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An Overview of the Ganges Coastal Zone: Climate, Hydrology, Land Use and Vulnerability

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The Ganges coastal zone is the contiguous area covering southern Bangladesh and Sundarbans region of West Bengal, India. Agriculture in this zone is the main source of livelihood for the inhabitants; however, it is influenced by several climate, soil, and anthropogenic activities. This zone is covered by polders in Bangladesh and islands in West Bengal. Cropping system in this area is very low due to several constraints particularly high soil salinity and irrigation water scarcity. Researchers and NGOs from Australia, Bangladesh, and India have been working together since 2015 under a project entitled "Cropping system intensification in the salt-affected coastal zones of Bangladesh and West Bengal, India" to sustainably increase cropping intensity and productivity in this area. The project is funded by the Australian Centre for International Agricultural Research (ACIAR). This special issue is based on the research findings of various experiments on the climatic variability, cropping system options, management of fertilizer, irrigation water as well as social and economic issues conducted under the aegis of the project in Bangladesh and West Bengal, India.

(***Key words:*** *Coastal zone, Ganges delta, Ground water, Island, Polders, Salinity)*

The mega-deltas of the world, such as the Ganges delta, are unique coastal zones of great significance for food security, biodiversity conservation, fisheries production and climate change adaptation and mitigation. Their low elevations make them highly vulnerable to rising sea levels. However, even in the absence of sea level change they are vulnerable to storm surges and flooding especially in cyclone-prone regions. The forest mangrove ecosystems that occurred in the mega-deltas (known as the Sundarbans in the Ganges delta) have been substantially diminished by land clearing in the late 20th century and this process continues. The present Special Issue concerns the contiguous coastal zones of the Ganges Delta in Southern Bangladesh and West Bengal in India. These have similar geomorphology, soils, agro-climatic conditions, and major limitations to livelihood enhancement (Fig. 1). Within this low lying deltaic region, large areas known as 'polders' have been enclosed and protected from seawater flooding by constructed earth embankments. Polders protect inhabited and cropped land, whereas the mangrove forest reserves of the Sundarbans in both Bangladesh and West Bengal are unprotected and are mostly in a natural state. The importance of the mangrove forest reserves for biological conservation (especially as habitat for the iconic Bengal tiger) and for fisheries warrant attention but are outside the scope of this Special Issue.

The ground level in polders is almost the same as the water level in the rivers of the Ganges delta. These being tidal rivers, the level of water rises and falls with the tides and is also affected by monsoon rain flows and sea water surges. This makes the drainage of rain water accumulated in the polders difficult to manage. Drainage can usually occur (at low tide), creating the possibility of gravity-drainage of excess water during the rainy season. However, the functioning of the sluice-gates controlling water flow through the polders, and the integrity of the polder earthen walls themselves for

