

GRAVITY DRAINAGE FOR CROPPING INTENSIFICATION IN POLDERS OF THE COASTAL ZONE OF BANGLADESH

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ABSTRACT

Bangladesh is currently self-sufficient in rice production; but is facing immense challenges of sustaining it due to the population growth and adverse effects of climate change. There is little scope to further increase cropping intensity except for the underutilized 1.2 M ha lands enclosed in the polders of the coastal zone. The rivers in the coastal zone are tidal with semi-diurnal water level fluctuations of 2 to 3 m and offer tremendous opportunities for agricultural development in the polders, which is not recognized by the professionals and policymakers. The late rice harvest and waterlogged soil prevent timely cultivation of dry season crops. But there are tremendous opportunities to capitalize on polder ecosystem services especially the tidal river dynamics, dense canal networks, water management infrastructure and community water management organizations to reduce waterlogging by gravity drainage during low tides and greatly increase land productivity. Synchronized crop and water management studies were conducted in a medium saline polder from 2015 to 2018 to assess the water inflow and outflow dynamics in relation to land topography and tidal fluctuations in the peripheral rivers and examine possibilities of cropping intensification in the coastal polders. The study demonstrated opportunities for cropping systems intensification and diversification with two to three times higher productivity than with the traditional farmers' practice through improved drainage capitalizing the water management infrastructure in the polders.

Keywords: Coastal zone, polder, tidal river, drainage, agricultural intensification, community water management, climate-resilient cropping, food security.

INTRODUCTION

Sustained economic growth, quality of life, and the social stability of a rapidly growing Bangladesh are depending largely on food security. Although Bangladesh as a whole is currently self-sufficient in rice production (BBS 2016), the country is facing immense challenges of sustaining the self-sufficiency status. There is little scope to further increase cropping system intensity in central and northern part of Bangladesh where farmers are already growing 2-3 crops. Contrary to this the cropping intensity in the southern Bangladesh is quite low; about 1.7 million farming households grow only one crop (World Bank, 2010). The Government of Bangladesh (GoB) recently adopted policy calling for investment of over USD 7 billion to support agricultural development in southern Bangladesh mainly the coastal zone (MOA and FAO, 2013).

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More than 30% of the cultivable land of Bangladesh is in the coastal zone (SRDI 2012). Of the 2.85 million ha of coastal and offshore lands, about 1.2 million ha of agricultural lands were enclosed in 139 polders (Figure 1) in the 1960s and 1970s to prevent inundation at high tide during the rainy season and enable the production of a tall-statured a man crop (wet-season rice), prevent saline water intrusion during the dry season and to protect life and livelihood of the people in the coastal zone. Poldering involved building large embankments around the perimeter of the islands between the rivers. Inside the polders are found also dense natural drainage networks (*khals* or canals), and some of the larger internal canals are connected to the surrounding tidal rivers by sluice gates/regulators installed in the polder embankments. The farmers in the polders generally grow a traditional a man crop which sometimes followed by a low-input, low-yielding grass pea, sesame and mung bean and/or proceeded by an early rainy-season a us crop (Mondal et al 2015).

Though the feasibility of increasing productivity in the polders by intensifying and diversifying cropping systems has been shown by many researchers in recent years (Mondal et al 2006, 2015, Ritu et al 2015), however, there has been little adoption of improved production systems in the polders of the coastal zone of Bangladesh. The main challenge of intensifying and diversifying the polder production system is the drainage that often results in stagnant/intermittent flooding which hinder adoption of short-statured high yielding varieties (HYV) of rice and delay the harvest of a man rice. The late harvest of the local a man rice and waterlogged soil prevent the cultivation of HYV rabi crops (maize, sunflower, wheat etc.), which need to be established in early December for maximum yield. Moreover, the late established dry season crops area often damaged by pre-monsoon rains and cyclones in May. Thus, large areas of the coastal zone (about 810,000 ha) lie fallow during the dry season (Hasan et al 2013).

