnation. This section also discusses the policy implications of the findings and knowledge gaps for future research.

1. Centrality of *boro* paddy in the agricultural growth story

2.1 Paddy dominates cropped area

Paddy dominates the cropping patterns in both West Bengal and Bangladesh. The share of paddy in the total food grain area and production has been high and relatively stable over time last 20 years in Bangladesh (for which we have the data) and over the last 50 years in West Bengal. When we define food grain area as the sum of wheat, maize, pulses, and paddy cropped areas, paddy accounts for 91% of the food grain area in 2018 in Bangladesh and 87% of the food grain area in West Bengal in 2015. Figure 1 (a to d) confirms that these trends have been constant since the mid-1990s.

2.2 Boro paddy has driven the overall growth in paddy production

Despite the share of paddy being constant, the composition of paddy has varied over time. Farmers in Bangladesh and West Bengal cultivate three paddy crops corresponding to three different cropping seasons. *Aman* is the monsoon season rice, grown from June/July to October/November and is largely a rainfed crop. However, in recent years, *aman* paddy needed supplemental irrigation due to long intervals between two rainfall events, most likely caused by climate change (Buisson et al., 2021). *Aus* is usually broadcasted at the beginning of the monsoon and harvested at the end of the monsoon and is an entirely rainfed crop. Finally, *boro* is cultivated in winter and is entirely reliant on irrigation. The trends in areas cultivated with *aman*, *aus* and *boro* have been similar in West Bengal and Bangladesh over the last 50 years. The area under *aman* paddy has remained more or less constant, that under *aus* has declined, and area under *boro* has seen a secular increase (Table 1 and Figure 2). While the average annual growth rates of the three are somewhat different in West Bengal and Bangladesh (Table 1), yet the trends are very similar. The highest period of growth in *boro* was in the 1980s in West Bengal and Bangladesh, with 13% and 9% average annual growth rates respectively in 1980-1989 (Table 1).

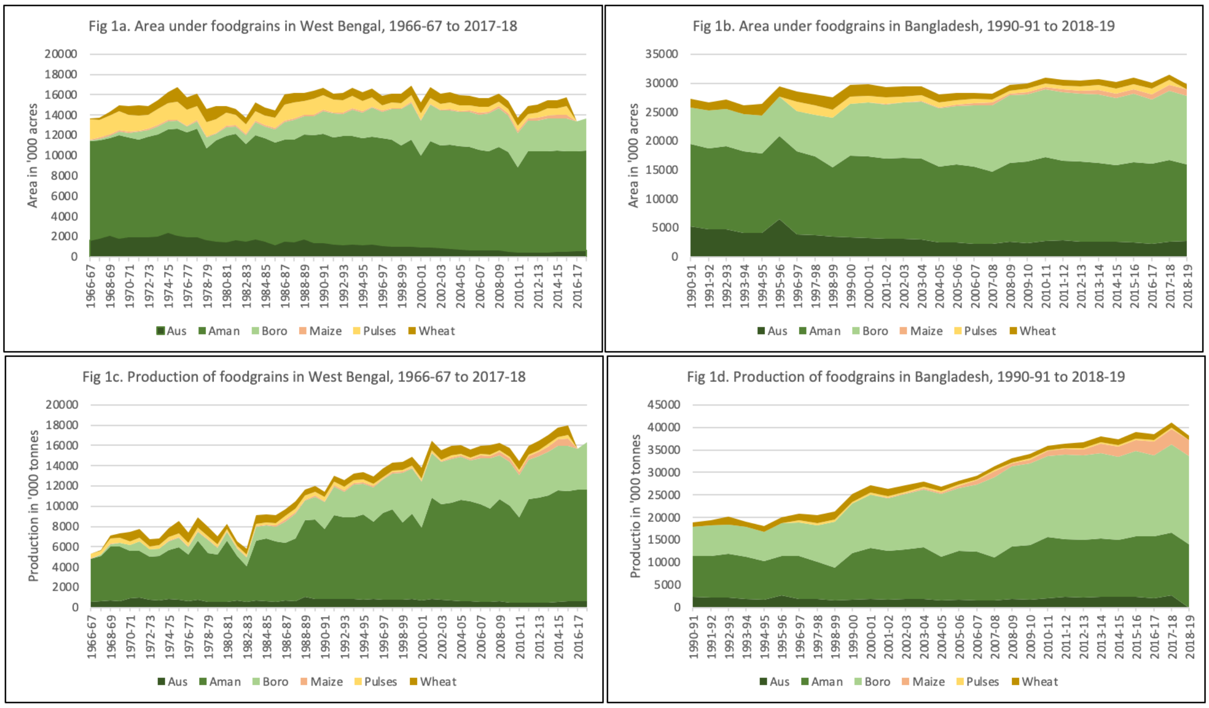


Figure 1: Area under food grains in West Bengal from 1966-67 to 2017-18 (Fig. 1a) and Bangladesh from 1990-91 to 2018-19 (Fig. 1b). Production of food grains in West Bengal from 1966-67 to 2017-18 (Fig. 1c) and Bangladesh from 1990-91 to 2018-19 (Fig. 1d)

Table 1: Average annual growth rate of area under paddy area by decade

	Bangladesh					West Bengal				
	1973-1979	1980-1989	1990-1999	2000-2009	2010-2020	1970-1979	1980-1989	1990-1999	2000-2009	2010-2017
Area paddy	1.29%	0.12%	-0.47%	1.55%	0.03%	-0.11%	1.47%	0.94%	-0.72%	-0.04%
Area Aus	1.17%	-1.80%	-6.13%	-2.35%	0.67%	-1.54%	0.53%	-2.83%	-6.27%	1.99%
Area Aman	1.07%	-1.80%	-0.30%	1.45%	-0.17%	0.04%	0.69%	-0.04%	-0.39%	0.39%
Area *Boro*	4.56%	8.88%	3.76%	3.13%	0.21%	9.32%	13.38%	7.44%	-0.21%	-1.01%

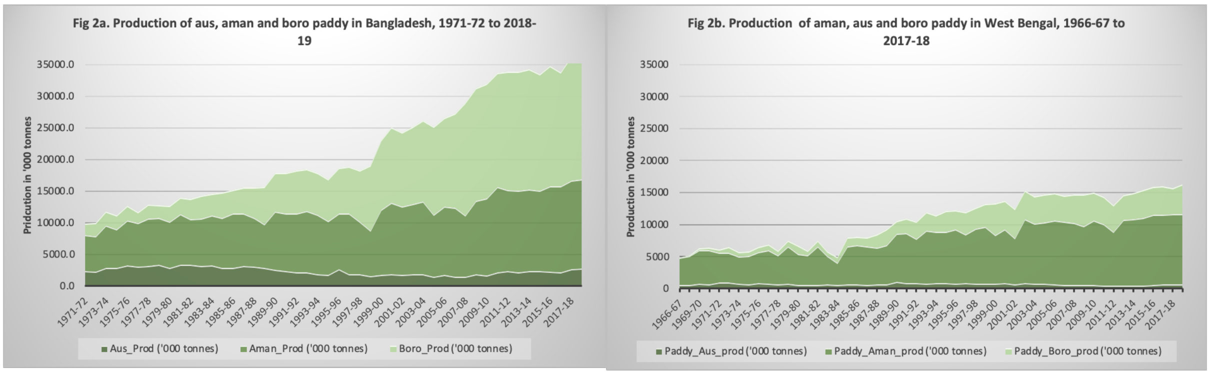


Figure 2: Production of aman, aus and boro paddy Bangladesh from 1971-72 to 2018-19 (Fig 2a) and West Bengal from 1966-67 to 2017-18 (Fig 2b)

It was *boro* paddy that drove agricultural growth in West Bengal and Bangladesh. High yielding *boro* emerged in the late 1960s and early 1970s in the form of innovation of a seed called IR8 by the International Rice Research Institute (IRRI) in partnership with national agricultural research centres like Bangladesh Rice Research Institute (BRRI) (Bose, 1974). As a wholly irrigated crop, the rise in area under *boro* coincided with the increase in area under groundwater irrigation (see Section 3). In Bangladesh, the area cultivated under *boro* was 16% of the area cultivated under *aman* in 1972, but it reached 89% of *aman* area in 2018-19. Similarly, in terms of production, in 1999, *boro* production was larger in volume than *aman* production, and in 2019, 54% of the total rice production in Bangladesh was from *boro* crop. In West Bengal, the relative importance of *boro* in the total paddy area and production is lower than that of Bangladesh. In 2017, *boro* paddy accounted for 32% of the total paddy area and 29% of the total rice production. If we define *aman* area as the maximum area suitable for rice cultivation, then Bangladesh has almost reached the limits of expansion in further *boro* cultivation, while West Bengal can bring more land under *boro* in the future.

2.3 Phases in growth in *boro* paddy: Surge, steady growth and stagnation

With *boro* being the primary driver of agricultural growth in West Bengal and Bangladesh since the 1970s, we look more carefully at the different phases of the APY of *boro* paddy. We identify three growth phases on the two sides of the border and call them surge, steady growth, and stagnation. The timing of the three phases differs between West Bengal and Bangladesh, but the overall direction of trends remains the same.

In West Bengal, the first period of the surge was from the mid-1960s to the mid-1990s. During this period, the average growth rate of the *boro* area is as high as 18% per annum. The massive conversion of land under *boro* cultivation resulted in an upsurge in production. During the same period, the average growth rate of *boro* production was 23% per annum. The increase in production is driven by the growth in the area and yield of boro paddy. During these 30 years (1967-1995), *boro* yields increased on average by 3.3% per year. A lot has been written about this phase in West Bengal, specifically on the role of land and institutional reforms in propelling growth (Bandyopadhyay, 1981; Banerjee, Gertler, & Ghatak, 2002; Ghatak & Roy, 2007; Leiten, 1990; Rogaly et al., 1999). In contrast, there has been relatively less attention given to the role of groundwater irrigation in this transition (Harriss, 1992, 1993; Mukherji, 2007; Palmer Jones, 1992; Palmer-Jones, 1999). The second period (the mid-1990s to the end of the 2010s) saw a slowdown in the growth of APY of *boro*. The area cultivated with *boro* still progressed but at an average annual growth rate of 2.1%. Yields stagnated with an average yearly growth rate of 0.5%, and area changes mainly drove production increases which grew by 2.9% per annum. This period starts with structural adjustment programs introduced in 1991 in India. As a result, fertilizer and diesel subsidies declined, input costs increased, and net returns from paddy cultivation declined (Bhattacharyya & Bhattacharyya, 2007; Sarkar, 2006). This period also coincided with increased restrictions in access to groundwater irrigation (Mukherji et al., 2012, 2020) (also see section 3 and 7). At the same time, access to institutional credit for agriculture also declined after 1991 (Bhattacharyya & Bhattacharyya, 2007; Satyasai et al., 2017). The third phase in West Bengal is from 2010 onward and is a period of stagnation. The area cultivated with *boro* recorded a slight decline at -1% per annum. The yields still rose at 2.4% per annum and became the main driver of the production, which rose by 1.4% annually. This increase in yields happened during the decade (2011 onwards) when there was a rapid increase in electrification of irrigation tube wells, possibly indicating the role of assured irrigation in yield growth (Mukherji et al. 2020, Buisson et al., 2021).

In Bangladesh, the first period of high growth is from independence (1971) to the end-1980s. From 1971 to 1989, the area cultivated with *boro* paddy rose by 6.7% annually on an average. The production followed the same trend with an annual average growth rate of 8.3%, while the yield increased annually by 1.4% during the same period. Higher yield growth in West Bengal compared to Bangladesh in the first period led to many scholars attributing the difference in yield growth in *boro* to land reforms in West Bengal and its lack in Bangladesh (Crow, 1999; Shahabuddin, 1999). However, this period (especially the 1980s) saw massive investment in irrigation and improved access to irrigation for marginal and tenant farmers in Bangladesh (see section 3), which supported the growth in *boro* area and production. In 1988, in response to a devastating flood in Bangladesh in 1987, the fertilizer and pesticide markets were liberalized, and previous import, spacing and licensing restrictions on pump and tubewells were removed (Biggs et al., 2011; Hossain, 2009). The entry of the private sector into the fertilizer and pesticide markets increased access to inputs (Talukder, 2018). Flat subsidies and supports were removed and replaced by more effective incentive devices such as fiscal waivers on licensing, fertilizer, seeds supply privatization and institutional reforms such as introducing transferability of supply licenses. Private investments from farmers all over the country ushered in the green revolution with massive production of high-yielding Boro rice (Shahid & Hazarika, 2010). Total factor productivity (TFP) and technical efficiency (TE) depended on seed, fertilizer, insecticides and irrigation infrastructure with irrigation had the greatest influence on productivity of rice (Hasnain, 2015; Wadud, 2003). Groundwater irrigated *aman* and *aus* yields were much higher as compared to rainfed plots (Bell et al., 2015).

In Bangladesh, liberalization measures were hailed as successful for increasing access to farm inputs (Hossain, 2009; Hossain & Deb, 2003), while similar market reforms in 1991 were deemed to have negative impacts in West Bengal (Bhattacharyya & Bhattacharyya, 2007; Sarkar, 2006). The second period in Bangladesh (1990 to 2010) witnessed high to moderate growth in the production of *boro* (+5.8% average annual growth rate), which was conjointly driven by the increase in area (+3.4% per annum) and the increase in yields (2.3% per annum). Compared to West Bengal, growth rates in yields were higher in Bangladesh during this second period. The long duration of this period of high to moderate growth is possibly a testament to the lasting effects of the liberalization from the end of the 1980s. Many studies estimated the impact of liberalization of the agricultural input market in 1988, associating it with increased input demand and rice production (Ahmed, 1995). Studies have estimated that 2 to 5.9 million tons of additional rice production were due to an expansion of irrigated rice (*boro*) resulting from the liberalization of the agricultural equipment market (Ahmed, 1995; Hossain, 2009; Salim & Hossain, 2006) with a net effect of about 38% of total incremental production (Ahmed & Sampath, 1992). Ahmed, (1995) argued that without the reforms, Bangladesh would have produced 1.3 million tons less rice annually (from 1988–89 to 1996–97), and this amount of additional rice that was produced due to the reforms would have fed around 22 million fewer people (Hossain, 2009; Hossain & Deb, 2003). In addition to irrigation, the development of suitable modern rice varieties and diffusion of such varieties also contributed to higher yields in *aman* and *boro*. With support from IRRI, Bangladesh was able to develop an active rice research system by establishing the Bangladesh Rice Research Institute (BRRI). To date, BRRI has developed 52 modern rice varieties to suit the agroecological conditions of all three rice growing seasons (Hossain et al., 2005).

Finally, the third period of the slowdown of growth and stagnation starts in Bangladesh later than in West Bengal. Since 2010, the average annual growth rate of the area cultivated with *boro* paddy is close to null (+0.3%), the yearly growth rate of the production is less than one (+0.9%) as well as that of yield growth (+0.7%). While West Bengal increased its yields of *boro* in this later period, possibly due to increased electrification and access to irrigation (see Section 3), Bangladesh's trends in yield growth seem to be levelling off in recent years. This levelling off also coincides with the larger policy discourse on the need for diversification to non-paddy crops (see Sections 4 and 7).

2.4 Variability in yield of *boro* paddy

While absolute yield and yield growth are important metrics, variability of yield is equally important. Lower variability in the crop yields is often synonymous with less income variation for farmers, provided that there are no large output price fluctuations. Lower yield variability also increases the likelihood of cultivating the same crop every year. Given *boro* is an entirely irrigated crop, we propose that less yield variability is an outcome of assured and timely irrigation. To examine the variability of yields over time in Bangladesh and West Bengal, we run simple regressions with the yield of *boro* as the dependent variable and the time as the independent variable for serval periods. Then, coefficients of variation (CV) are calculated as the ratio of the standard deviation of residuals to the sample mean of the dependent variable. The trends and the coefficients of variations are presented in Figure 3. Alternatively, we plot the distribution of the residuals of the same regressions in Figure 4. Distributions centred around the null value translate lower variation in yields over time.