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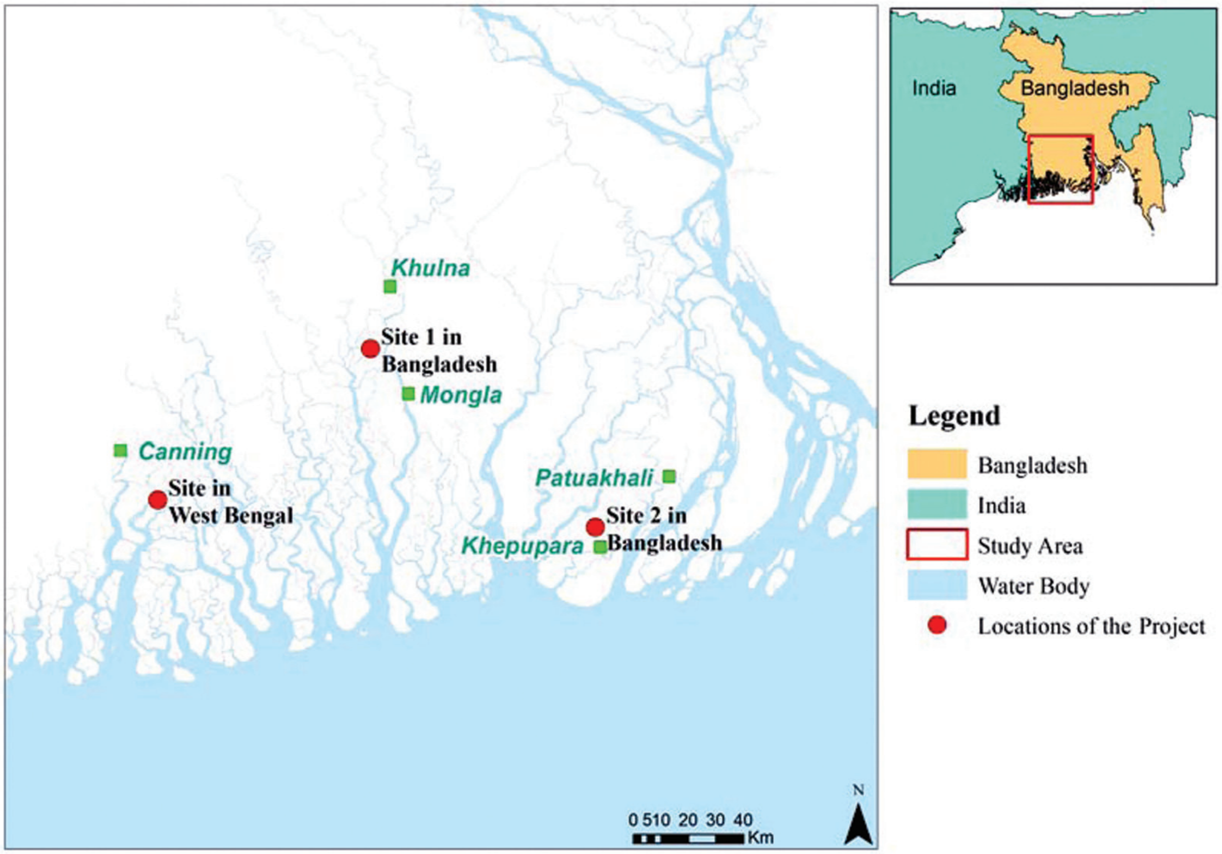

Fig. 1. *The coastal region of Bangladesh and West Bengal, India showing locations of the project*

controlling the flow of water between the polder and the rivers is critical, complex and often not well managed.

Due to this difficult drainage situation, and the ~ 2000 mm of annual rainfall concentrated mostly in the monsoon season, polders are prone to flooding in the wet season and salinity in the dry season. About 65% of the coastal zone of Bangladesh and West Bengal is affected by various levels (low to high) of salinity in the dry season (Brahmachari, 2011; SRDI, 2010).

There are 139 polders in Bangladesh and a less-well-developed polder system in the Sundarbans region of West Bengal (Fig. 1). This Special Issue relates to research conducted mostly at three sites, Amtali, Barguna and Dacope, Khulna in Bangladesh and Gosaba, 24 South Parganas, West Bengal, India (Fig. 1). The main characteristics of the sites are given in Table 1.

The population of the Ganges Delta region is about 31million in Bangladesh [Khulna and Barisal Division and the Faridpur region, 2011 Census, BBS, (2018a)] and 23 million in West Bengal. These areas are disadvantaged by poverty, food insecurity, environmental vulnerability and limited livelihood opportunities (MoA and FAO, 2013; Sanchez-Triana *et al*., 2014). The living standards of residents in the West Bengal coastal region are described as dismal; Sanchez-Triana *et al*. (2014) showed that, of a typical group of residents, 19% get only one meal a day, and for 6% of them it would be a substandard meal; 65% live below the poverty line. Similarly, in Bangladesh, 30.8 and 37.2% of the population of Khulna and Patuakhali (near project site at Amtali), respectively, live below the poverty line compared with 24.3 % for the whole country (BBS, 2017). Traditionally, farms produce low-yielding local rice varieties under rainfed conditions in the wet season (Karim, 2006; Rashid *et al*., 2014; Sarangi *et al*., 2014; Sarangi *et al*., 2015a). The average yield of wet season rice (also called *aman* rice) in the coastal districts is the lowest in Bangladesh [In 2015-16, average yield of husked rice was 1.77 t ha^{-1} in Barguna, and 2.51 t ha^{-1} in Khulna, (BBS, 2018b)] compared to yields of 2.5 to 3.0 t ha^{-1} achieved in the other districts