The investment on agriculture in the polders often gets restricted due to concerns on feasibility of draining large volume of water. This paper examines the feasibility of gravity-fed drainage through assessing the water outflow dynamics in relation to land topography and tides in the river, and evaluate a novel approach of crop and water management involving the communities for cropping intensification in the polders of the coastal zone of Bangladesh.

METHODOLOGY

2.1 Site Selection and Site Description

The study was conducted in Polder 30 (Figure 1) of the coastal zone of Bangladesh. The area belongs to geo-ecological zone of the Ganges Tidal Floodplain (BARC 2005). The climate is subtropical, with average annual rainfall of 1,850 mm.

The soil is mostly silty clay and the topsoil (0–15 cm) salinity (electrical conductivity of the saturation extract) varies from 4 to 14 dS/m in the dry season and remained in between 2 to 4 dS/m in the wet season (Mondal et al 2006). The river water salinity remained below 1 dS/m from July to December and gradually increased from January to a peak of 20-25 dS/m in April-May (Mondal et al 2006, 2015, IRRI 2017). The net cultivable area of the polder is about 4,240 ha, enclosed by about 41 km embankment that protects the area against tidal flooding, cyclonic storm and salinity intrusion.

Five rivers are flowing along the periphery, of which two major rivers (Kazibacha and Lower Salta) are flowing through the east and west side of the polder. There are 21 regulators (11 sluice gates used for water intake and drain-out and 10 flash gates for water intake only) on the embankment of the polder through which river water is taken-in for irrigation during high tide and excess water is drained-out to the rivers at low tide.

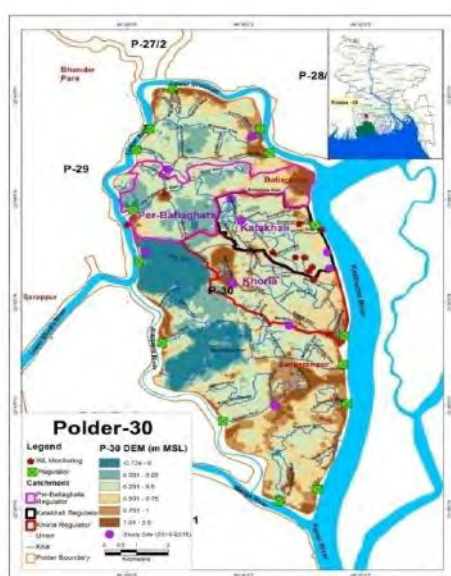


Figure 1. Map of Polder 30 showing the catchment area of the regulators and study sites.

2.2 Selection of Regulators and Water Management Units

Out of 11 sluice gates/regulators, three regulators located in the east (Katakhal and Khorla) and west (Per-Batiaghata) side of Polder 30 was selected for this study (Figure 1). The catchment area of Katakhal, Khorla, and Per-Batiaghata regulators was about 605, 886, and 986 ha, respectively (IRRI 2017). The Fultala village, situated within the catchment area of Katakhal regulator was selected for integrated crop and water management trials in 2015-16. The village was divided into two water management units (WMU1 and WMU2) by installing a gated culvert on the rural road. The WMUs were hydraulically connected with the main drainage systems of Katakhal regulator (Figure 2).

2.3 Water Level Monitoring

The water level in the Kazibacha and Lower Salta rivers, drainage canals connected with three regulators and on the floodplains WMU1 and WMU2 was measured from June to December 2015 to establish the rising and recession characteristics of the hydrographs and generate land inundation map. Automated pressure gauges were installed in both the rivers in June to record tidal dynamics at 10-minute intervals to ascertain the correct tidal cycle up to December (Figure 1). In addition, 18 gauges were installed inside WMU1 and WMU2 (within Katakhal catchment) to monitor the water depth on the paddy field in 2015.

The cropping intensification study was extended to other catchments of the polder from 2016 to 2018. Twenty four gauges were installed in 2017 at eight sites (WMU) at Partighata, Hogolbunia, Hetalbunia, Basurabad, Fultala, Fultala Moth, Tengramari and Gangarampur villages situated within the catchment area of seven regulators (Per Batiaghata, Khalshibunia, Hogolbunia, Katakhal, Katianangla, Khorla and Amtala) and in 2018, 96 gauges were installed at three sites (Bayerbhanga, Fultala and Katianangla villages) within the catchment area of Khorla, Mailmara, Katianangla and Katakhal regulators to monitor water depth in the wet season.