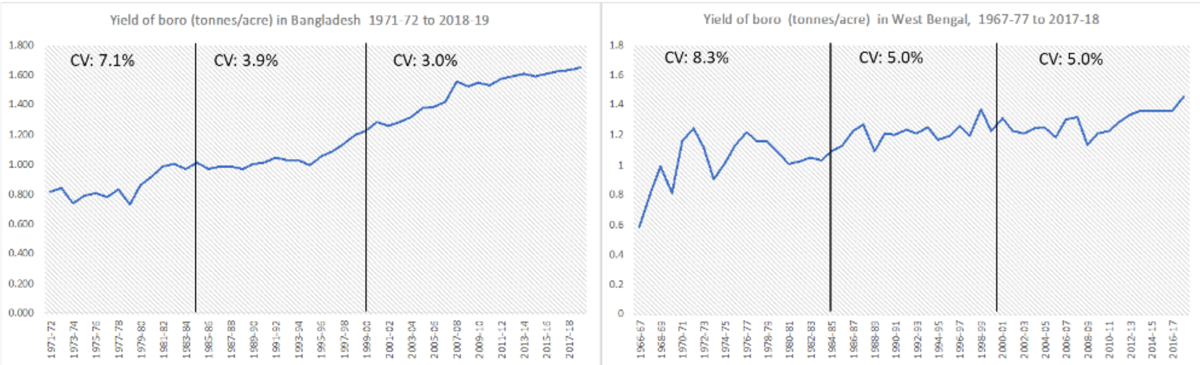


Figure 3: Trends in yield and coefficient of variation of the yield of boro paddy in Bangladesh and West Bengal

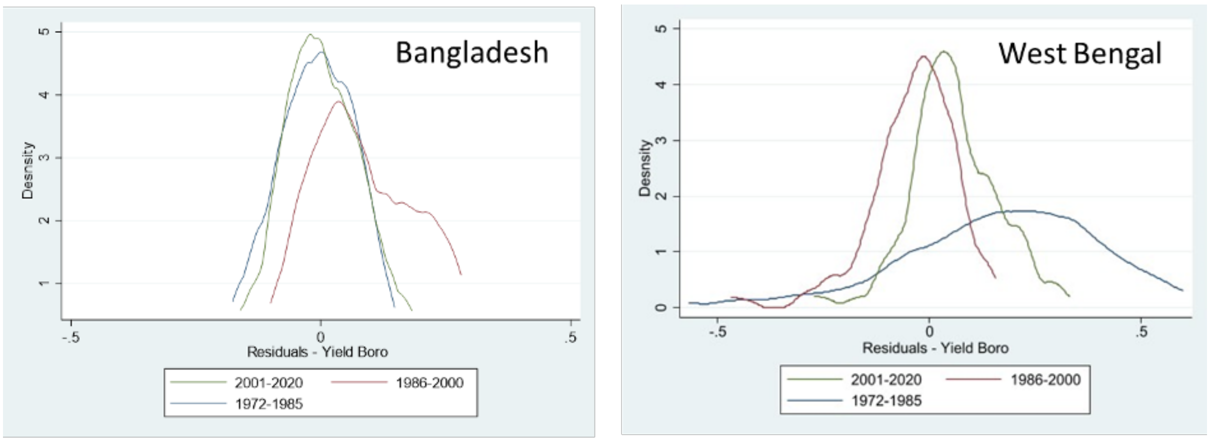


Figure 4: Yield variability of boro paddy from distribution of residuals in Bangladesh and West Bengal

The first observation is that the variability of yield has decreased over time. This finding holds in both West Bengal and Bangladesh. For example, in recent years (2001-2020 period), the coefficient of *boro* yield variation was 3% in Bangladesh and 5% in West Bengal, while it was 7.1 and 8.3% during the 1970s and 1980s in Bangladesh and West Bengal, respectively. The second observation is that yield variability is lower in Bangladesh compared to West Bengal. While the agroecology and the weather shocks are expected to be quite similar across these two geographies, other factors may explain the difference in yield variability. One can be the type of seeds and inputs used on the two sides of the border. Adoption of HYV varieties is higher in Bangladesh than in West Bengal. Bangladeshi farmers may also have access to better seeds more adapted to the local conditions and less vulnerable to droughts or floods, given the intensive research carried out by BRRI. On the other hand, India's agricultural research system may be less responsive to the needs of the humid eastern region, with its historical focus being in northwest India. Similarly, reliable irrigation for farmers may explain less yield variability for *boro* paddy in Bangladesh than in West Bengal. Indeed, the growth of groundwater irrigation has been more consistent in Bangladesh than in West Bengal, as the next section shows.

2. Trends in groundwater irrigation coincided with trends in *boro* paddy

Expansion in APY of *boro* paddy was made possible through rapid growth in groundwater irrigation, especially the number of shallow tube wells (STWs) since the 1980s in Bangladesh and West Bengal. Expansion in the number of STWs stagnated in West Bengal by the mid-1990s due to policy restrictions discussed later in this section. However, the number of STWs kept increasing in Bangladesh till around

2010 or so, after which growth stagnated. Bangladesh had an estimated ~1.5 million groundwater extraction structures in 2018-19. There are no definitive estimates of the number of groundwater structures in West Bengal due to inadequate and inconsistent data. Using various estimates, we arrived at a tentative number of roughly 0.9 million groundwater structures in 2013-14 in West Bengal (see section 3.2). Initial expansion in groundwater structures in West Bengal was attributed to land and institutional reforms (Bandyopadhyay, 2003; Banerjee et al. 2002), but this was contested by others who attributed the increase to the availability of cheap pumps (Harriss, 1993; Palmer-Jones, 1999). On the other hand, in Bangladesh, the literature is unequivocal that rapid expansion in STWs resulted from policies like the relaxation of well spacing norms and removal of restrictions on pump imports in 1987-88, following a severe drought event (Ahmed, 1995; Hossain, 2009).

3.1 Groundwater irrigates a larger share of the cultivated area than surface water

In Bangladesh, the area irrigated from groundwater sources is larger than from surface water sources since 1985. While the area irrigated by surface water sources has been relatively constant from the 1980s to the end of the 2000s, groundwater irrigation has grown rapidly till around 2010. Since 2010, the area irrigated by groundwater has been constant from one year to another, and surface irrigation is increasing moderately (Figure 5). The decade of 2010s has also seen an increased policy discourse around fears of groundwater over-exploitation and renewed emphasis on surface water irrigation. (Krupnik et al., 2017; Qureshi et al., 2014). Evidence from Bangladesh shows that intensive groundwater irrigation has enhanced recharge through a mechanism called the "Ganges Water Machine Hypothesis" (Shamsudduha et al., 2011). At the same time, the lowering of groundwater levels has been limited to small pockets in northwest Bangladesh with semi-confined aquifers (Kirby et al., 2015b), also see section 6).

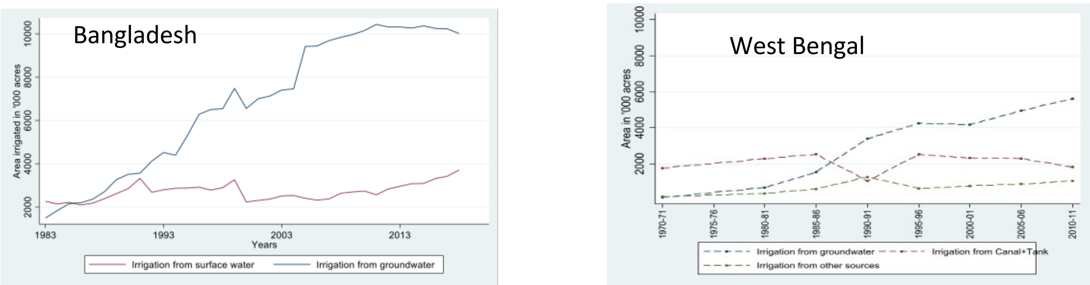


Figure 5: Area irrigated and sources in Bangladesh (1983-84) and West Bengal (1970-71 to 2010-11)

In West Bengal, unlike Bangladesh, there is no long-term time series data on area irrigated by groundwater. Instead, the data on the area irrigated by different sources of irrigation is available from the Agricultural Census, at a gap of 5 years, starting from 1970-71[iii]. Like Bangladesh, the area irrigated from groundwater (wells and tubewells) has been steadily increasing in West Bengal, while surface water irrigated areas remained more or less constant. By 1990, groundwater has become the most important source of irrigation in West Bengal. However, the contrast with Bangladesh is the much slower growth in groundwater irrigation in West Bengal. While groundwater irrigated areas in Bangladesh increased from 4.5 million acres in 1993 to 9.4 million acres in 2005, it went from 4.2 million acres in 1996 to just 4.9 million acres in 2006 in West Bengal. Assuming the total *aman* area as a proxy for the net sown area (NSA) (due to the lack of NSA data from Bangladesh), we estimate that 67.6% of the NSA was irrigated by groundwater in West Bengal and 73% in Bangladesh in 2011.

3.2 Expansion in the number of groundwater irrigation structures

According to data from Bangladesh Agriculture Development Corporation (BADC), in 2018, there were 13.56 million STW, 0.176 million low lift pumps (LLP), and 0.037 million deep tubewells (DTW). Since 1990, the expansion of irrigation has been almost exclusively through the exploitation of groundwater by private STWs (Rahman & Parvin, 2009). In Figure 6, we note that the rise in the number of STW started in the mid-1980s, which coincided with the liberalization of pump import policies and removal or other restrictions. Import taxes and standards for diesel pump imports were removed in 1988, and well permits regulation was suspended in 1992 (Hossain, 2009a). These policies resulted in 20 years of high growth in STW, coinciding with an increase in APY of *boro* paddy. From 1990 to 2010, on average, 55,482 new STWs were recorded every year. Also, from the end of the 1990s and the beginning of the 2000s, nearly all centrifugal pumps initially imported from China and India are now being manufactured locally in Bangladesh, allowing farmers to access less expensive pumps (Biggs et al., 2011a). However, since 2010, the number of STW started declining, coinciding with the decline in growth in APY of *boro* paddy. Reasons for the decrease in the number of STW are not well understood and needs further research. In 2018, a new law was introduced that requires that farmers take prior permission from authorities to construct new wells and tubewells. Retrospective registration of existing wells and tube wells is also needed (see section 7). The actual status of implementation of the law is not clear yet.

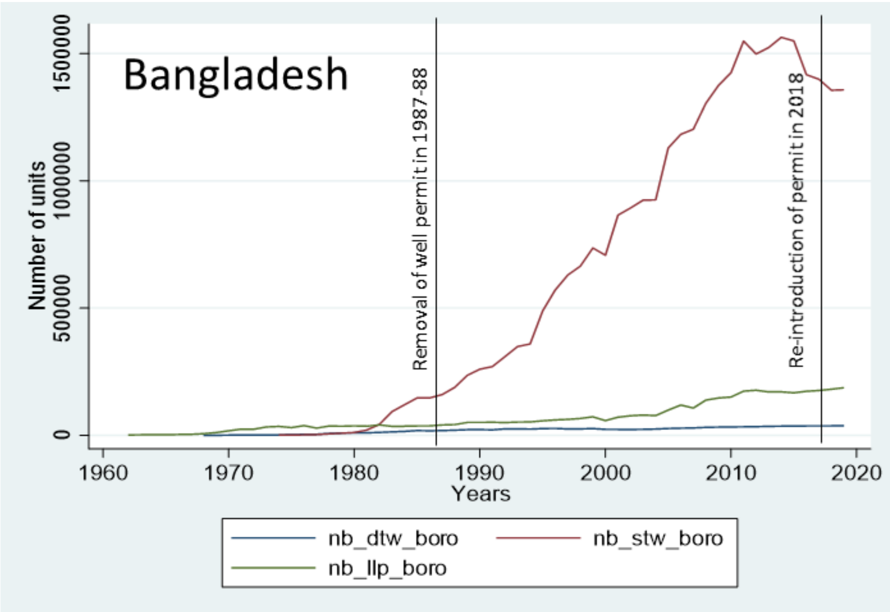


Figure 6: Number of groundwater extraction structures in Bangladesh, 1960-2019

West Bengal lacks long-term statistical data on private tubewells, including information on the motive power of pumps (diesel or electric). The state also records significant discrepancies in data on the number of wells and tubewells from different sources of statistical records (Rawal, 2012; Rawat & Mukherji, 2014). Lack of data is a major constraint hindering any rigorous economic analysis of the contribution of groundwater irrigation to agricultural growth in the state (Fujita et al., 2003; A. Sarkar, 2006a, 2020a). In addition, there is no separate data on the number of diesel pumps. On the other hand, the number of electric pumps is relatively easy to compile based on data provided by the electricity utility in the state – the West Bengal State Electricity Distribution Company Limited (WBSEDCL). Based on five rounds of minor irrigation (MI) censuses (GOI 1986, 1993, 2005, 2014, 2017), and with point data from various agricultural censuses, National Sample Survey Organization (NSSO, 2004) surveys, one round of Indian Human Development Survey (IHDS 2005, 2012), and secondary data from WBSEDCL we have constructed various estimates of number wells and tube wells (STW, DTW and dug wells) and the number of electric pumps in the state. Based on MI census reports, the number of water extraction structures vary widely from between 11.4 million (if the number of structures is added up year after by ignoring the unaccounted drops in numbers recorded at the beginning of every MI census) to 4.2 million wells (if abrupt reductions in numbers of water extraction structures are included) in 2013-14. Based on a relatively close match with three independent point estimates (namely, IHDS in 2004-05, Agricultural Census, 2010-11 and NSSO in

2012-13), we propose that 0.9 million water extraction structures may be a realistic estimate (estimate 3 based on MI Census in Figure 7). Of these, roughly 1/3rd (~3.0 million) are electric pumps (WBSEDCL data), and the rest 2/3rd are diesel pumps (Figure 7).

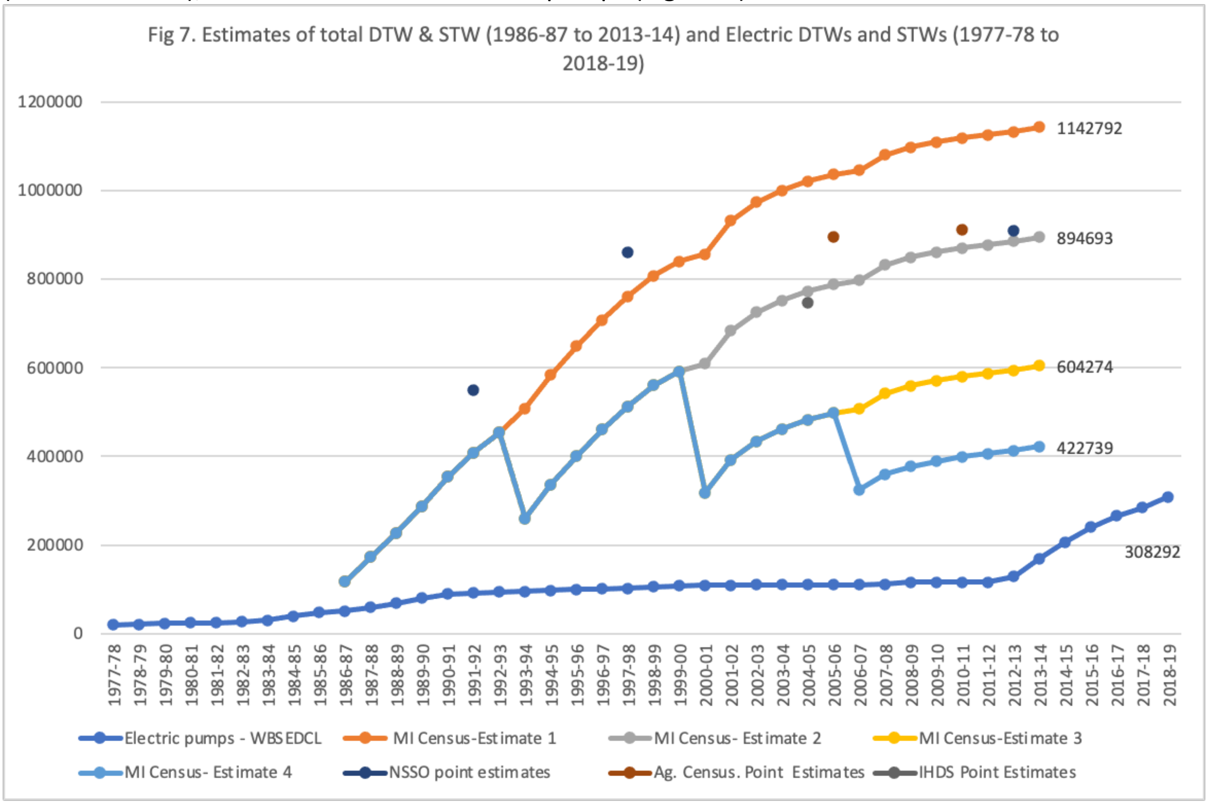


Figure 7: Estimates of groundwater extraction structures (STW and DTW) based on MI Census (1986-87 to 2013-14), point estimates STW and DTW of various years based on NSSO surveys, Agricultural censuses and IHDS survey and number of electric pumps (1997-78 to 2018-19) based on WBSEDCL data.