Table 1. *Location and characteristics of study locations (see also Fig. 1.)*

Location	Main characteristics
Barguna district, Bangladesh	Pronounced inundation in monsoon season but moderate salinity. Available fresh water from outside the polder (river water) for supplementary irrigation in rabi and kharif I season. *Boro* and *aus* rice are also options for this region.
Khulna district, Bangladesh	High salinity and prolonged inundation of low and medium land in monsoon season. Fresh water stored in canals are available for irrigation for a limited period of time after the end of the rainy season
Gosaba Block in the Canning Sub-division of South 24 Parganas district, West Bengal, India	Salinity and inundation vary with elevation within Island. No freshwater available from outside the Island in *rabi* and *kharif* I seasons. Supplementary irrigation depends on collection of rain water from the monsoon season in ponds and canals. Pond water prone to acid discharge and salinisation with the passage of the dry season.

(BBS, 2018b). Similarly, due to standing floodwaters, the average yield of wet season rice in the coastal zone of West Bengal (< 2.0 t ha^{-1}) is below both the national average (2.4 t ha-1, 2011-12) and the average of West Bengal (2.6 t ha-1) (Sarangi *et al*., 2015b).

In the dry season, most agricultural land remains fallow due to: (i) late rice harvest and prolonged waterlogging (which delays the planting of *rabi* crops until such a time that exposes the late planted crops to high soil salinity and untimely rains during the latter part of the season), and (ii) the lack (or perceived lack) of good quality irrigation water for *rabi* season irrigation (Mondal *et al*., 2008; Brahmachari, 2011; Mainuddin *et al*., 2013). A scoping study showed that there are over 700,000 ha of under-utilized land that can be brought under cultivation during the *rabi* season in Southern Bangladesh (Mainuddin *et al*., 2013). Similarly, Schulthess *et al*. (2015) showed that there are about 800,000 ha left fallow or underutilized in the poldered coastal zone. Thus, the cropping intensity in the districts along the coast of Bangladesh is below 150% (148% in Patuakhali (which includes Barguna as well) and 132% in Khulna (2011-12) compared to the country average of 190% (BBS, 2018a). Similar conditions (fallow lands in the *rabi* season and low cropping intensity) exist in the coastal zone of West Bengal (Sarangi *et al*., 2015b). Hence there is potential to grow more dry season crops provided the previously-mentioned constraints can be alleviated or managed. The development of such technologies and their likely impact on the communities of the Ganges delta, including marginalised and disadvantaged groups and sectors, are the subject of the following papers:

1. Yu, Y., Mainuddin, M., Maniruzzaman, M. Mandal, U. K. and Sarangi, S. K. (2019). Rainfall and temperature characteristics in the coastal zones of Bangladesh and West Bengal, India. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 12-23.
2. Hossain, M. B., Maniruzzaman, M., Yesmin, M. S., Mostafizur, A. B. M., Kundu, P. K., Kabir, M. J., Bishwas, J. C. and Mainuddin, M. (2019). Water and soil salinity dynamics and dry season crop cultivation in coastal region of Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 24-31.
3. Ghosh, A., Nanda, M. K., Sarkar, D., Sarkar, S. Brahmachari, K. and Ray, K. (2019). Application of multi-dated Sentinel-2 imageries to assess the cropping system in Gosaba island of Indian Sundarbans. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 32-44.
4. Mainuddin, M., Rahman, M. A., Maniruzzaman, M., Sarker, K. K., Mandal, U. K., Nanda, M. K., Gaydon, D., Sarangi, S. K., Sarkar, S., Yu, Y., Islam, M. T. and Kirby, M. (2019). The water and salt balance of polders / islands in the Ganges delta. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 45-50.
5. Kabir, M. E., Sarker, B. C., Ghosh, A. K., Mainuddin, M. and Bell, R. W. (2019). Effect of sowing dates on yield of wheat grown in excess water and salt affected soils in southwestern coastal Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 51-59.
6. Kamar, S. S. A., Wohab, M. A., Rahman, M. A. and

Raziuddin (2019). Deep placement of urea increased fertilizer use efficiency and yield of summer tomato. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 60-63.