The water depth was measured daily in 2015 and 2017 and it was done on weekly basis in 2018.

2.4 Drainage System Design and Drainage Scenario Analysis

Most of the agricultural lands in the coastal zone of Bangladesh remain inundated to various degrees in the wet season. A dedicated “Polder 30 Drainage Model” was developed by the Institute of Water Modelling (IWM 2014) using Rainfall-Runoff (NAM model) and Hydrodynamic (Mike11 HD) modelling tools of the Danish Hydraulic Institute (DHI 2014). Rainfall, cross-sectional data on the canals and rivers, regulator dimensions, and land elevation were used to develop the model. Boundary condition was taken from the well calibrated southwest regional model to design the main drainage canal (IWM 2015).

The extreme value analysis was carried out using 48 years (1961-2008) rainfall data of the Khulna meteorological station (~10 km north to Polder 30) to calculate a 10-year, 25-year, and 30-year return period of 5-day maximum rainfall from July to December. Finally, the drainage systems were designed based on a 10-year return period event in consultation with different stakeholders including the polder community (Figure 2).

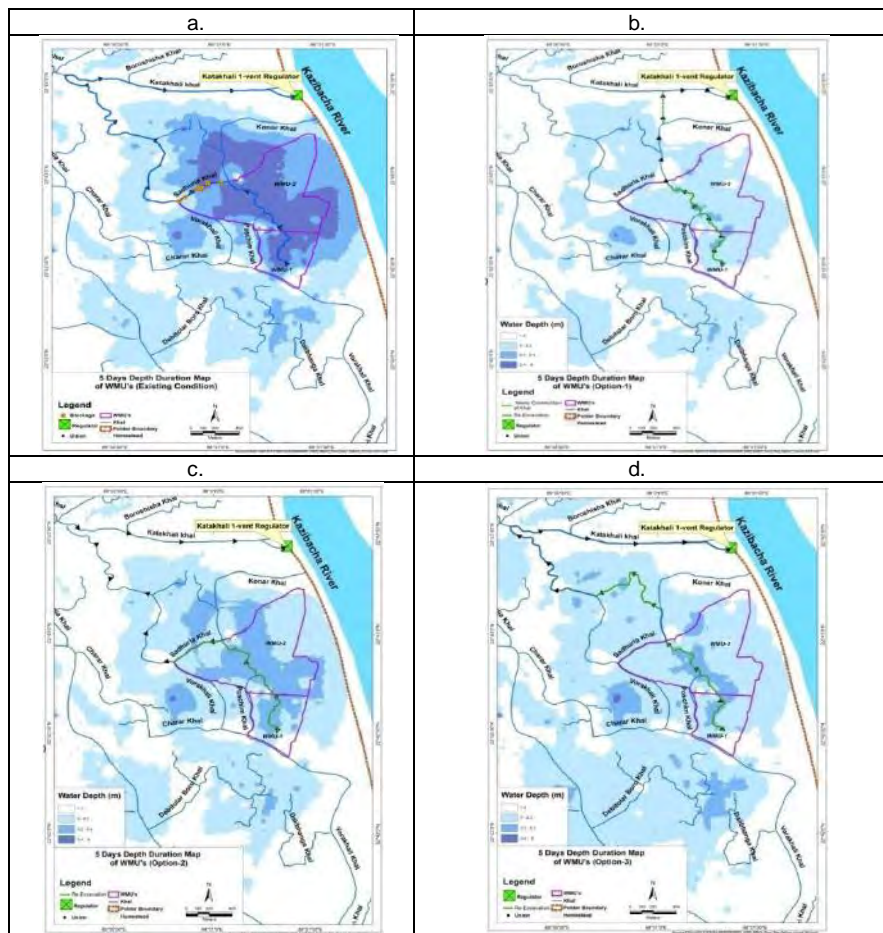


Figure 2. The 5-day depth-duration inundation map of WMU1 and WMU2 showing pre-project condition (a), and improved drainage considering drainage option 1 (b), option 2 (c) and option 3 (d).