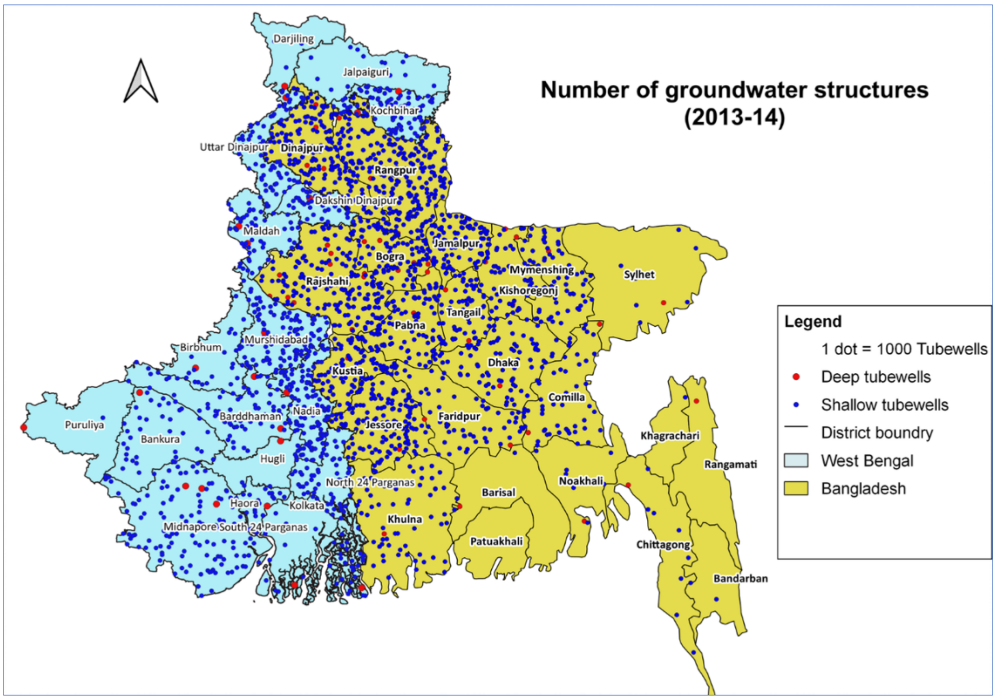


Figure 8: Groundwater irrigation structures in Bangladesh and West Bengal

Beyond national and state-level figures, it is also interesting to consider the geographical heterogeneity in wells' location. For example, from figure 8, it is clear that the density of STW is higher in the western districts of West Bengal (Nadia, Murshidabad, Malda, Uttar and Dakshin Dinajpur) and the eastern districts of Bangladesh (Dinajpur, Rangpur, Rajshahi, Kustia, Jessore, Bogra and Pabna). These are the alluvial plains with extensive unconfined aquifers.

3.3 Electrification of groundwater pumps

In the initial years (the 1970s), electrification of pumps was rare. The only pumps to be electrified were government-owned deep tube wells, while most (>95%) of privately owned STWs were diesel operated. However, the electrification of private pumps has picked pace in both Bangladesh and West Bengal in recent years. Recent studies in West Bengal (Buisson et al., 2021; Mukherji et al., 2020) looked at the impacts of rapid electrification of groundwater structures on agricultural outcomes in West Bengal, no such research comparing electric and diesel pumps exist for Bangladesh to the best of our knowledge. Nevertheless, electrification of groundwater pumps assumes importance given the increased cost of diesel that has started to impact the profitability of irrigated crops like *boro* paddy (see section 5).

In Bangladesh, 21% of the STW were electrified by 2019, and this share has progressively risen over the last decades. Farmers pay metered tariffs, and meter rates are nominally subsidized, being somewhat lower than domestic and industrial tariffs. In 2004, irrigation accounted for only 5% of electricity use. The National Energy Policy of 2005 acknowledged the issue of low pump energization and noted, "Adequate attention has not been given to meet the total energy needs of rural areas." In line with the objective of the Private Sector Power Generation Policy (PSPGP) of 1996 and the vision statement of 2000, one of the major policy goals of the 2005 Energy Policy was to bring the entire country under electrification by the year 2020. With the 100% electrification target likely achieved in 2021, more diesel pumps are expected to be electrified. However, the impacts of rising electrification rates on agricultural outcomes and informal water markets are yet to be studied.

In West Bengal, initial investments in STWs in the 1970s were supported through local governments (*panchayats*). Most of these STWs were diesel operated. Between 1985 to 1990, the Government of West Bengal (GoWB) received World Bank funding where farmers or the *panchayats* received subsidies for construction and electrification of STWs (Rao, 1995). The decade of 1980s saw rising trends in the electrification of STWs. However, around 1993, GoWB imposed restrictions in some selected districts in the state on low duty tube wells fitted with submersible pumps and made it mandatory for farmers to seek prior permission from State Water Investigation Directorate (SWID) before applying for electric connection. Seeking prior permission for electrification of groundwater pumps was later codified in the State Groundwater Act of 2005. In addition, starting from around the mid-2000s, state electricity boards started asking farmers to pay the full cost of a new connection, including poles, wires and transformers (Mukherji et al., 2012). All these policy restrictions led to a slow down and near halt of electrification of wells and tube wells in West Bengal (Figure 9). Till 2007, farmers paid flat electricity tariffs, and these tariffs had increased substantially over the years. In 2007, the GoWB and its electricity utility, the WBSEDCL, decided to meter all agricultural pumps in the state, which affected informal groundwater markets, as we will see in the next section (section 4). In 2011, in response to policy recommendations made by IWMI scientists, GoWB removed the provision for the prior requirement of SWID permits for electricity connections, leading to a massive spurt in the number of electric wells and tubewells (Figure 9). Currently, as per our estimates, roughly 1/3rd of all groundwater extraction structures is electrified. We have examined the impacts of changes in electricity policies on agriculture in West Bengal in another ACIAR report (Mukherji et al., 2020).

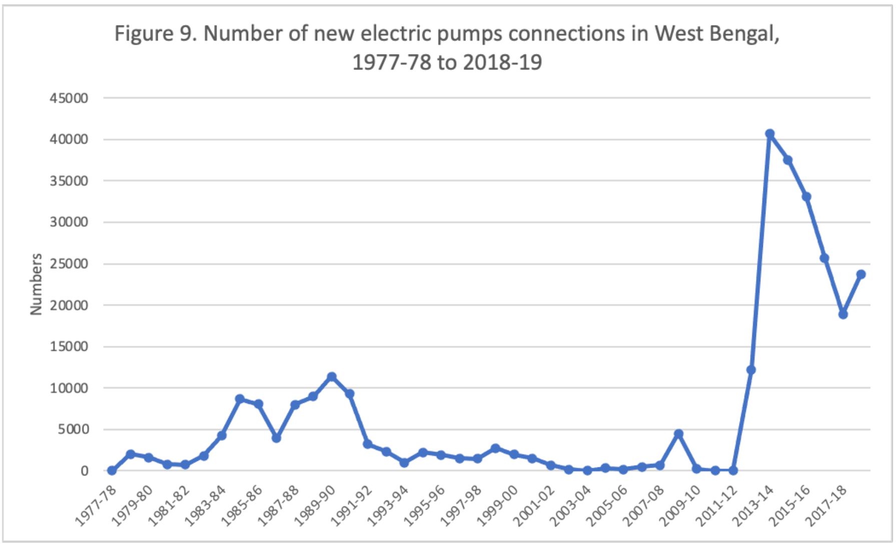


Figure 9: Trends in the electrification of pumps in West Bengal, 1977-78 to 2018-19

3. Informal groundwater markets as a vehicle of irrigation access

Even though the number of groundwater extraction structures increased over the years, not all farmers could afford to invest in them. As a result, most farmers in West Bengal and Bangladesh got access to groundwater irrigation through informal water markets. For example, based on NSSO data, Mukherji (2008) showed that 2/3rd of rural cultivating households in West Bengal purchased irrigation from their neighbors'. A lot has been written on the functioning of these informal markets, including claims and counterclaims on whether they are exploitative or not (Akteruzzzaman et al., 1998; Islam et al., 2017; Modak & Bakshi, 2017; Mukherji, 2007). Also of interest to our storyline is the impact of electricity tariffs and diesel prices on the functioning of these informal markets (Section 4.2), which ultimately affects crop economics and profitability (section 5).

4.1 Extent and coverage of groundwater markets

The informal market for groundwater irrigation services remains fairly ubiquitous in Bangladesh and West Bengal. However, there is an absence of representative national or state-wide surveys measuring the extent and coverage of groundwater markets. This is especially true for Bangladesh, where village-level case studies remain the only authoritative source of information on groundwater markets. For West Bengal, we use a few large-scale national surveys to understand the scope and extent of informal water markets.

Based on three rounds of NSSO data, and two rounds of IHDS data, we estimate the proportion of rural agricultural households who buy irrigation services from other pump owners in West Bengal. These numbers are, at best broad estimates, and comparisons are rough, as each of these data sources uses different measures and ways of estimating. Table 2 present these various estimates.

Table 2: Estimates of extent and prevalence of informal markets for groundwater-based irrigation services in West Bengal

Year	Percentage of households who "buy" irrigation services from others	Remarks on method of calculation	Source
1976-77	~51% (denotes % of pumps rented out to others for irrigation)	Data for the percentage of pumps that are rented is reported in the survey results.	NSSO, 31st Round, cited in Mukherji (2008)

1997-98	~67%	Provides data on percentage of households who purchase irrigation services.	NSSO, 54th Round, cited in Mukherji (2008)
2004-05	~78.7% to 80.6% (depending on definition, see next column)	IHDS collects data on households that own wells and tubewells, and households who use irrigation from wells and tubewells. We define "pure" water buyers as those who use irrigation from wells and tubewells, but do not own them (first estimate). IHDS also asks a direct question on the purchase of irrigation, where there is an overlap between who own wells and tubewells and reports buying water (second estimate). These are owner-cum buyers of groundwater.	IHDS, 2005
2011-12	~66.0% to 74.7% (depending on definition, see next column)		IHDS, 2011-12
2012-13	~ 57% to 63% (depending on season of enumeration)	NSSO survey asked crop-producing agricultural households how irrigation was procured, with purchased irrigation being one of the options. This survey was done in June-December 2012 (largely coinciding with rainfed *aman* in West Bengal, this gives us our first estimate) and in Jan-June 2013 (largely coinciding with irrigated *boro* in West Bengal, this gives us our second estimate.	NSSO, 2012-13

Source: Mentioned in the last column

While the actual estimate of the extent of water markets differs across these various data sources, two things emerge. First, at least 2/3rd of all agricultural households in West Bengal who irrigate their land do so by purchasing irrigation from others. Second, over the last decade or so, it is possible, even though we cannot say this with a high level of confidence, that share of households who purchase irrigation has declined to some extent. Possible contraction in the size of water markets is partly a result of the metering of agricultural pumps (see Section 4.2). It could also result from an increased number of electric pumps (Figures 7 and 9), which may mean that some erstwhile water buyers have become pump owners (Mukherji et al., 2020). In Bangladesh, no such macro-level information on the extent of water markets exists to the best of our knowledge.

4.2 Functioning of water markets, equity implications and role of energy prices

In West Bengal, previous studies have shown that irrigating from electric pumps is cheaper than diesel pumps (Buisson et al., 2021; Mukherji, 2007). Studies have also shown that high flat tariffs in West Bengal, which continued until 2007, promoted relatively competitive water markets. Small and marginal water buying households benefitted from competitive prices and received better services from electric pump owners (Mukherji, 2007; Mukherji et al., 2009). However, the nature of water markets changed in West Bengal following the metering of all-electric pumps since 2007. Metering changed the incentives for water selling, negatively impacting small water-buying farming households. First, right after metering, water prices went up by 30-50% in most villages (Meenakshi et al., 2013; Mukherji et al., 2009). Second, the bargaining power of water buyer's *vis-a-vis* the water sellers declined considerably (Shah & Chowdhury, 2017). As a result, sellers demanded payment at the beginning of the season rather than after the harvest, as was the norm earlier (Meenakshi et al., 2013). Similarly, instead of selling water, many pump owners wanted to lease in buyers' land for *boro* cultivation (Mukherji et al., 2009), depriving opportunity for many smallholder farmers to grow *boro* paddy. All these changes happened in the water market due to the pump owners' changed incentive structure. Earlier, electric pump owners had to sell water proactively to recover the electricity bill (as they had to pay a hefty electricity bill irrespective of hours of pumping). Under a metered tariff regime, they no longer had any compulsion to sell water (as electricity bills depended on the number of hours of pumping) unless they wanted to make additional profits. As a result of metering, water markets contracted, which led to further demand for electrification. Some of these demands were met through an ad-hoc policy of temporary electricity connections only for the four months of the *boro* season, and the number of temporary connections increased from 2007 onwards (Mukherji et al., 2012). However, getting a permanent agricultural electricity connection in West Bengal was not easy due to several policy restrictions, including the requirement to obtain a prior permit from the groundwater department before applying for an electric pump, as discussed in the previous section. Based on policy advocacy by IWMI researchers, the GoWB relaxed these norms in 2011. As a result, there was rapid electrification of agricultural wells and tube wells between 2011 to 2019, and over 200,000 new agricultural pumps were electrified (see Figure 9). A study by IWMI and supported by the ACIAR (Mukherji et al., 2020) showed that electrification of wells and tubewells did not result in rapid agricultural growth as was envisaged, except in a few districts in North Bengal where extent of irrigation was abysmally low before electrification. That study concluded that the ever-increasing cost of cultivation and stagnant paddy prices in the absence of government-led procurement squeezed farmers' profits, making them unwilling to cultivate *boro* paddy (see Section 5).

In Bangladesh, low diesel prices, resulting in low diesel price to paddy price ratio, led to beneficial impacts of water markets on crop production. However, there is not literature on the impact of energy prices on the functioning of groundwater markets in Bangladesh. Instead, much of the literature in the early years was about whether or not water markets were exploitative. By mid- 1990s, a consensus had emerged about the beneficial impacts of these informal markets for irrigation service provision. Palmer - Jones (2001) characterized these informal groundwater markets as "private provision of local public goods”. Mandal, (1987) noted that widespread ownership of STWs has helped to break monopolistic control over the supply of irrigation water by the landed wealthy farmers.

4. The rising cost of cultivation of paddy and resulting crop diversification

In recent years, the rising price of diesel, and other inputs, including labour, has made *boro* cultivation unprofitable in both West Bengal and Bangladesh. We posit that the increasing cost of cultivation has resulted in stagnation in APY of *boro* paddy (see Section 2), further encouraging a move towards diversification away from paddy (Section 5.2). Crop diversification is more apparent in West Bengal than in Bangladesh. In Bangladesh, some amount of diversification away from paddy has started happening only since 2010.

5.1. Rising cost of cultivation and falling profitability

In Bangladesh, based on various estimates on the cost of cultivation and value of paddy production, we have calculated the profit ratio from *boro* paddy as a proportion of the total value of the product to the total cost of cultivation. We have included two types of cultivation costs – cash costs and total costs, which includes non-cash costs. In Bangladesh, data for the cost of cultivation is available for 2008-09, 2009-10, 2018-19 and 2019-20. The value of paddy to cost of cultivation in cash was 1.5 in 2008-09 and 1.4 in 2009-10 but declined drastically to 0.82 (denoting loss) in 2018-19 and then rose a bit to 1.06 in 2019-20. Corresponding values when considering value of produce to total (cash and non-cash) cost of cultivation were 1.0, 0.95, 0.58 and 0.76 in 2008-09, 2009-10, 2018-19 and 2019-20 respectively. This decline in profitability possibly explains stagnation in paddy growth post-2010 (Figure 10).