7. Mahanta, K. K., Burman, D., Sarangi, S. K., Mandal, U. K., Maji, B., Mandal, S., Digar, S. and Mainuddin, M. (2019). Drip irrigation for reducing soil salinity and increasing cropping intensity: case studies in Indian Sundarbans. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 64-71.

8. Saha, R. R., Rahman, M. A., Rahman, M. H., Mainuddin, M., Bell, R. and Gaydon, D. S. (2019). Cropping system intensification under rice based system for increasing crop productivity in salt-affected coastal zones of Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 72-81.

9. Sarker, K. K., Kamar, S. S. A., Hossain, A., Mainuddin, M., Bell, R. W., Barrett- Lennard, E. G., Gaydon, D. S., Glover, M., Saha, R. R., Ali, M. A., Khan, M. S. I. and Maniruzaman, M. (2019). Cropping system-based irrigation for improving crop and water productivity in the coastal zone of Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 82-97.

10. Sarkar, S., Samui, I., Brahmachari, K., Ray, K., Ghosh, A. and Nanda, M. K. (2019). Management practices for *utera* pulses in rice-fallow system under coastal saline zone of West Bengal. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 98-103.

11. Shahadat, M. K., Rashid, M. H., and Ali, M. A. (2019). Performance of garden pea varieties as intercrop with maize in the coastal area of Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 104-114.

12. Sarangi, S. K., Maji, B., Mahanta, K. K., Digar, S., Burman, D., Mandal, S., Mandal, U. K., Sharma, P. C., Mainuddin, M. and Bell, R. W. (2019). Alternate *kharif* rice crop establishment methods and medium duration varieties to enable cropping system intensification in coastal saline region. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 115-122.

13. Maniruzzaman, M., Kabir, M. J., Hossain, M. B., Yesmin, S., Mostafizur, A.B.M., Biswas, J. C., Ali, M. A., Mainuddin, M. and Bell, R. W. (2019). Adjustment in wet season rice planting for cropping intensification in coastal Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 123-133.

14. Yesmin, M. S., Maniruzzaman, M., Hossain, M. B., Gaydon, D. S., Mostafizur, A. B. M., Kabir, M. J., Biswas, J. C., Mainuddin, M. and Bell, R. W. (2019). Selection of suitable sowing window for boro rice in coastal regions of Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 134-143.

15. Ray, K., Brahmachari, M., Goswami, R., Sarkar, S., Brahmachari, K., Ghosh, A. and Nanda, M. K. (2019). Adoption of improved technologies for cropping intensification in the coastal zone of West Bengal, India: a village level study for impact assessment. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 144-152.

16. Bell, R. W., Mainuddin, M., Barrett-Lennard, E. G., Sarangi, S. K., Maniruzzaman, M., Brahmachari, K., Sarker, K. K., Burman, D., Gaydon, D. S., Kirby, J. M., Glover, M., Rashid, M. H., Khan, M. S. I., Kabir, M. E., Rahman M. A. and Hossain, M. B. (2019). Cropping systems intensification in the coastal zone of the Ganges delta: opportunities and risks. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 153-161.

The annual rainfall in the Ganges delta is adequate for two crops per year, but little of the excess in the monsoon is stored as surface or groundwater. Indeed, waterlogging is a problem in the late wet season and early dry season due to (i) infrastructure that impedes rapid drainage from polders, (ii) currently-inefficient polder water management practices, and (iii) low soil permeability. Later in the dry season, soil drying leads to salinity problems (*in-situ* soil salinity due to the shallow saline groundwater) which may be exacerbated by the use of brackish water for irrigation. In West Bengal, there are reports of extreme acidity in pond water due to acid sulphate soil layers at the base of the ponds (Haldar and Debnath, 2014).