The land inundation maps of WMU1 and WMU2 was prepared considering three simulated drainage options by using both Hydrodynamic model and DEM (Digital Elevation Model) of Polder 30 to improve waterlogging environment in the wet season (IWM 2014). The drainage routes from the middle of WMU1 to the Katakhal regulator of these options were 2.4 km, 5.5 km and 4.5 km, respectively (Figure 2b-d). The simulated drainage indicated that inundation level significantly improved in all three options (<40 cm inundation in almost 100% area of WMU1 and WMU2) over the pre-project scenario (Figure 2a). Among them, option-2 was adopted for this study in consultation with the community in which the silted-up canal passes through WMU1 and WMU2 was re-excavated for improving drainage (Figure 2c).

2.5 Design and testing of improved cropping pattern

The main cropping pattern of Polder 30 is traditional rice-fallow. Some farmers used to grow traditional sesame and mungbean in dry season, but the crops are partly or fully damaged by waterlogging due to pre-monsoon rains. As a consequence, most farmers abandoned the dry season cropping with investment loss. Improved cropping patterns (Figure 3) were, therefore developed in consultation with the community and evaluated by the farmers in partnership with the researchers under improved crop (BRRRI 2013 and BARI 2006) and water management in WMU1. The farmers in WMU2 practiced traditional cropping under their own management. Based on the first-year experience, evaluation of improved cropping with drainage by the community was extended to 10 different sites in Polder 30 from 2016 to 2018 (Figure 1). Crop cuts were taken to assess the yield of rice, maize and sunflower from 2015 to 2018 and yield was converted to standard moisture content (14% for rice, 12% for rabi crops).

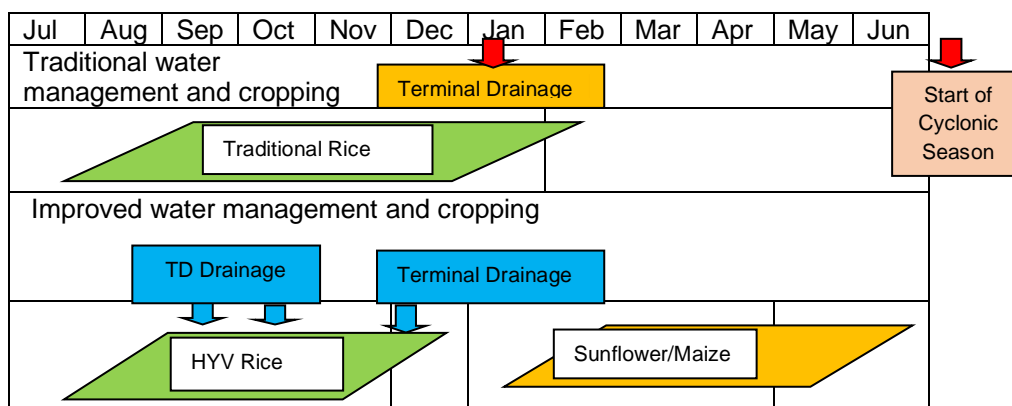


Figure 3. Traditional and improved cropping patterns showing water management and drainage interventions.

RESULTS

Drainage from the polders is primarily dependent on land topography and water level elevation in the rivers flowing around the polders of the coastal zone of Bangladesh. Consequences of improved drainage options for cropping intensification in Polder 30 are discussed in the subsequent sections.

3.1 Land Topography

The land topographic data of the CPWF G4 project (IWM 2014) were used to develop area-elevation curves of the catchment area of Katakhal, Khorla and Per Batiaghata regulators of Polder 30. Although the catchment area of the regulators varied widely, the land topography within the catchments was almost similar (Figure 4). The lowest

and highest land elevation was 0.40 m below MSL (-0.4 m MSL) and 3.00 m above MSL (+3.00 m MSL), respectively. The elevation of about 80% of the agricultural land within the catchment area of three regulators varied from +0.10 to +1.00 m MSL. Major agricultural lands in Polder 30 having almost similar elevation to that observed within the catchment of three regulators (Figures. 1 and 4).