A similar trend was observed in West Bengal. For West Bengal, we take the profit ratio as the ratio between the product's value to cost of cultivation as A2+ FL (A2 is the total paid out cash cost and FL is imputed family labour). This profit ratio was 1.27 in 2004-05, which reached a maximum of 1.46 in 2009-10 and steadily declined after reaching a low of just 1.08 in 2017-18. Such a continuous decline in the profitability of paddy in the last decade indicates that the cost of cultivation has increased at a much faster rate than the price of paddy, making paddy cultivation unprofitable (Figure 10).

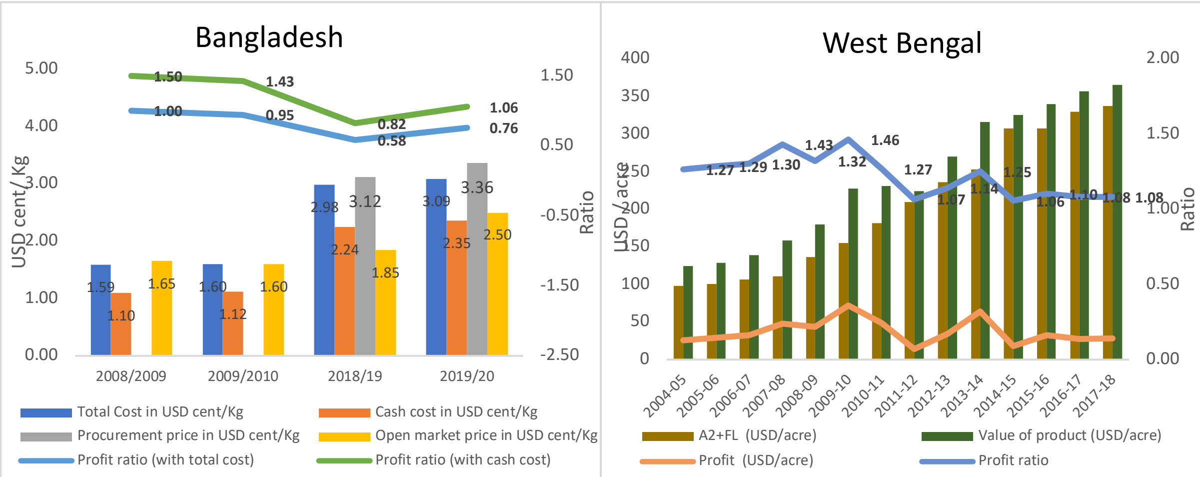


Figure 10: Profitability of paddy in West Bengal and Bangladesh.

Source for Bangladesh: Authors' calculations based on Ministry of Agriculture (FPMU), Department of Agricultural Marketing and Ahmed et al. 2020. Source for West Bengal: Authors' calculations from Cost of Cultivation surveys, Directorate of Economics and Statistics, GoWB

5.1.1 Rising cost of energy leading to high irrigation costs

A critical component of the cost of *boro* paddy cultivation is the irrigation cost. Over the years, the steep increase in diesel prices lowered paddy profitability. Figure 11 shows that the ratio of farm harvest price to diesel price started declining from the middle of the 1990s, indicating that diesel price increased more rapidly than farm harvest price for paddy. The ratio declined till 2006-07, after which it has been rising very slowly, indicating improving price to irrigation cost ratio. However, the ratio is still not as favourable as in the early 1990s and 1980s when diesel prices were highly subsidized. In West Bengal, the cost of electricity also increased rapidly in recent years. Farmers in West Bengal have paid a time of the day (TOD) metered tariff since 2007. TOD tariffs are tools for demand management, where agricultural electricity tariffs are highest during peak demand time (6 pm to 11 pm) and lowest during night time (11 pm to 6 am). The average weighted agricultural tariff had increased nearly threefold from INR 2.31 per kWh in 2009 to INR 6.51 per kWh in 2016 (Shah & Chowdhury, 2017). These are some of the highest agricultural electricity tariffs anywhere in India. We saw earlier (Section 3.3) that 80% of pumps in Bangladesh are diesel operated. With spiralling world prices of diesel, irrigation costs went up, squeezing farmers profit. Figure 12 shows rising diesel and electricity costs in Bangladesh.

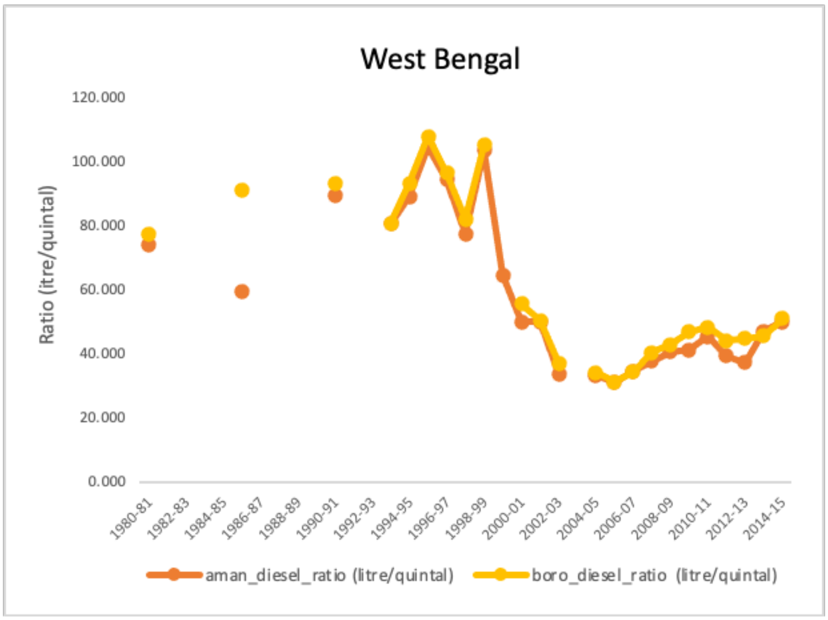


Figure 11: Ratio of Farm harvest price to diesel price in West Bengal

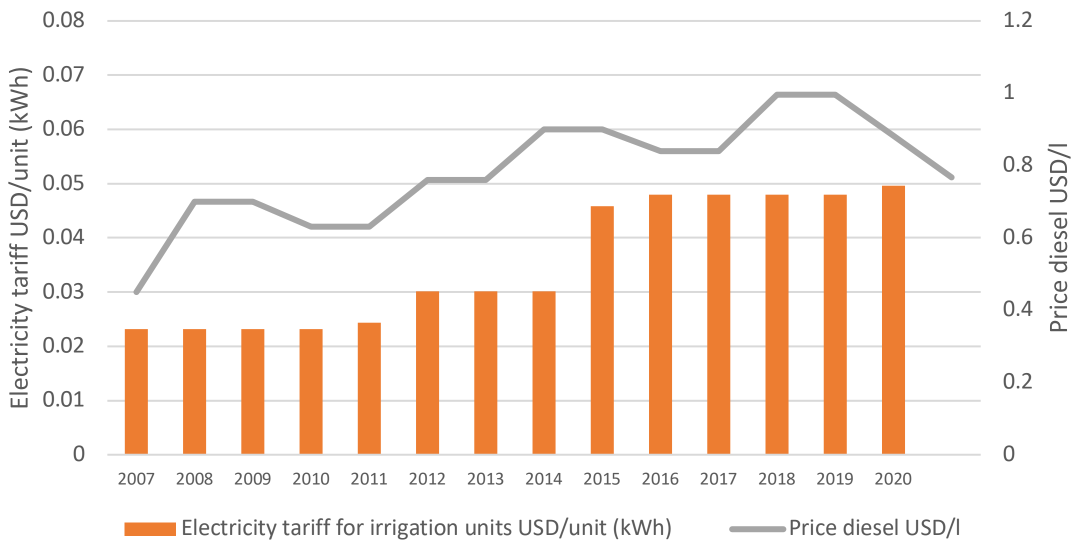


Figure 12: Diesel price and electricity tariff in Bangladesh
Source: World Development Indicators and Bangladesh Energy Regulatory Commission

5.1.3 Increasing labour costs

Labour cost is another critical element of the cost of cultivation and accounts for the largest share of total costs in paddy. In West Bengal, labour costs are rising at a much faster rate than the price for paddy, implying that paddy cultivation has become less profitable over the years (Figure 13). The ratio of farm harvest price to the daily wage rate of male agricultural field labourers for *aman* and *boro* paddy in West Bengal has been steadily declining over time. While the ratio was 30 days of labour cost per quintal in 1981, it decreased by 60% to 12 days per quintal in 2015. The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) introduced in India in 2005 played an important role in wage increase in rural West Bengal (Das, 2019). In West Bengal, the MGNREGA provided a minimum wage starting at Rs. 67 per day in 2005, which then increased to Rs. 75 in 2009, and Rs. 100 in 2010. In 2012 it was revised to Rs. 136 per day, and in 2021 it rose to Rs. 213 per day. The wage rate has increased faster than paddy price, implying that paddy productivity had to increase significantly for paddy to be profitable, which has not been the case. Declining paddy profitability over the years has led to stagnation in paddy production in West Bengal (Section 2). There has been a move towards diversification (Section 5.4), but still, a large majority of farmers cultivate paddy, and declining profitability affects farmers' incomes. Overall impacts on poverty alleviation due to changes in wage rates is an important topic of future research.

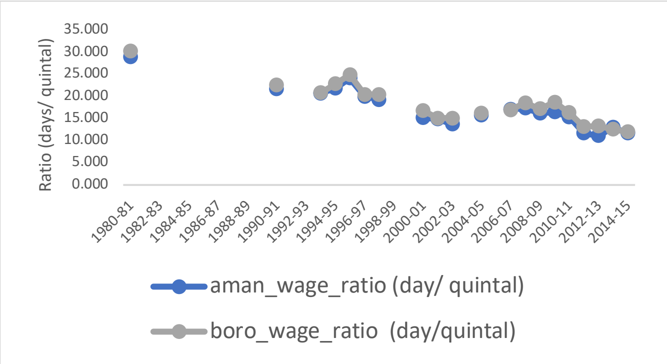


Figure 13: Ratio of farm harvest price to daily wage rate in West Bengal

High costs of production can be compensated with commensurate market price, or procurement price of paddy. However, studies have shown that the minimum support price (MSP) of paddy declared by the GOI were less than the Cost of Production (COP) for West Bengal (Mandal et al., 2017). The possible reason might be that MSP is recommended by the Commission for Agricultural Cost and Prices (CACP) and declared by the GOI and is uniform for all the states, although the COP of paddy was different across the states. Farmers in Bengal incur one of the highest rates of electricity charges in India and even irrigate with diesel pumps increasing the cost of cultivation to a considerable amount (Sarkar, 2020), which is not the case in many other major rice producing states where agricultural electricity is free or highly subsidized. The cost of production of paddy particularly increased after 1999. The rice farmers have thus suffered from lower price realization than the respective MSPs since 2000-01, lower (7 per cent) returns over total costs and higher growth in costs of production compared to the whole sale price indices between 2002-03 and 2006-07 (Sarkar et al., 2013). Data reveal that farmers incurred losses in paddy cultivation up to 14 times except for in 2007 – 08 and in 2009 -10 during 2000 – 01 to 2015 – 16. In addition, most farmers cannot sell their crops to the government due to inadequate procurement infrastructure (Paul, 2019). There are some recent reforms in public procurement system, but those reforms have not been highly effective in West Bengal (Section 7.1.2).

In Bangladesh, we note that the cost of labour is the most significant component of the *boro* cost of production. The share of labour cost in the total cost of production has been rising from 36% in 2009 to 48% in 2020 (Figure 14). In Bangladesh, the public procurement system has several shortcomings and less than 7% of the production is sold though the procurement system. farmers sell most of their produce in the open market, and remain subject to vagaries of market price (Ahmed & Bakhtiar, 2020). However, to counteract rising cost of labour, and labour shortages during peak season, GoWB and the private sector has been investing in small labour-saving machineries (Mottaleb et al., 2016, 2017)

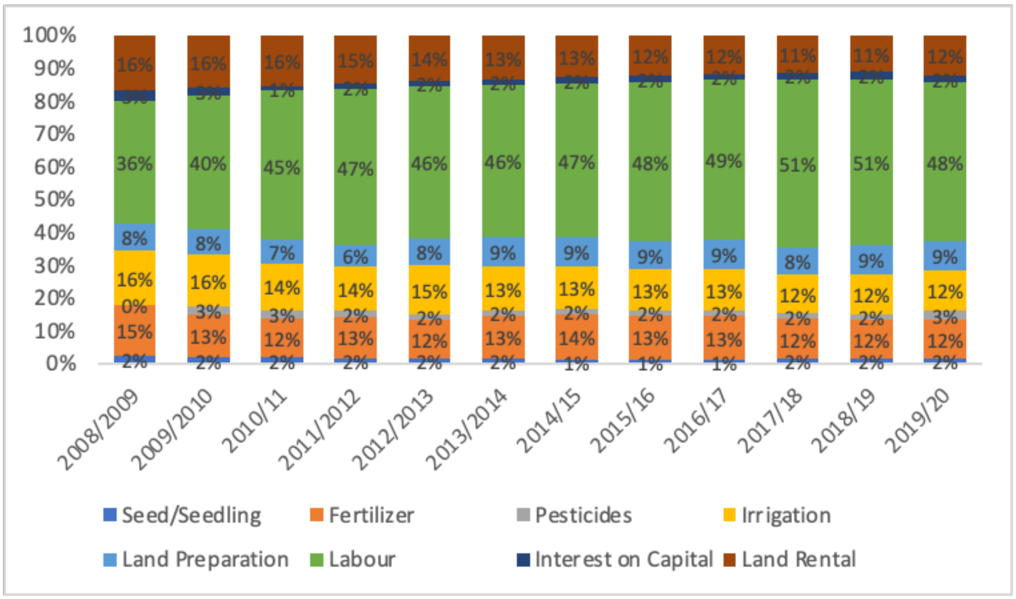


Figure 14: Component of the cost of boro cultivation in Bangladesh
Source: Authors' calculations based on Ministry of Agriculture (FPMU) data

5.2 Diversification away from paddy

In both West Bengal and Bangladesh, diversification of cropping pattern away from paddy has started, with diversification happening faster in West Bengal than in Bangladesh. We use the "Herfindahl index" (H) to measure crop diversity, where $H = \sum_{i=1}^{N} s_i^2$; s_i is the proportion of cultivated area under crop i. The index has a maximum at 1 when there is no crop diversification, i.e., there is only one crop cultivated. Smaller values of the Herfindahl index mean more crop diversification. In creating this index, we included major crops of the region, i.e., paddy, potato, pulses, oilseeds, jute, maize, and wheat. Since our interest was in measuring diversification in non-paddy crops, we club *aus, aman,* and *boro* as a single crop (paddy) for our calculation.

Herfindahl index, thus calculated (Figure 15), shows higher crop diversification in West Bengal than Bangladesh for the entire period since 1998 when data for both are available. In West Bengal during the 1990s, the Herfindahl index decreased (i.e., crop diversification increased) from 0.35 in 1990 to 0.30 in 2003 and continued to be in that range. On the other hand, the Herfindahl index for Bangladesh was almost twice West Bengal's value at around 0.65 in 1997 and continued to increase to 0.73 till 2010, indicating comparatively less crop diversity in Bangladesh. Post-2010, however, diversification started increasing in Bangladesh (the index went down from 0.73 in 2010 to 0.66 in 2018). The move towards diversification coincides with the stagnation in Bangladesh's *boro* area post-2010.