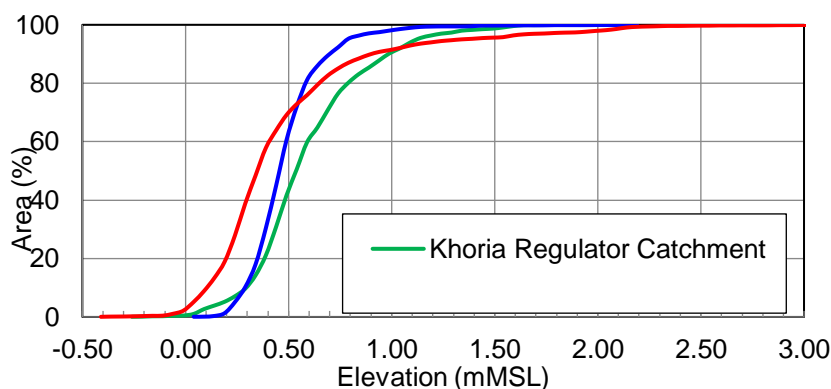


Figure 4. Area-elevation curve of the catchments of Katakhal, Khor, and Per-Batiaghata regulators.

3.2 Water Level

The tidal water level in Kazibacha river varied from -2.02 to +2.80 m MSL at spring tide and from -1.32 to +1.90 m MSL at neap tide and that in Lower Salta river varied from -2.16 to +3.05 m MSL and -1.44 to +1.94 m MSL in spring and neap tides, respectively from June to December, 2015 (Figure 5).

The water level in the Lower Salta river was higher than that at Kazibacha river during high tides, but it was lower during low tides (Figure 5). The water level elevation in the main drainage canals connected to Katakhal, Khor, and Per-Batiaghata regulators varied from -0.79 to +0.91 m MSL during monsoon. A slightly higher water level was observed in Katakhal drainage canal (-0.62 to +0.91 m MSL) than in other canal systems (-0.79 to +0.81 m MSL) of the polder. The water level elevation at low tides in the peripheral rivers remained much lower than the land elevation in all three catchments (Figures. 4 and 5). At low tides, water level elevation at Kazibacha and Lower Salta rivers varied from -2.02 to -0.27 m MSL and -2.16 to -0.44 m MSL; and at high tides, it varied from +1.06 to +2.80 and +1.21 to +3.05 m MSL, respectively. The highest water elevation in both the rivers at low tides (-0.44 to -0.27 m MSL) indicated opportunities for gravity drainage from the agricultural lands of Polder 30 (lowest and highest land elevation in three catchments was -0.41 and +3.00 m MSL and 80% land elevation varied from +0.10 to +1.00 m MSL).

3.3 Drainage option and land inundation

3.3.1 Land Inundation Under Traditional Water Management

The 5-day land inundation map of WMU1 and WMU2 showed that about 60% land area remain inundated to >40 cm depth throughout the wet season under traditional water management (Figure 2a). This water environment is considered unfavorable for HYV rice cultivation, as the topdressing of nitrogen (N) fertilizer at the critical growth stages of rice is not possible under such inundation level that might reduce wet season productivity. Although the tidal dynamics of the peripheral rivers indicated the possibility of gravity drainage from the agricultural lands in Polder 30 (Figure 5), in reality about

60% lands in WMU1 and WMU2 remained inundated to 40-80 cm water depth in the wet season (Figure 2a) due to poor water management.

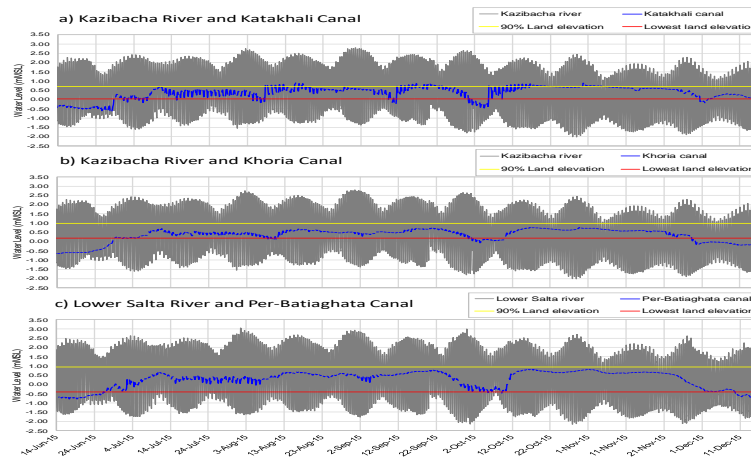


Figure 5. Water level hydrographs in the peripheral rivers and drainage canals of three regulators in Polder 30.

3.3.2 Land inundation under improved drainage option

In 2015 wet season, the maximum water depth in WMU1 and WMU2 varied from 27 to 46 cm (27–43 cm in WMU1 and 33–46 cm in WMU2), which was favourable for HYV rice cultivation (Figure 6). The farmers of WMU1 in partnership with the water management organization of Katakhal regulator drained out water twice from the paddy field to topdress N fertilizer (Figure 7).



Figure 6. Land inundation (5-day depth duration) in WMU1 and WMU2

The water depth in the lowest pocket in WMU1 seldom exceeded 50 cm. As a result, waterlogging condition in WMU1 was significantly improved over the pre-project conditions (Figures. 2a, and 6) and most farmers (95%) cultivated HYV rice in 2015. There was no standing water in major part of WMU1 during N topdressing (Figure 7). Only 5-10 cm water remained in the low lands (only about 5% area of WMU1), where the farmers cultivated traditional rice. The water management organizations at different catchments in Polder 30 gradually adopted improved water management from 2016. As a result, water environment at different study sites (WMUs) in 2017 and 2018 was

favourable for adoption of improved production systems. In general, the water depth varied from 5 to 45 cm in the wet season (IRRI 2017, 2019).

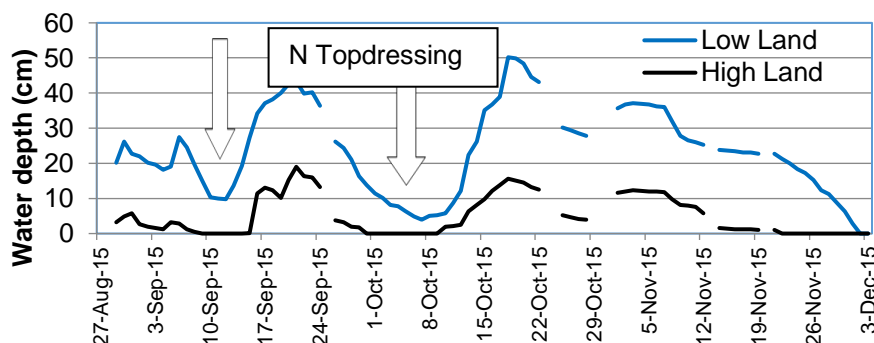


Figure 7. Water depth in WMU1 in the wet season, 2015

During the drainage cycles, water recession pattern at Karakahli and Vorakhali drainage canals connected to the outfall regulator (Katakhal) was almost similar (Figure 8), despite the gauges were installed about 3.5 km apart. This recession dynamics indicated good connectivity between the Katakhal and Vorakhali drainage canals to the outfall regulator. But, about a week delay in drainage from WMU1 was observed during the drainage cycles during 7-13 September 2015 and 27 September-6 October 2015. The main reason was the blockages in Sadhuria canal (Figs. 2a and 6) that connected the main drainage canals (Vorakhali and Katakhal canals) with WMU1 to the Katakhal regulator.