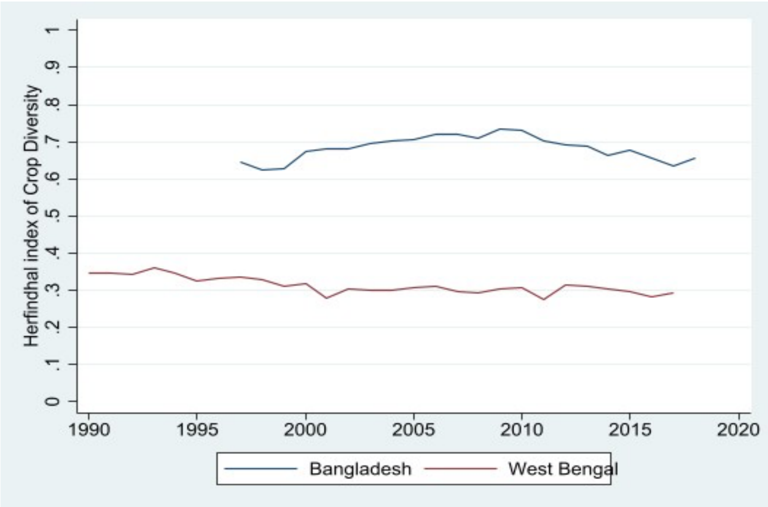


Figure 15: Herfindahl index in Bangladesh and West Bengal

To understand the composition of cropped areas in these two regions and the different non-paddy crops to which farmers in Bangladesh and West Bengal have diversified, we look at two snapshots of major crops cultivated in 1997-98 and 2017-18, respectively. During 1997-98, we had cropped area data on paddy, jute, wheat, maize, potato, pulses, and oilseeds. In Bangladesh, among these crops, 79.5% was under paddy (45.4% under *aman*, 21.8% under *boro,* and 12.4% under *us*), while in West Bengal paddy area percentage was nearly similar at 73.5% (*boro* area was only 12.5%). For the remaining 20% area under other crops in Bangladesh, it was almost equally split between pulses (26.8%), wheat (26.6%), and oilseeds (21.5%), followed by jute (19.7%) and potato (5.2%). In West Bengal in 1997-98, jute area (30.1%) was the most important crop amongst other crops, followed by oilseeds (25.1%), wheat (17.0%), potato (15.6%), and pulses (10.5%) (Figure 16).

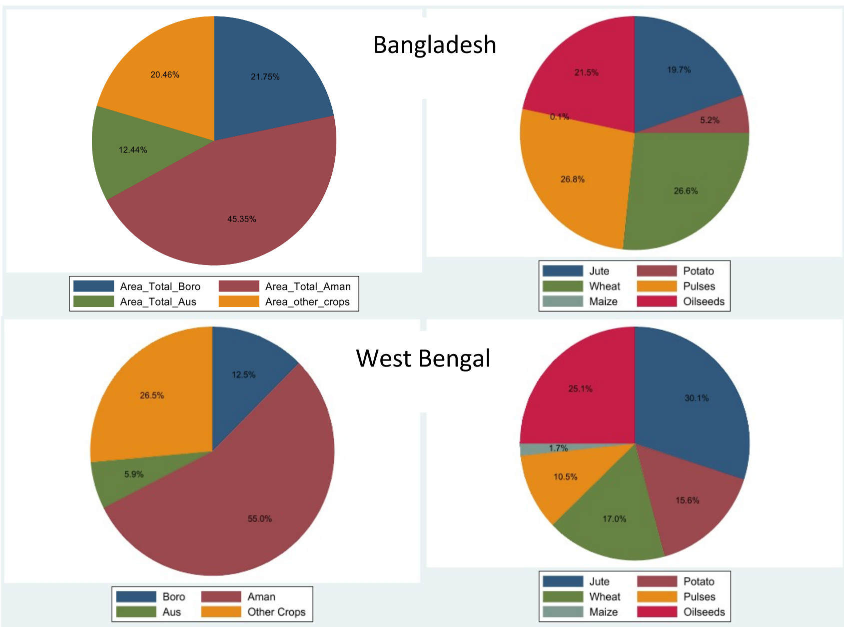


Figure 16: Cropping pattern in Bangladesh and West Bengal in 1997-98

During 1997-1998, data on the area under vegetables, fruits, and flowers are not available, and consequently, these do not feature in Figure 16. But the composition of cropped area in 2017-2018 provides a more complete picture of the different crops other than paddy cultivated in West Bengal and Bangladesh (Figure 17). However, Figures 16 and 17 are not comparable over time since the same data were unavailable for both periods.

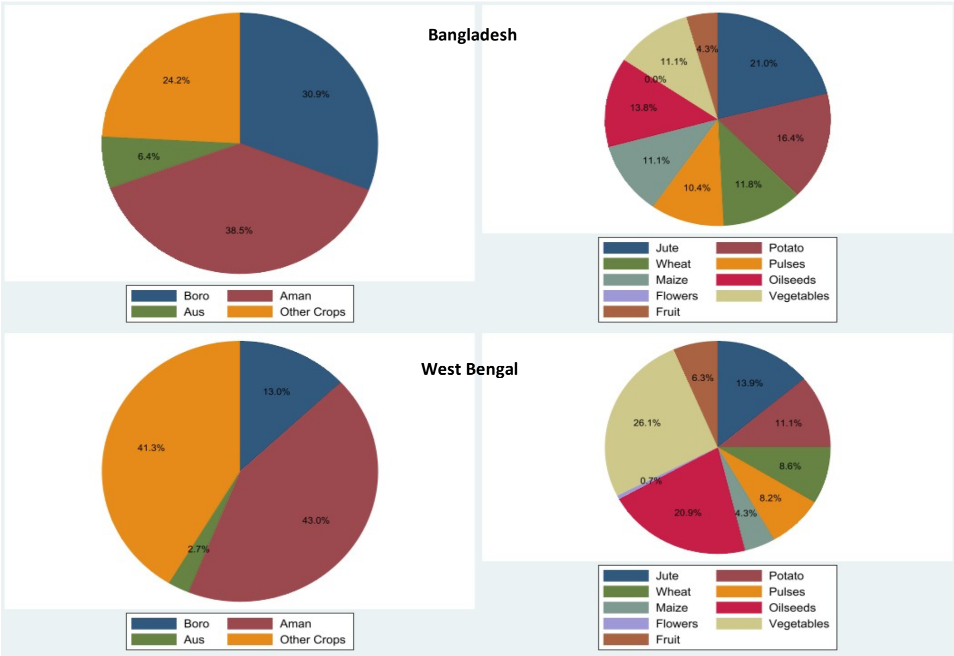


Figure 17: Cropping pattern in Bangladesh and West Bengal in 2017-18

During 2017-18, in Bangladesh, 75.8% of the cultivated area was under paddy (38.5% under *aman*, 30.9% under *boro,* and 6.4% under *aus*); while in West Bengal, paddy area percentage was only 58.7% (*Boro* area was only 13.0%), a sharp decline from the previous period (even though not strictly comparable). In Bangladesh, area under non-paddy crops was divided amongst jute (21.0%), potato (16.4%), oilseeds (13.8%), wheat (11.8%), maize (11.1%) and vegetables (11.1%). In West Bengal in 2017-18, a much larger share of the non-paddy area was under vegetables (26.1%), oilseeds (20.9%), jute (13.9%), potato (11.1%), wheat (8.6%), and pulses (8.2%). Thus, we can see that the differential agricultural development in Bangladesh and West Bengal resulted in Bangladesh's *boro*-dominated cropping pattern and a more diversified cropping pattern in West Bengal with a substantial area under vegetables, oilseeds, jute, and potato.

Categorizing the major non-paddy crops grown in this region based on their irrigation requirements into relatively more "water-intensive" and less "water-intensive" crops help understand if cropping systems moved towards more or less water-intensive crops. We categorize potato, maize (mostly grown during *Rabi* season in these regions), and jute as more water-intensive crops and pulses, oilseeds, and wheat as less water-intensive crops. In Bangladesh, the area under less water-intensive crops pulses, oilseeds, and wheat decreased from the mid-1990s to 2010, followed by some recovery post-2010. On the other hand, the area under oilseeds area showed a steady increase in West Bengal, with no decline in the area under wheat and pulses. So overall, the area under less water-intensive crops declined in Bangladesh until 2010, while it increased in West Bengal. But during the same period, the area for relatively more water-intensive crops (even excluding paddy) like potato, maize, and jute had a much sharper rise in Bangladesh than in West Bengal. For both potato and maize, the area under cultivation increased over time in Bangladesh and West Bengal, but the increase was much sharper in Bangladesh. These changes in cropping pattern match the irrigation development in these two regions as discussed previously, i.e., more accessible access to irrigation under a liberalized policy in Bangladesh and a stagnation of irrigation access in West Bengal, facilitating a shift towards less water-intensive crops (Figure 18). Diversification away from paddy in West Bengal has been promoted through policies and discourses that have traditionally restricted groundwater irrigation due to perceptions of scarcity (Mukherji, 2006) Section 7). Yet, studies are unequivocal that humid and semihumid eastern Indian states like West Bengal are more suitable for paddy production from a groundwater perspective than water scarce states of Punjab and Haryana where a bulk of the marketable surplus production now takes place (Gaydon et al., 2021). From a pan-India perspective, therefore, West Bengal could have become rice basket of India, provided it devoted more (not less) of its land to *boro* production, and farmers got remunerative prices for their produce.

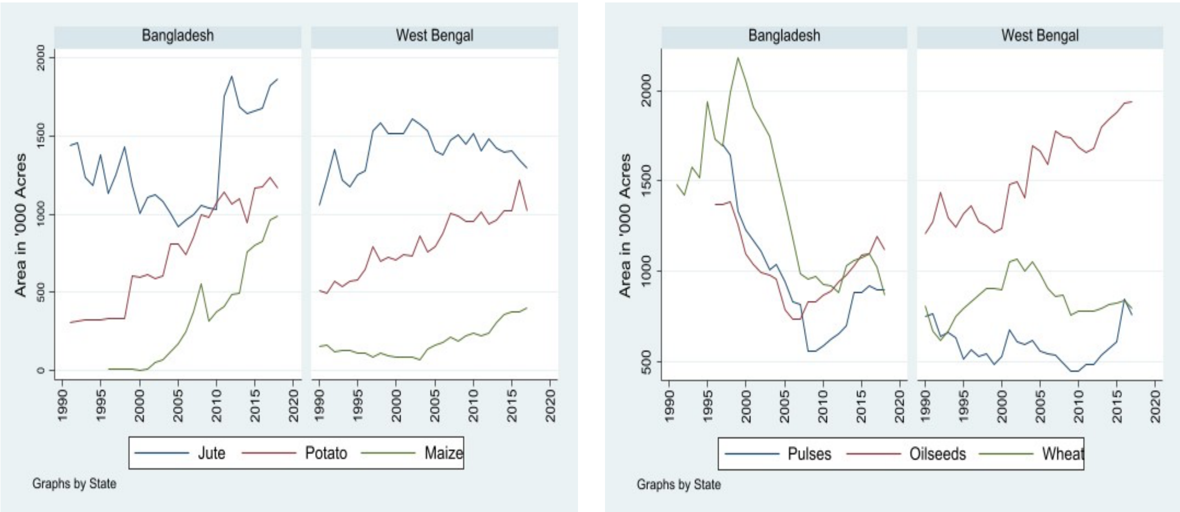
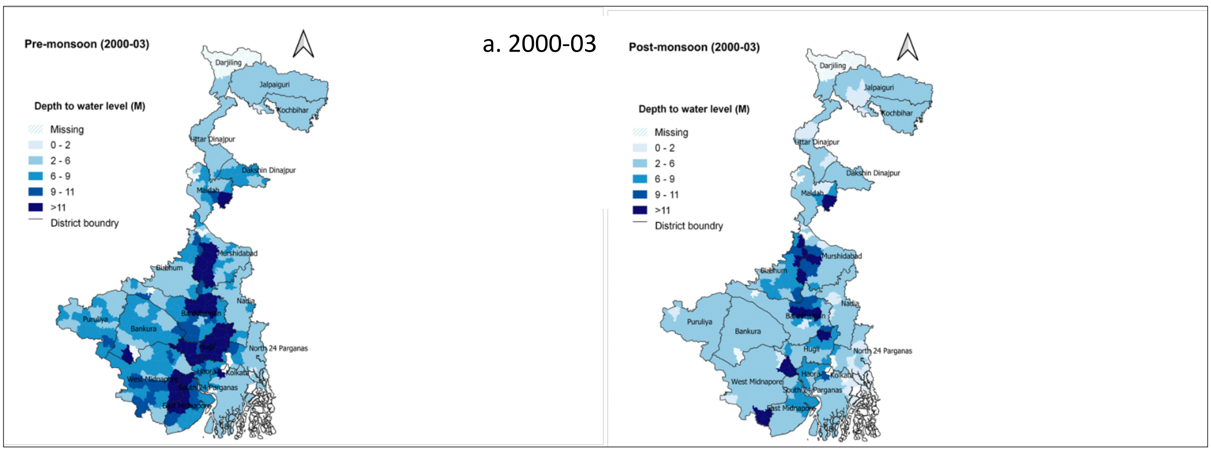


Figure 18: The trajectory of the shift to high and low water-intensive crops in Bangladesh and West Bengal

5. Groundwater depletion and climate change

While area under water intensive *boro* paddy stagnated in West Bengal since mid 2000s, with an overall move away from water-intensive crops (Section 5.2), groundwater level data from recent years shows a trend towards lowering of water tables in the state (Figure 19). This trend is also observed in Bangladesh where area under *boro* paddy has not expanded since 2010-11 (Figure 20). We also observed that the declining trend is more prominent in post monsoon season, than pre-monsoon season which it is counter-intuitive because more recharge is expected in post monsoon season. Could long term changes in rainfall and temperatures be the reason for decline in groundwater levels? It is possible that increase in ET and lesser precipitation may affect effective recharge. (Bhanja et al., 2018; Kirby et al., 2016; Mainuddin et al., 2021; Malakar et al., 2021; Mojid et al., 2021). However, more work is needed to understand the exact nature of change in groundwater recharge due to climate change, which was beyond the scope of this project.



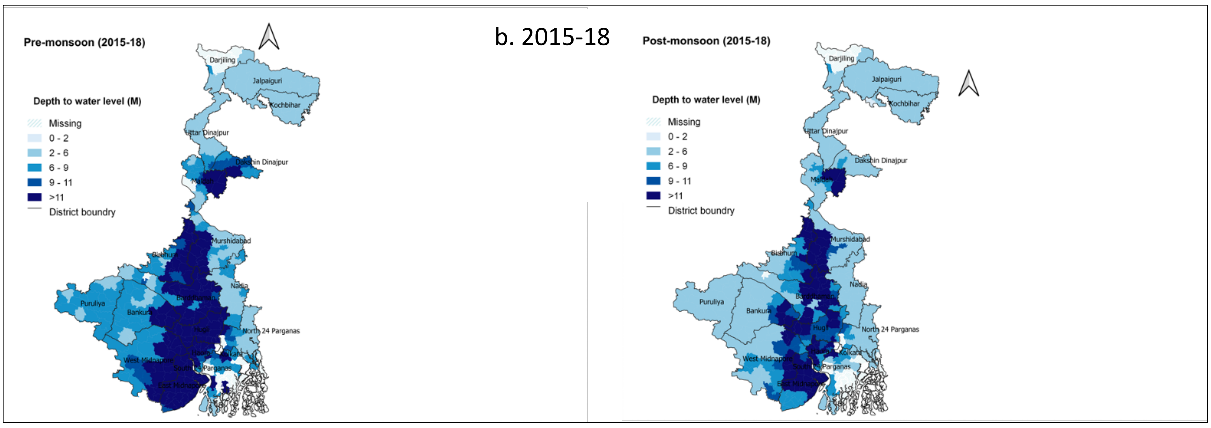


Figure 19: Pre and post monsoon water levels in West Bengal, 2000-03 and 2015-18

Source: Data from SWID

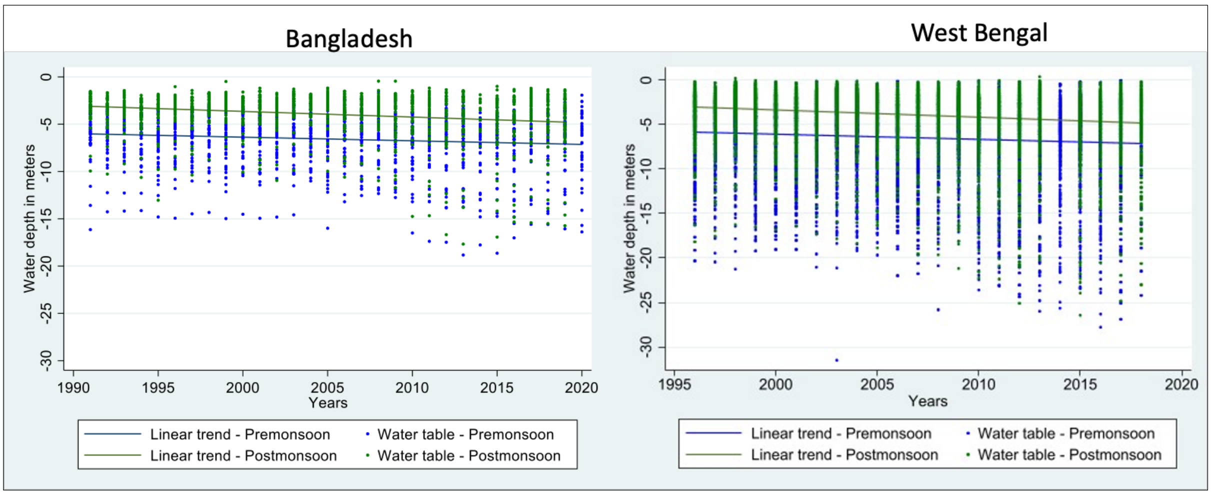


Figure 20: Trend in pre and post monsoon water tables in Bangladesh and West Bengal

6. Public policies and discourses on water, energy and food

West Bengal and Bangladesh have experienced similar phases of growth and stagnation in agricultural development since the 1970s (Section 2). Despite overall similarities, the difference between the two lies in the duration of each phase. In Bangladesh, the phase of high growth in *boro* APY lasted for a decade longer than in West Bengal, where the period of low/stagnant growth started in the mid-1990s, compared to the 2010s in Bangladesh. These phases and their timing were not accidental but a clear outcome of public policies and discourses on groundwater, food and energy. In the following subsections, we compare the contrast water, food and energy policies in Bangladesh and West Bengal and link those policies to broad outcomes discussed in previous sections.

6.1 Agricultural policies to boost production

7.1.1 Market-based agricultural policies in support of Green Revolution in Bangladesh

In Bangladesh, the adoption of modern varieties (MVs) and High Yielding Varieties (HYVs) of rice was initiated in the *boro* season in 1967 when the Bangladesh Academy for Rural Development in Comilla imported IR8 seeds from the International Rice Research Institute (IRRI) in the Philippines (Bose, 1974). Later IR20 was introduced in the *aman* season. With support from IRRI, Bangladesh established the Bangladesh Rice Research Institute (BRRI). To date, BRRI has developed 52 MVs to suit the agroecological conditions of all three rice growing seasons (Hossain et al., 2005).

Traditionally, Bangladesh Agricultural Development Corporation (BADC) had the sole responsibility of procuring and distributing agricultural inputs (Ahmed, 1995b). However, a fundamental change in the government policy in 1979 was the privatization of the provision of minor irrigation equipment and other inputs. Scholars agree that the process of diffusion of MV/HYV of rice was made possible by the adoption of irrigation technology along with the provision of chemical fertilizers, pesticides, institutional credit, product procurement, storage and marketing facilitated through market liberalization that started in the 1970s (Gisselquist et al., 2002; Hossain, 2010; S. Rahman, 2003; Turner & Shajaat Ali, 1996). Ahmed, (1995) assessed a loss of 1.3 million tons in *boro* production had the market reforms not been undertaken, and with similar parameters, (Hossain & Deb, 2003) estimated an incremental rice production between 1988 and 2008 to the tune of 5.9 million out of the total 15.5 million tons due to these policy changes. Table 3 summarizes some of the major policy reforms in procurement and marketing of inputs other than irrigation, while irrigation reforms are discussed in Section 7.2.

Table 3: Timeline of liberalisation of agricultural input markets, Bangladesh

Changes in policies and procedures	**Period**	**Outcomes**
	Fertilizer	
BADC withdrew from retail and wholesale markets, allowing private vendors to enter	1978-1983	Private vendors entered into retail and wholesale markets at Thana levels
Licensing requirement for trading in inputs was abolished and restriction on movement removed (except 5-mile border zones with India)	1982-1983	Vigorous response from traders
Deregulation of fertilizer price	1982-1984	Markets started to get competitive
Allowing private traders direct purchase from factory gates and port points	1987	Positive response from traders
Import of all fertilizers without permits allowed for private sector	1991	Good response, but fear of oligopoly persisted
No barriers to new compositions and low barriers to market entry	1991–95	Private traders took over import trade, but quality assurance became an issue
Fertilizer crisis and partial reversal of reform	1994/95	Subsidy for fertilizer re-introduced
Government assigned markets to each fertilizer dealer, banning sales outside assigned markets.	1995	Restrictions to new entrants in fertilizer wholesale trade
The government began to limit the list of fertilizer compositions allowed for sale.	1996	Competitive wholesale and retail trade
	Pesticides	
Restriction on import by brand names removed for pesticides	1989	Modest response
	Seed	
Compulsory variety registration for all crops except five (rice, wheat, jute, potatoes and sugarcane) ended.	1990	• Hybrid maize and sunflower introduced • Limited market entry by foreign companies (only one Thai-Bangladesh joint venture)

Table 4: Timeline of liberalisation of agricultural input markets, Bangladesh
Source: Authors compilation from various sources

7.1.2 Land and institutional reforms, followed by market reforms in West Bengal

In West Bengal, the spread of Green Revolution technologies played out somewhat differently. During India's third five-year plan (1961- 1966), HYV seeds were introduced in selected districts of the country under a scheme called the Integrated Area Development Programme (IADP), which was later extended to more districts and called the Intensive Agricultural Areas Programme (IAAP). IADP and IAAP laid the foundation for India's Green Revolution (Pingali, 2012). Districts were chosen based on the availability of assured irrigation, well-developed cooperatives, good physical infrastructure, and minimum climatic hazards (Rao & Gulati, 1994). Unfortunately, none of the districts from West Bengal was chosen in the first phase.

Meanwhile, acute food shortages in the mid-1960s led to food riots and social unrest in West Bengal. In 1966-67, the GoWB undertook bureaucratic measures to procure rice from surplus growers and rice mills to create a buffer stock of food grains. Throughout the 1960s to mid-1970s, the focus of the GoWB remained on public distribution and food rationing instead of increasing production, even though Green Revolution had started elsewhere in the country, e.g., in Punjab and Haryana. The overall policy discourse at the national level was that West Bengal was not suitable for Green Revolution due to its humid climate (Dasgupta, 2017; Rao & Gulati, 1994). The state-level discourse was around the lack of incentives among tenant farmers to invest in yield-enhancing inputs in the absence of land reforms (Boyce, 1987; Ray & Ghosh, 2016).

In 1977, a Left Front government was voted to power, and they initiated land and institutional reforms. Under land reforms, called Operation *Barga*, tenant farmers (or *bargadaars*) were registered and given secure land rights. Some redistribution of vested land (land over and above the maximum landholding limit) also happened, but the quantum of redistributed land was relatively small. At the same time, village local government institutions, called the *panchayats,* were strengthened, and regular elections on party lines were held across all three tiers of the *panchayats*. Several scholars have argued that land reforms led to stronger incentives among sharecroppers and others to invest in yield-enhancing technologies (Banerjee et al. 2002; Bardhan & Mookherjee, 2012) while newly empowered panchayats funded some of these investments, including that of STWs (Saha & Swaminathan, 1994).

In 1983, the Reserve Bank of India (RBI) and National Bank for Agricultural and Rural Development (NABARD) appointed a committee to investigate the factors constraining agricultural growth in eastern India. The committee concluded that the primary constraint was the lack of adequate water control and irrigation (RBI, 1984). Subsequently, in 1985-86, the West Bengal government launched a scheme for developing minor irrigation with financial assistance from the World Bank. Private investments in STWs also picked up around this time, fuelled by affordable drilling costs, pumps and almost ubiquitous groundwater markets. As a result, 1981 to 1991 saw unprecedented growth in agriculture (Saha & Swaminathan, 1994). Sarkar, 2006 called this the '*boro* revolution' as *boro* cultivation grew at an average annual rate of 12% and overall foodgrain at a rate of 5.5% in the 1980s. West Bengal emerged as India's largest rice-producing state, contributing more than 15% of national production. Bhattacharyya & Bhattacharyya, (2007) called agricultural growth in the 1980s in West Bengal a groundwater-dependent 'belated green revolution'.

However, agricultural growth witnessed in the eighties was not sustained in the 1990s. Instead, growth rates decelerated to 1.2-2.0% per year with a slowing down of HYV *boro* cultivation (Ray & Ghosh, 2016; Sarkar, 2006). Many scholars attributed the slowdown in agricultural growth to India's structural adjustment and liberalization policy (GOI) in 1991. The new economic policy of 1991 drastically slashed food and fertilizer subsidy and reduced rural credit and priority sector lending (Palaskas & Harriss-White, 1993; Sarkar, 2006). Input-output price ratios were unfavourable, and farmers often did not get remunerative prices for their *boro* paddy crops. Due to faulty procurement strategies, GoWB failed to sell its surplus rice to other states or export abroad (Bora et al., 2018). In 1997-98, the GOI launched a decentralized local procurement of food grains program, and the GoWB signed an MOU with the GOI. Even after the initiation of decentralized targeted procurement of food grains policy in 1997, West Bengal has not been able to procure enough food grain for the centre due to inadequate procurement infrastructure (Sarkar, 2020). However, this policy was criticized because the initial costs of procurement had to be borne by the state governments, and often they did not have the needed resources for the same (Mandal et al., 2017; Raghavan, 2004). In addition, given higher costs of cultivation of irrigated *boro* rice, centrally announced MSP have fallen short of capturing actual costs of cultivation in West Bengal (Bora et al., 2018; Sarkar, 2020)

In the state budget of 2019, the GoWB launched a new scheme called "*Krishak Bandhu*" (translated as a friend of farmers) (West Bengal state Budget 2019). This is an "assured income scheme", where financial assistance of INR 5000 is provided to all the farmers (https://pmmodiyojana.in/krishak-bandhu-scheme/). Table 4 summarizes some of the important policy reforms related to land, and agriculture, while water and irrigation related policies and reforms are presented in Section 7.2.

Table 5: Timeline of agricultural policies in West Bengal

Period	Changes in policies and procedures	Outcomes
1947-1960 Low agricultural productivity, food grain import and food shortages		
1951-56	The first five-year plan of India - central government prioritized agriculture	Agriculture remained rainfed with low productivity, sizeable fallow land in West Bengal
1955	GOI Implemented Estates Acquisition Act of 1953	Zamindari and all forms of intermediary tenure were abolished in India Implementation was not successful with land kept clandestinely; tenure of sharecroppers remained insecure
1956	GOI signed an agreement with the USA under Public Law 480 (PL 480) to import wheat grain	Imported food distributed through PDS Food distribution was unreliable, and food shortage continued
1960 – 70: introduction of HYV cultivation following an area-specific approach, and West Bengal was left out		
1961	India launched Integrated Area Development Programme (IADP)	HYV seeds were introduced in selected districts of India. No district of West Bengal was selected
1964-65	Indian launched the Intensive Agricultural Areas Programme (IAAP)	144 districts out of 325 were selected in India No district of West Bengal was selected
1970 – the 1980s: Agrarian reforms: Making way for a conducive environment to invest in technology in agriculture; ushering in late Green Revolution in West Bengal		
1977	GoWB launched land reforms "Operation Barga."	Facilitate registration of sharecroppers to implement the tenancy laws; redistribution of vested land to landless households
1978	Elected *Panchayati* Raj institutions - a three-tier system of government	*Panchayats* facilitated all production-related activities like drilling of STWs, electricity connections, allocation of rural credits and distribution of subsidized input packages to farmers
1983	RBI and NABARD Committee Report on ways of boosting agricultural production in eastern India	Lack of irrigation is recognized as a major constraint.
1990 -2010: Slowing down of agriculture growth		
1991	Structural adjustment Programme and economic liberalization	Increase in input prices (especially fertilizer and diesel), unfavourable output prices, lowering of net returns
1997	Decentralized food procurement system where GoWB signed an MoU with GoI	Not much effect on actual procurement, which remains low compared to states like Punjab and Haryana.
2010 to present: Policy of Central government to spread Green Revolution in Eastern India		
2010-11	Central government forms policies to extend Green Revolution to Eastern India	The Union Budget earmarked INR 400 crores
2011	Policy document "Strategies for Agricultural Transformation of Eastern Region."	It recommended: Conjunctive use of rain, surface, and groundwater resources for efficient utilization of available water resources; providing adequate energy supply to farmers for developing groundwater irrigation.

2019	Introduction of the cash-transfer program (*Krishak Bandhu*) to small and marginal farmers	No evaluation was done.

Source: Authors compilation based on various sources

6.2 Groundwater related policies to support agricultural intensification

7.2.1 Groundwater policies in Bangladesh

Until the 1960's Bangladeshi farmers used traditional surface water technologies like the swing baskets and '*doans*' for irrigation (Dewan et al., 2015). In 1964, a formal appraisal of water resources projects around the country was formulated, which led to the establishment of the East Pakistan Water and Power Development Authority (EPWAPDA). EPWAPDA came to be known as Bangladesh Water Development Board (BWDB) after the independence of Bangladesh in 1971. The BWDB formulated its first 25-year Master Water Plan (MWP) in 1964 that targeted large-scale surface water development through public finance. During the first phase of the MWP, the general perception among policymakers was that private investment-based minor irrigation was inappropriate for Bangladesh because of the dominance of small-scale farmers and scattered holdings. However, these large-scale schemes failed in flood control and irrigation (Pal et al. 2011).

In 1961, the then East Pakistan Government established a special corporation to supervise the country's agricultural development, which later came to be known as BADC in 1971. BADC was in charge of supplying, operating and maintaining low lift pumps and tubewells for irrigation, among other things. Both BADC and BWDB simultaneously introduced minor irrigation and groundwater irrigation programmes in Bangladesh through DTWs, STWs, hand pump tubewells (HTWs) and LLPs. Later the Bangladesh Rural Development Academy (BARD) in Comilla successfully experimented with smaller-capacity tubewells and formed cooperatives of small scale and marginal farmers (Mandal, 1987; Palmer-Jones, 1992). The Bangladesh Rural Development Board (BRDB) replicated the Comilla approach throughout the country. Barind Multipurpose Development Authority (BMDA) Project was also run by farmers' cooperatives (Rashid & Hossain, 2019).

In the decade that followed, there was a new emphasis on groundwater irrigation through the privatization of irrigation equipment. In 1973, the First Five-Year Plan of Bangladesh underscored the need to remove agricultural input subsidies. In 1979, the government decided to privatize the marketing of irrigation equipment along with chemical fertilizers (Hossain, 2009). Thus, with structural adjustment programmes and the liberalization policy, all existing and new STWs, LLPs and DTWs were initially sold to farmers' cooperatives and later to individual farmers (Akteruzzaman et al., 1993; Mandal, 1987). Throughout the 1980s, there were continued efforts to decrease public-sector involvement in minor irrigation. The government also initiated various special programmes to encourage groundwater irrigation.

In 1983 Bangladesh experienced a severe drought that led to a drawdown of groundwater in the dry season (Palmer Jones, 1992), raising concerns about the long-term sustainability of groundwater irrigation. These concerns resulted in the introduction of a Groundwater Management Ordinance and Groundwater Management Rules in 1985 and 1987 (Hossain, 2009). This ordinance empowered the local government to permit, renew or cancel the license of STW and DTW and specified spacing norms. However, some scholars (Hossain, 2009; Mandal, 1987) believed that the policy of market liberalization in the late 1970s did not have widespread support within the bureaucracy, and they seized the first possible opportunity to bring back bureaucratic controls.

However, soon afterwards, Bangladesh experienced devastating floods and cyclones during 1987 and 1988. The cyclone wiped out the oxen population used for ploughing, and under existing rules, only equipment meeting high standards (e.g., Japanese tractors, pumps and motors) could be imported. However, less expensive equipment for farm mechanization and irrigation pumps was urgently required at a large scale to avoid impending food shortages, prompting the GOB to disband the Standards Committee to facilitate the rapid import of comparatively cheaper equipment from China (Biggs et al., 2011). Further, in 1988, the government eliminated duties on diesel engines, withdrew standardization requirements, and allowed imports of agricultural machinery without government permits. As a result, this period saw significant increases in growth in STWs from 93,000 in 1982 to 260,000 in 1990.