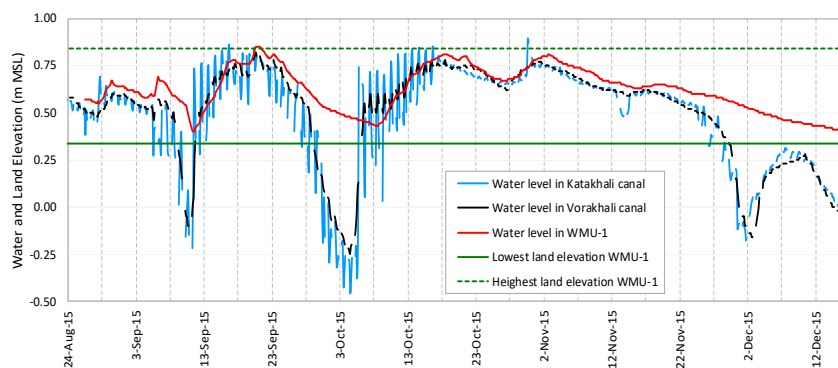


Figure 8. Variation in water level in the main drainage system of Katakhal regulator in 2015 wet season.

3.4 Annual System Productivity

Generally, the terminal drainage is practiced around mid-December to facilitate rice harvest and this water management disfavor crop cultivation in the dry season. As a result, most lands in Polder 30 remain fallow in this season (January-May). Moreover, HYV of rice cannot be grown under this water environment. Therefore, with improved drainage, performance of HYV rice and rabi crops was evaluated in 20 ha WMU1 in partnership with the farmers and water management organizations of Katakhal regulator in the wet season 2015 and dry season of 2015-16. Later, it was gradually extended to other catchments in Polder 30 (Figure 1) from 2016 to 2018.

The mean yield of HYV rice (2015 to 2018, n=407) was about 5 t/ha, which was about 2 t/ha higher than traditional rice varieties (n=282) grown in Polder 30 (Table 1). Improved drainage created opportunities for HYV rice cultivation in the wet season, and improved drainage and HYV rice in wet season created opportunities for timely establishment and safe harvest of dry season crops. Therefore, performance of maize and sunflower was evaluated by the farmers following the harvest of HYV rice from 2016 to 2018. Although the yield of HYV rice was more or less stable over the study period (2015-2018), it was high variable for dry season crops. The yield of maize varied from 1.4 to 10.1 t/ha (n=58) and that of sunflower varied from 0.4 to 3.7 t/ha (n=175) mainly due to weather variability and inexperience of the farmers to adopt recommended cultural management practices. The yield of rabi crops was relatively better in a normal year than in the dry (low yield due to water stress) and very wet years (crop partly damaged by excessive rainfall).

Table 1. Annual system productivity in Polder 30

Cropping Pattern		Yield (kg/ha)		System rice equivalent yield (kg/ha/yr)
		Rice (av 2015-18)	Rabi crops (av 2016-18)	
Traditional	Traditional Rice-Fallow	3080 ± 26.9		3080
Improved	HYV Rice-HYV Maize	4854 ± 46.6	3812 ± 336.2	8920
	HYV Rice-HYV Sunflower		1226 ± 44.2	7633

Annual system productivity was calculated as rice equivalent yield (REY) based on the local market price for each crop (HYV rice 18.75 Tk/kg, sunflower 42.5 Tk/kg, and maize 20.0 Tk/kg). Over the study period (2015-2018), the mean REY of the improved system (7.6-8.9 t/ha/yr) was 2-3 times higher than traditional cropping system (Table 1). The result indicated that with timely drainage and recommended cultural practices, higher cropping intensity and productivity is achievable in the polder ecosystem of Bangladesh.

4. DISCUSSION

Cropping system intensification in the polders of the coastal zone of Bangladesh has been limited by the misperception that most lands remained waterlogged in the wet season that cannot be improved easily for wide-scale adoption of improved rice-based production systems in the polder zone. In addition, soil and river water is saline in the dry season prevents cropping intensification.