Policies before 2000 were about improving access to groundwater irrigation. Policies since the 2000s have focused on reducing dependence on groundwater amidst concerns over over-exploitation. National Water Policy of 1999 (GOB, 1999a) and National Agricultural Policy of 1999 (GOB, 1999b) highlighted the importance of conjunctive use of ground and surface water, suggested reducing groundwater use by delaying the sowing of *boro* paddy. In addition, the. National Food Policy Plan of Action was formulated for 2008 to 2015 (GOB, 2008). It recommended increasing irrigation coverage, improving irrigation efficiency, reducing dependence on groundwater, and reducing the cost of irrigation water. Meanwhile, National Agricultural Extension Policy, 2012 made it amply clear that groundwater irrigation was the prime pillar of food security of Bangladesh and the need to expand command areas of existing irrigation (GOB, 2017). The Integrated Micro-Irrigation Policy of 2017 (GOB, 2018) placed more importance on surface water by substituting groundwater irrigation. The National Agricultural Policy 2018 also encouraged the cultivation of water-saving new crop varieties and low water consuming crops in drought-prone areas. For the first time, the National Agricultural Policy in 2013 (GOB, 2013) proposed preparing groundwater zoning maps.

Interestingly, seven years after the withdrawal of groundwater sitting norms in 1992, the National Agricultural Policy of 1999 mentioned negative impacts due to the withdrawal of siting restriction and standardization of irrigation equipment. On the other hand, the Agricultural Policy 2013 encouraged specific measures like keeping an appropriate distance between wells. Based on the recommendations of these policies, the Bangladesh government enacted the Bangladesh Water Act of 2013 to institute the tubewell siting norms. Further, in 2018, Groundwater Management in Agricultural Activities Act came into force. The Groundwater Management Rules in Agriculture were formulated in 2019. This Rule requires all new and existing tubewells (STWs and DTWs) to seek a licence from the *Upazila* Irrigation Committee. The actual implementation of the Act is not entirely clear, but it brings back similar provisions which were removed in 1988 in the aftermath of the cyclone. Table 5 captures the timeline of groundwater-related policies and their outcomes in Bangladesh.

Table 6: Timeline of key groundwater policies in Bangladesh

Name of the policy or Act	Key features	Outcomes
1971-1980: Focus on surface water projects, but groundwater irrigation also started through government initiatives		
A 25-yearsWater Master Plan (WMP)	• Emphasis on surface water irrigation projects with public funding	• Most projects suffered from large cost overruns and long implementation delays
	• Key irrigation equipment like DTW and LLP were introduced by BADC and BWDB	• LLPs and DTWs spread fast, facilitating *boro* cultivation. • Government management of a large number of DTWs and LLPs became expensive and made the system inefficient
	• From 1979, the government liberalized the input market and privatized irrigation equipment. Bangladesh Krishi Bank (BKB) was set up to distribute special agricultural credit for the purchase of STWs, LLPs and DTWs	• STWs became most successful as they were affordable, scale-appropriate and most importantly, individually owned and hence better managed and utilized

Name of the policy or Act	Key features	Outcomes
1980 to mid-1990s: Initial restrictions, replaced with the liberalization of import of irrigation equipment, relaxation of spacing norms and the subsequent boom in private STWs		
UN-declared "Clean Drinking Water Decade."	• The government and private sector installed millions of HTW and STWs for drinking water and irrigation	• Boost of HTWs and STWs and expansion of groundwater irrigation
Groundwater Management Rules of 1985	• The government banned the import and sale of small diesel engines. • Installations of STWs restricted in 22 districts with sitting norms	• Expansion of minor irrigation equipment slowed
Deregulation and liberalization of imports and suspension of Groundwater Management Rules of 1985	• Reversal of restrictions • Groundwater irrigation through STWs flourished due to irrigation business privatization and substantial reduction of government taxes. • No monitoring and inspection on sitting of STWs and DTWs	• Development of a competitive water market for water transactions in irrigation • Bangladesh became food self-sufficient in 1999 • STW became the most important source of irrigation
The mid-1990s onwards: Focus on management, governance and conservation of groundwater resources		
The Guidelines for People's Participation (GPP) for water development projects	• Ministry of Water Resources formulated guidelines for people's participation in water development projects • Enacting *Upazila* (Sub-district) Parishad Act 1998 to strengthen local government institutions • Developing Local Government Engineering Department (LGED) guidelines to involve local people in water projects	• Experience of participatory management has been mixed. • Progress in creating and developing user groups remain slow, and public-sector agencies remain de facto owners of all levels of the irrigation sector.
The National Water Policy and National Water Management Plan (NWMP)	• 25 years NWMP and developed plans like BWDB Strategic Plan 2009–2014, National Water Act 2013, and *Haor* Master Plan 2012–2032. • Challenges lie in implementation with limited resources and skills.	• Focus on conjunctive water use and reducing dependence on groundwater
The Bangladesh Water Act of 2013	• Empowered Water Resources Planning Organization to limit the extraction of groundwater in certain areas with critical groundwater conditions	• No installations of STW and DTW in water-scarce regions
Groundwater Management Rules in Agriculture	• All new and existing tubewells (STWs and DTWs) to be installed/or installed for irrigation purposes needs to take a licence from the *Upazila* Parishad • The licenses will have to be renewed after every three years.	• Yet to be realized, it may create difficulties for small and marginal farmers while benefitting institutional players like IDCOL, BMDA and others.

Source: Author's compilation

7.2.2 Groundwater policies in West Bengal

Till 1960-61, irrigation was used to supplement water for rainfed *aman* crops by surface water irrigation through canals and tanks (Ray & Ghosh, 2016). Boyce (1987) recognized "Irrigation, or, more broadly, water control", as the key technological constraint to agricultural growth", and regressive agrarian structure was thought to prevent unleashing of technological diffusion. Based on the regressive agrarian structure argument, the Left Front government instituted land and institutional reforms in 1977 (Section 7.1.2). Around this time, other Indian states like Punjab and Haryana started reaping the Green Revolution's benefits. However, West Bengal still had not adopted HYV technologies due to the area development approach of GOI. By the mid-1980s, the RBI and NABARD committee had recommended accelerating irrigation infrastructure in Eastern India to boost agricultural production.

As mentioned earlier (Section 7.1.2), in 1985-86, the GoWB launched a scheme for developing minor irrigation with financial assistance from the World Bank. The installation of the wells was done in consultation with the elected village panchayat members (Rao, 1995). From 1988 to 1995, another centrally sponsored scheme called the Million Wells Scheme (MWS) was launched to support the construction of open dug wells. Unfortunately, West Bengal performed poorly because open dug wells were unsuitable for its alluvial geology. Yet, the rate of expansion of groundwater irrigated area in West Bengal was phenomenally high compared to the other states during the 1990s due to increased private investments by farmers given low costs of drilling and availability of cheap diesel pumps, and subsidized diesel prices (Bhaduri et al., 2012; T. Shah, 2004). This period also coincided with unprecedented growth in the agricultural sector from 1981 to 1991 (Saha & Swaminathan, 1994).

As mentioned in the previous section (Section 7.1.2), market reforms in 1991 were thought to slow down agricultural growth in the state. However, what remains unacknowledged in that slowdown story is the series of policy restrictions on groundwater use which emanated from concerns around over-exploitation of groundwater in the mid-1990s. In 1993, GoWB enacted an order that put restrictions on groundwater use in agriculture for the first time. Under this order, farmers who wanted electricity connections for their wells and tubewells needed to get permission from the State Water Investigation Directorate (SWID) before applying for an electric connection. This restriction was imposed through an administrative order in 8 districts of West Bengal (Mukherji et al., 2012; Sengupta, 2011). These restrictive policies negatively impacted the electrification of wells and tubewells, which had almost stopped by the early 2000s (see Figure 9).

In 1996 the Supreme Court of India expressed deep concern over the rapid deterioration of groundwater levels in many parts of India (though not in West Bengal). As a result, the Ministry of Water Resources, GOI, came up with a Model Bill to Regulate and Control the Development and Management of Groundwater in 1996 and instructed state governments to bring about necessary regulations. West Bengal was one of the first states to adopt this Model Bill, and West Bengal Groundwater Resources (Management Control and Regulation) Act 2005 came into effect on 31st August 2005. This Act extended the jurisdiction of the 1993 Act to all districts in the state, and all farmers needed prior permission from SWID before applying for electricity connection, which led to a sharp fall in the number of new electricity connections (Section 3.3 and Figure 9).

After years of restrictions on the expansion of groundwater irrigation, the decade of 2010 saw a new government take power after 34 years of Left Front rule. The new government promoted several schemes in support of irrigation development. For example, "*Jal Dharo-Jal Bharo*" was launched in 2011-2012. The main objective of this program was to harvest rainwater and reduce surface runoff by creating water bodies, including tanks, ponds, and reservoirs. A similar program called "*Jalatirtha Scheme*" was initiated in 2014-2015 to build check dams, water harvesting structures and surface flow minor irrigation schemes. The West Bengal Accelerated Development of Minor Irrigation (WB-ADMI) project was also launched in 2012 to promote sustainable irrigation over 75,000 hectares and improve the livelihoods of 100,000 farmers through minor irrigation schemes. WB-ADMI was financed through a World Bank loan. Table 6 provides a timeline of groundwater-related policies in West Bengal.

Table 7: Timeline of key groundwater-related policies in West Bengal

Policy / Scheme	Consequences
1947-the 1970s: Low agricultural productivity, food grain import and food shortages	
India's first multipurpose river valley project Damodar Valley Corporation (DVC) Project in West Bengal	• Mainly used for flood control • Created less than 50% of its irrigation potential through canals

The 1970s to 1990s: Investments in groundwater irrigation coincided with a period of high growth in agriculture	
Operation Barga, and elected Panchayati Raj institutions - a three-tier system of government	• Panchayats facilitated production-related activities like drilling of STWs, making of irrigation channels, electricity connections, allocation of rural credits and distribution of subsidized input packages to farmers • Sharecroppers with secure tenure had better incentives to invest in irrigation
World Bank Assistance programme to develop minor irrigation in West Bengal	• Various types of water extraction structures were constructed, prioritizing small and marginal farmers • Initially successful, but many of the groups did not function well.
Launch of a centrally sponsored scheme called the Million Wells Scheme (MWS) was launched	• Provided free of cost open wells for irrigation to poor small and marginal farmers belonging to the SCs/STs and freed bonded labourers. • Modest performance as open dug wells are not suitable for alluvial aquifers
The 1990s to 2010s: Restrictive groundwater policies and slowing down of groundwater irrigation and agriculture growth	
The government-imposed restrictions on tube wells fitted with submersible pumps in 1993	• Farmers needed permission from SWID before applying for electric connection in eight selected districts • Hindered groundwater irrigation and *boro* cultivation
MWS was extended to cover non-Scheduled Castes/non-Scheduled Tribes small and marginal farmers who are below the poverty line	• Poor performance because open wells were not suitable farmers preferred to buy water from neighbouring tubewell owners • Later the scheme permitted digging of tubewells and bore-wells but was hindered by the 1993 restriction clause
West Bengal Groundwater Resources (Management Control and Regulation) Act, 2005	• All farmers in all districts needed to obtain a registration certificate and a permit SWID for electrification of wells and tubewells. • The arduous task of registering about a million tubewells with inadequate capacity made the system inefficient, leading to rent-seeking and corruption.
The 2010s onwards: Policies on increasing groundwater use through water harvesting and conjunctive use	
Policy document "Strategies for Agricultural Transformation of Eastern Region."	• Conjunctive use of rain, surface, and groundwater resources to increase crop production • Adoption of technologies for groundwater recharge and conservation • Providing adequate energy supply to farmers
Jal Dharo-Jal Bharo project was launched	• Helped create minor surface water irrigation structures like tanks, ponds, and reservoirs to harvest rainwater
Jalatirtha Scheme was launched	• It built check dams and water harvesting structures to conserve rainwater for surface water irrigation for farmers
West Bengal Accelerated Development of Minor Irrigation (WB-ADMI) project	• Created minor irrigation infrastructure and formed water users' association for water management

Source: Author's compilation based on policy review

6.3 Energy policies and their impacts on groundwater irrigation

6.3.1 Energy policies and groundwater irrigation in Bangladesh

In the early 1970s, almost all groundwater extraction mechanisms were diesel operated. In 1977, the rural electrification board ordinance came into force to speed up rural electrification (GOB, 1977). However, the rural electrification scheme was bureaucratic, where all scheme benefits needed to be availed through cooperatives with no provision of individual connections. As a result, rural electrification remained exceptionally low, and diesel consumption increased with the number of STWs in the country. It was not until the 1990s that electrification for pumps received special attention.

The Agricultural Policy of 1999 (GOB, 1999) emphasized reducing irrigation costs by prioritizing irrigation pumps for electricity connections. The National Energy Policy of 2005 (GOB, 2005) expressed concern over low pump energization. The National Food Policy Plan of Action (2008 to 2015) (GOB, 2008) also recommended reducing the cost for groundwater irrigation by electrification of tubewells. The Integrated Micro-Irrigation Policy of 2017 (GOB, 2017) emphasized prioritizing electricity connections to irrigation equipment. BADC Act 2018 had similar provisions. Currently, roughly 20% of all agricultural pumps are electrified, but with near 100% rural electrification, it is expected that electrification of pumps will continue to pick pace. In line with the National Agricultural Policy of 2013 (GOB, 2013), which encourages the use of solar energy to reduce irrigation costs, the Solar Power Development Program was launched in 2013. Infrastructure Development Company Limited (IDCOL) is responsible for implementing all the projects through the private sector. So far, around 1600 solar irrigation pumps have been installed in Bangladesh. Other organizations such as BMDA, Bangladesh Rural Electrification Board (BREB) and the Department of Agricultural Engineering (DAE) have started implementing SIP projects during different financing and operational modalities. The Guidelines for Grid Integration of Solar Irrigation Pump was formulated in 2020, enabling SIPs to evacuate excess energy to the grid. IWMI, through an SDC funded project, is working closely with IDCOL to study the impact of solar irrigation on farmers' livelihoods and incomes (Mitra et al., 2021).

There has been less attention paid to energy-irrigation nexus issues in Bangladesh than in West Bengal. For instance, there is not much literature on how the cost of pumping varies between diesel and electric pumps and how different modes of electricity tariff can impact informal water markets.

7.3.2 Energy policies and groundwater irrigation in West Bengal

In West Bengal, there is rich literature on the impact of energy prices and energy tariffs on groundwater pumping and water markets. Until recently, almost 80-90% of all irrigation pumps were diesel operated, and rising diesel prices have been one reason for the slowdown in *boro* paddy cultivation since the mid-1990s.

As mentioned earlier, one of the immediate effects of the structural adjustment programme of 1991 was the rise in diesel prices. The rapid increase in diesel prices since the mid-1990s surpassed the increases in paddy output prices, affecting net returns of the diesel operating tubewell irrigators (Mukherji et al., 2013, 2018) (Section 5.1.2). It has become uneconomical to use diesel pumps to irrigate water-intensive *boro* paddy.

West Bengal also has a long history of electrification of agricultural pumps. Electrification started in the mid-1970s and peaked in the mid-1980s, before coming to a literal halt by the mid- 2000s due to several policy restrictions on agricultural electrification (Section 3.3, Figure 9). Historically, West Bengal, like other Indian states, charged farmers a flat electricity tariff. However, unlike other states, where flat tariffs were kept perpetually low, in West Bengal, flat tariffs were revised every year. As a result, agricultural flat tariffs in West Bengal were one of the highest in the country. For example, flat electricity tariffs increased from INR 1,100 (US$ 14.60 @1 USD=INR 75) per year per HP in 1994 to INR 10,800 (US$ 144) per year per HP for a standard five horsepower (HP) pump in 2007, an increase of almost ten times over ten years, while during this time, water prices in informal water markets increased by only three times (Mukherji, 2007).

By the mid-1990s, amidst concerns about groundwater over-exploitation elsewhere in India, GoWB adopted a precautionary principle and introduced restrictions on electrification of pumps, such as the need for prior permission from the state groundwater officials, which was later codified through the Groundwater Act of 2005 (section 7.2.2). In addition, in 2003, the state electricity utility, WBSEDCL, started demanding the full cost of electricity connections, including the costs of wires, poles, and transformers. These costs ranged from USD 1,000 to USD 4,000 per tubewells and were beyond the means of most smallholder farmers in the state (Mukherji et al., 2018).

Meanwhile, in 2007, the GoWB decided to meter all agricultural wells and tube wells following the directive of the Electricity Act of 2003. West Bengal is only one of the very few states in India that have adopted universal metering. WBSEDCL introduced high-tech, remotely read and tamper-resistant meters. Power theft and tampering with meters have also been declared a serious offence under the 'Indian Electricity (West Bengal Amendment) Act 2001' (Mukherji et al. 2009). In addition, these meters are also time of the day (TOD) meters. In their study, Mukherji et al. (2009) found that metering has been beneficial to the pump owners. In contrast, the buyers lost their access to groundwater for irrigation due to the contraction of informal water markets (Section 4.2). For example, electric pump owners with metered tariffs sold a lower volume of water during the *boro* season than pump owners facing high flat tariffs (Meenakshi et al., 2013; Mukherji et al., 2009; Shah et al., 2019).

Continuous increases in diesel prices, difficulty in getting electricity connections due to bureaucratic hurdles, and contraction of water markets in the aftermath of metering created a huge unmet demand for a cheaper source of irrigation water, particularly for *boro* paddy. Subsequently, following popular demand from the districts, the WBSEDCL introduced temporary, seasonal electricity connections covering four months of the *boro* paddy season. As a result, there was a high demand for temporary connections even though these connections were expensive, but demand declined once barriers for permanent electricity connections were eased in 2011-12.

With policy inputs from IWMI researchers, the newly elected state government amended the West Bengal Groundwater Resources (Management, Control and Regulation) Act 2005 vide a memo dated 9th November 2011. This executive order enabled farmers located in 'safe' groundwater blocks and owning pumps of less than 5 HP and tubewells with discharge less than $30m^3$/hour to apply for agricultural electricity connections without seeking prior permission from SWID. Furthermore, in November 2012, GoWB introduced a tube well subsidy programme called the One Time Assistance for Electrification of Pump Sets. Farmers could avail up to INR 7000 to cover electrification costs. (Buisson, 2015; Mukherji et al., 2012)

These two initiatives were aligned to the central government's policy directive of increasing food production in eastern India. The impact of the policy was visible from the sharp increase in the number of pump sets electrified from 2011-12 to 2018-19 (Figure 9, Buisson, 2015; Mukherji et al., 2020), with over 200,000 additional pumps electrified during this period alone. Initial village-level studies showed that cropping intensity increased by 10.6%, and the share of the net cultivated area under *boro* increased by 21.0% for electric pump owners compared to their non-electrified counterparts. Electric pump owners earned on an average INR 2900 more per acre for *boro* rice since they were able to reduce their cost of irrigation compared to their diesel counterparts (Buisson, 2015; Buisson et al., 2021). However, a recent analysis based on secondary data did not find commensurate benefits of electrification on agricultural production at the state level, even though some districts in North Bengal experienced high growth after electrification (Mukherji et al., 2020). The study concluded that low profits from *boro* paddy in the absence of remunerative market prices and public procurement system could be a reason for the same.

More recently, there has been a directive from the central government to use solar energy to operate agricultural pumps, and the GOI has launched a scheme called PM-KUSUM. The West Bengal State

Water Resource Investigation and Development Department and the West Bengal State Electricity Distribution Company Limited (WBSEDCL) have launched a pilot project to produce solar power and then connect it to shallow water tubewells for irrigating fields. The project has been implemented in 28 locations in the Cooch Behar district and has been launched as a pilot project in North 24 Parganas, South 24 Parganas, Nadia, East Midnapore and West Midnapore districts. According to the department's estimates, each of these units will cost around Rs 9 lakh and have the capacity to channelize water across 80 to 100 bighas land. In 2021, WBSEDCL has received sanctions for 700 pumps under the KUSUM-C program. Individual farmers with electric connections will be given solar panels and connected to the grid and provided with the option for selling excess power to the utility (https://wberc.gov.in/sites/default/files/SM27.pdf). To the best of our knowledge, no studies have evaluated the impacts and performance of solar irrigation in West Bengal. Table 7 provides a timeline of key energy-related policies and Figure 21 provides a pictorial depiction of the key policies on water, energy and food that affected trajectory of growth in groundwater irrigation.

Table 8: Timeline of key energy sector policies that affected groundwater irrigation in the state

Period	**Policies**	**Consequences**
The 1970s and 1980s	Flat tariffs for agricultural electricity supply	Pump electrification picked pace in the 1980s, and high flat tariffs encouraged pro-active water markets
1993	The government-imposed restrictions on submersible pumps	Farmers had to seek permission from SWID before applying for electric connection
Since 2000	WBSEDCL demands the full cost of new farm electricity connections	Farmers to pay the full cost of electricity connection for new tube wells. Costs can range from USD 1000 to USD 4000.
~2003-2011	GoWB announces temporary connections called the "*boro* season electrification scheme."	Despite high costs, demand was high between 2007 to 2011, but demand fell after GOWB eased norms for pump electrification in 2011.
2005	Groundwater Act of 2005	Mandatory registration and permits for all groundwater structures leading to bureaucratic hurdles, rent-seeking and corruption
2007	GoWB started metering electric tubewells, with universal metering by 2014-15 achieved. Electricity tariffs are revised upwardly every year	Positive impacts in terms of energy accounting benefitted pump owners but negatively affected smallholder water buyers
November 2011	Groundwater Act 2005 amended	Need for permits abolished for pumps of less than 5 HP and tubewells with discharge less than $30m^3$/hour located in 'safe' groundwater blocks. More than 200,000 pumps electrified within a short period from 2011-2019
2011	WBSEDCL introduces a fixed connection fee for new connections reversing its earlier policy of payment of the full cost of electrification by farmers	For new connections, farmers have to pay a fixed connection fee ranging from INR 1000 to INR 30,000 per connection depending on the connected load plus the flat change of electricity use
November 2012	GoWB introduced One Time Assistance for Electrification of Pump Sets	It included up to INR 7,000 towards the cost of electrification.
August 2021	WBSEDCL receives approval of 700 solar irrigation pumps under the PM-KUSUM C model, where these SIPs would be connected to the grid.	Too early to have any impact

Source: Author’s compilation

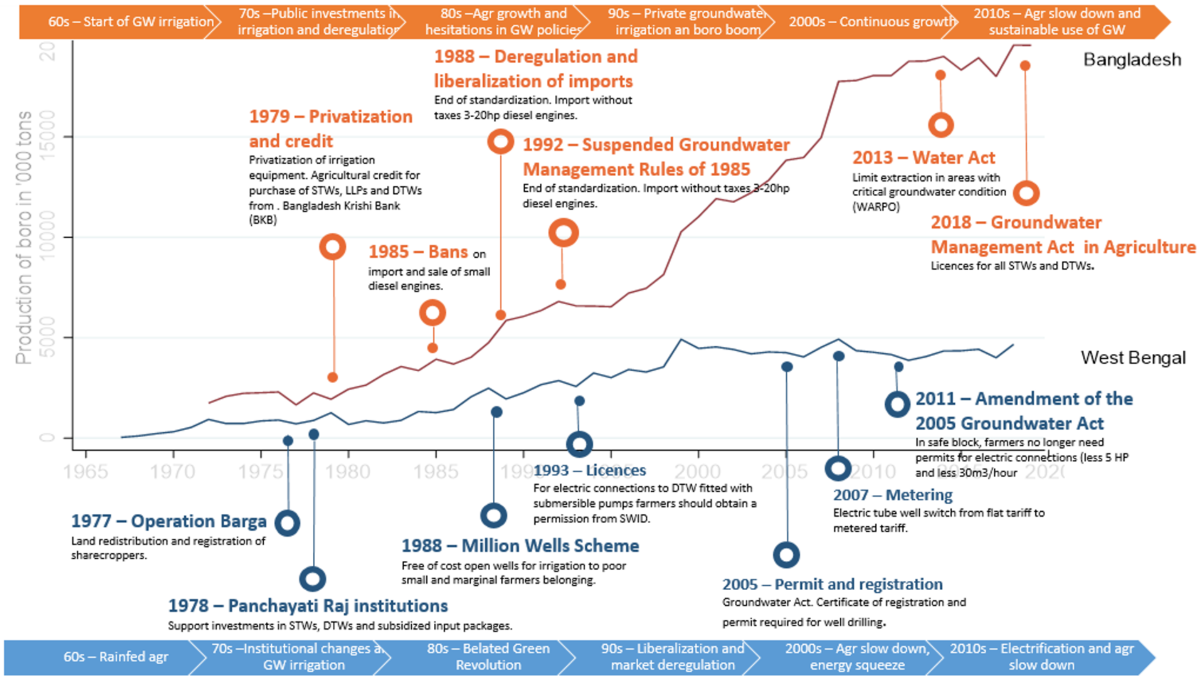


Figure 21: Timeline of key policies plotted against production of boro paddy in Bangladesh and West Bengal from 1970s to 2010s.

7.4 Popular discourses on water, energy and food

Previous sections show that agriculture, groundwater, and electricity policies have charted different trajectories in Bangladesh and West Bengal. In Bangladesh, water, energy, and food policies have been more supportive of groundwater irrigation, while policies in West Bengal have restricted access to groundwater irrigation. We explain these differences through differences in popular public discourses, attitudes towards farmers, and the criticality of food security.

In Bangladesh, public policies have acknowledged that groundwater irrigation is the prime pillar of food security of Bangladesh. As such, the public discourse around the need for food security has been entwined with access to groundwater irrigation. Bangladesh is a small land-scarce country with a high population density, and as such, food security concerns are paramount in the country. So much so, it was usual till recently, to plunge the capital city of Dhaka in darkness for a few hours in the evening in January-March every year, to transfer electricity to rural areas for irrigating *boro* paddy. Almost all scholars have acknowledged the positive role of groundwater in making Bangladesh food self-sufficient. Consequently, there have been very few restrictions on access to groundwater irrigation until recently. Only now, when Bangladesh produces surplus paddy, some groundwater-related restrictions have been put in place.

In West Bengal, on the other hand, the role of groundwater in agricultural production has never been adequately acknowledged within policy circles, with earlier literature attributing high growth rates in the 1980s to land reforms. Moreover, West Bengal, as a part of India, does not have to secure its own food production in the way that Bangladesh has to. Therefore, the food security narrative has never really been a part of the popular discourse. Instead, given the importance of Kolkata and the considerable influence of urban intelligentsia (called *bhadraloks*) on public policymaking, environmental concerns, like groundwater drawdown, have captured the state's public imagination. Elsewhere, (Mukherji, 2006) shows how several things, such as lack of a formidable farmers' lobby, co-option of any such lobby by the Left Front and pre-dominance of non-agricultural urban voices in policymaking ensured that farmers demand cheaper access to inputs never surfaced in West Bengal, in the way they do in agriculturally prosperous states like Punjab or Haryana. But, overall, concerns around groundwater over-exploitation seems to have dominated the public discourse, resulting in ever-increasing restrictions on groundwater access.

8. Conclusions, knowledge gaps and way forward

We have traced the trajectory of agricultural growth in Bangladesh and West Bengal since the 1970s, using the APY of *boro* paddy as a proxy for overall growth. We find that Bangladesh and West Bengal have gone through a phase of high growth, followed by a phase of low or stagnant growth.

Two storylines have emerged. The first storyline is of high growth in West Bengal (the early 1980s to mid-1990s) and Bangladesh (the early 1980s to the end of 2010s). During this period, both saw a rapid rise in APY of *boro* paddy, supported by appropriate water, energy and food domains policies that encouraged intensive groundwater use. However, this high growth phase lasted much longer in Bangladesh than in West Bengal. In West Bengal, restrictions on groundwater use kicked in much earlier, way back in the mid-1990s. As a result, West Bengal's period of high growth was short-lived and merely lasted 10-12 years. In contrast, Bangladesh's agricultural growth story was more enduring and lasted for almost three decades, underpinned by strong policy support for expansion in groundwater led *boro* cultivation.

The second storyline is of the slowdown in APY of paddy, which happened in West Bengal (from the mid-1990s) and Bangladesh (from early 2010s onwards). This phase in both countries was characterized by policy restrictions on groundwater and subsequent slowdown in growth or stagnation in groundwater irrigation. This period also coincided with rising cultivation costs relative to the paddy prices and consequent diversification away from paddy. However, the degree of diversification varied. In Bangladesh, *boro* is cultivated in over 80% of the land on which *aman* is cultivated, showing there is no further scope for expansion in *boro*. Diversification in Bangladesh has been towards other water-intensive crops like irrigated maize and vegetables. In contrast, West Bengal only grows *boro* on 30% of the land it grows *aman* paddy, showing further scope for expansion in the *boro* area. Yet, in relatively water abundant West Bengal, farmers have diversified to rainfed crops like oilseeds and pulses. When seen in conjunction with the paddy-wheat cropping pattern in water-scarce Punjab and Haryana, West Bengal's move away from paddy towards low water consuming crops provides a paradox that is best explained by incongruous groundwater and energy policies in India (Mukherji, 2006b, 2020).

There are similarities in trajectories of agricultural change but dissimilarities in the way those changes have been explained in the literature. For example, in West Bengal, most scholars (with a few exceptions) have attributed high growth in the 1980s to land reforms. In Bangladesh, there is near unanimity that market reforms, including removal of restrictions on import of cheap groundwater equipment in the aftermath of a devastating cyclone in 1987 ushered in a long period of growth. Perhaps the understanding that groundwater irrigation has been instrumental for agricultural development in Bangladesh ensured that there were no policy restrictions on groundwater use till 2010. In contrast, in West Bengal, the role of groundwater in the agricultural transformation story was subsumed within the larger consensus around the role of land reforms. As such, it was easier to bring about policy restrictions on groundwater in the mid-1990s amidst exaggerated fear of groundwater over-exploitation. Elsewhere, we have shown that lack of farmers lobby, the nature of left dominated peasant politics, and predominance of urban voices in policymaking in West Bengal enabled the kinds of restrictions around groundwater which would have been deemed impossible in most other states in India (Mukherji, 2006b). Overall, the divergence in periods of high growth, which lasted for a mere decade in West Bengal, and for almost three decades in Bangladesh, can be best explained through differences in groundwater policies between the two.

Yet, several unanswered questions remain. First, we are seeing a secular decline in groundwater levels in Bangladesh and West Bengal even when the area under the most water-intensive crop *boro* has remained stagnant or declined over the last decade or more. Could climate change be implicated, and what does it mean for the future of groundwater irrigation in the Bengal plains? Second, the last decade (2011-21) has seen significant changes in energy provision for agriculture. These include lower subsidies for diesel, rapid electrification of groundwater pumps, and changes in the way electricity is priced (metered as opposed to flat tariffs of an earlier era). Earlier, we have seen that type of energy (diesel vs electricity) and energy pricing (metered vs flat tariffs) have a profound influence on the functioning of informal water markets. We have also seen that informal water markets are still the predominant way farmers in Bengal access irrigation. Yet, relatively few studies in recent times have looked at the impact of changes in energy access on the functioning of water markets. Solar irrigation pumps have been introduced in both countries, and it is also time to study their impacts on agricultural outcomes and the functioning of water markets. Third, much of our knowledge on water markets is based on small village surveys, given the lack of large-scale representative surveys and censuses. Given that most farmers get access to irrigation in Bengal through these informal water markets, the government agencies need to include informal water market-related information as a part of their larger surveys or censuses. For example, Minor Irrigation Surveys/Censuses in Bangladesh and India can consist of a module on water markets and pump rental behaviour.

As a way forward, we advocate for a detailed understanding of the role of groundwater in agriculture in Bengal and how climate change may impact groundwater and agricultural outcomes.

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Endnotes

[i] India became Independent in 1947, and Bangladesh (called East Pakistan) became a part of Pakistan. Bangladesh then became independent in 1971.
[ii] *Boro* paddy is sown in December/January and harvested in April/May, and as such is an entirely dependent on irrigation.
[iii] Data missing for 1975-76 in West Bengal