The results of the study presented above clearly demonstrate that excess water from the polder lands can be drained by gravity during low tides in the peripheral rivers of Polder 30. The lowest land elevation within the study catchments was -0.41 m MSL (80% land elevation is +0.10 to 1.00 m MSL) and the highest water level during low tides in the peripheral rivers of Polder 30 ranged from -0.27 to -0.44 m MSL at neap and spring tides. The results also demonstrated that the main drainage canals were well connected with the outfall regulators and the water level recession during drainage cycles was almost similar with the recession near the regulator to about 3.5 km apart. Drainage from WMU1 was delayed due to blockage in Sodhuria canal connecting WMU1 to the Katakhal regulator. Such blockages are common in many secondary canals pass by the settlement area. Despite, the community was able to successfully drain out water twice and topdress N fertilizer in HYV rice. In Khorlia and Per Batiaghata

catchments, where there was no crop and water management interventions in 2015, the drainage was done only once in the second week of October mainly to reduce the growth of algae. This implies that agricultural land is drainable by gravity. Moreover, the difference between the lowest land elevation and the highest water level at low tides, and functionality of the canal networks in Polder 30 clearly indicated all excess water from the polder lands can easily be drained by gravity.

The results of the cropping pattern trials across Polder 30 show that it is possible to triple annual productivity in the medium salinity polders of the coastal zone of Bangladesh, using improved rice and *rabi* crop varieties, recommended crop management practices, and good water management, particularly drainage at critical crop growth stages. A key prerequisite for cropping intensification in the polders of the coastal zone of Bangladesh is the cultivation of HYV rice in wet season instead of the current practice of late maturing, photoperiod sensitive traditional rice varieties and drainage in mid-November instead of traditional practice of doing it in mid-December. Cultivation of HYV rice in wet season means the need for drainage when the field water depth is too high for HYV (eg. following excessive rainfall), and prior to topdressing of nitrogen fertilizer. Early terminal drainage is essential to allow suitable conditions for harvest of wet season rice and allow the soil to dry sufficiently for timely establishment of dry season (*rabi*) crops. Late establishment of *rabi* crops results in damage or destruction by pre-monsoon rainfall and cyclones in May at maturity or prior to harvest, as happened four times in the last five years (IRRI 2017 and 2019).

The opportunity for increasing cropping intensity and productivity through gravity drainage has not yet been recognized by the policymakers, water management and agricultural extension authorities, and more than 1 million farming families living in the polders of the coastal zone of Bangladesh. Successful large-scale implementation of these opportunities requires a change in mind set and increased investment in agriculture and in-polder water management. Until the needs for community water management within small hydrological units (WMUs) or within a regulator catchment and cropping system synchronization are addressed, farming communities in the polders of the coastal zone will not be able to adopt and benefit from the improved technologies that most of Bangladesh benefits from.

5. CONCLUSIONS

The results show that it is possible to drain out water from the agricultural lands by gravity using tidal dynamics in the peripheral rivers of the coastal polder zone. The cropping intensity and annual productivity can be increased two to three times than the current production level using improved rice and *rabi* crops and good water management – in particular, drainage after excessive rainfall during the monsoon to enable cultivation of HYV rice and advancing terminal drainage in mid-November instead of doing it in mid-December (traditional practice).

Introduction of HYV rice not only increased productivity in the wet season (~2 t/ha), its cultivation in the wet season with improved drainage created opportunities for timely establishment and safe harvest of dry season crops. Although the yield of HYV rice (~5 t/ha) was more or less stable over the study period (2015-2018), it was high variable for dry season crops. The yield of maize varied from 1.4 to 10.1 t/ha and that of sunflower varied from 0.4 to 3.7 t/ha mainly due to weather variability and inexperience of the farmers to adopt recommended cultural management practices. The yield was relatively higher in a normal year than in the dry (low yield due to water stress) and wet years (crop partly damaged by excessive rainfall in a wet year). Capacity building of the farmers and water management organization is expected to overcome such yield vulnerability in the dry season.

The result indicated that with timely drainage and recommended practice, higher cropping intensity and productivity is achievable in the polder ecosystem. Since cropping intensity and productivity in other parts of Bangladesh is already high, the under-utilized agricultural lands in the polders of the coastal zone of Bangladesh may well be the only region where significant gains in food production can be made to address future challenges to the food security and in achieving the sustainable development goal 1 and 2 within the timeframe.

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