Notwithstanding these constraints, it is postulated that cropping can be intensified through several management strategies including:

- surface drainage of excess water at the end of the wet season,
- better understanding and use of the limited fresh groundwater (bearing in mind the potential acid sulphate soil problems),
- increased surface water storage capacity, and better maintenance and use of the existing limited storage,
- separation of lands of higher and lower elevation taking advantage of existing infrastructure (e.g. roads), and
- strategic construction of small levees,
- planting of earlier maturity and shorter season rice varieties during the monsoon season to provide better timeliness of crops in relation to water availability,
- increased use of salt tolerant *rabi* cultivars, and
- optimising areas of cropping in relation to areas devoted to surface storage.
- pumping to lower saline water tables during *rabi* season, and reduce salt build-up in surface soil
- use of mulches to reduce *rabi* season soil evaporation and hence reduce salinity build-up in surface soil

A further barrier to crop intensification in the coastal zone is the missing linkages between field-level cropping choices and the polder-scale water and salinity management decisions (Humphreys *et al*., 2015). Despite substantial research by many agencies in the coastal zone to increase crop productivity (*e.g.* see papers in Humphreys *et al*., 2015), studies continue to overlook such linkages.

There is also limited knowledge of cropping and management options among farmers and extension officers, and poor availability of salt-tolerant varieties of crops. Moreover, as noted by Tuong *et al*. (2014) "*water resources in the coastal zone have largely been misunderstood and under-utilized. In reality, valuable resources are available which can be used to support agricultural and aquacultural production and livelihood improvement of farming families and communities*".

There may also be the opportunities for strategic pumping of saline groundwater during the dry season which will increase the amount of freshwater recharge and thereby fresh water for irrigation from groundwater during the dry season. Realising this potential, while avoiding the potential acid sulphate soil problems noted earlier, and avoiding saline water intrusion to the aquifers, relies on developing the opportunities in a systematic and integrated way. Mandal *et al*. (2011) also identified high soil salinity and water scarcity, non-scientific nutrient management, scarcity of good quality irrigation water during the *rabi* season, low crop diversification, and under-utilised brackish water resources as major critical gaps for crop intensification in the coastal region of West Bengal, India.

Most previous studies (Rawson, 2011; Sarangi *et al*., 2014; Humphreys *et al*., 2015; Sarangi *et al*., 2015a) focused either on field-scale crop management or on polder/regional-scale water management and modelling (IWM and CEGIS, 2007; World Bank, 2010a; Humphreys *et al*., 2015), but did not link the two which is essential for guiding long-term sustainable intensification of the region. The key research questions for sustainable intensification of the cropping system in the coastal zone include:

1. Where, when and how much low-salinity surface water is available for irrigation, and where and how can low-salinity groundwater be used sustainably for irrigation? What are the spatial and temporal trends in surface water, groundwater, and soil salinity and how do they interact? These questions are addressed by Ghosh *et al*. (2019); Hossain *et al*. (2019) and Yu *et al*. (2019).
2. Will strategic pumping of saline groundwater during the dry season increase the amount of freshwater recharge during the wet-season, and thereby significantly increase the amount of fresh water available for irrigation from groundwater during the dry season? What are the risks of further salinization from this approach? These questions are addressed by Mainuddin *et al*. (2019).
3. What are the best options for using available fresh water resources to increase production of dry season crops such as wheat, maize, pulses and oilseeds; e.g. early sowing to minimise irrigation water requirements and the risk of high soil salinity, irrigation practices such as flood, furrow or drip, mulching, land shaping and crop nutrient

management? How profitable and sustainable are these options? These questions are addressed by a series of papers (Kabir *et al*, 2019; Kamar *et al*., 2019; Mahanta *et al*., 2019; Saha *et al*., 2019; Sarkar *et al*., 2019; Sarker *et al*., 2019; Shahadat *et al*., 2019).

4. Can polders be managed and redesigned to improve drainage to enable production of earlier maturity (modern) rice varieties during the wet season, earlier drainage of monsoon flood waters to allow earlier planting of dry season crops, and for storage of non-saline water for irrigation of pre- and post- monsoon crops? These questions are addressed by a series of papers (Maniruzzaman *et al*., 2019; Sarangi *et al*., 2019; Yesmin *et al*., 2019).

5. What barriers to improved water management in polders are presented by farmers' crop and management preferences, and other water users, and how can they be overcome? How can the options developed be more socially inclusive and provide benefits to women, children, and marginalised groups? These questions are addressed by Ray *et al*. (2019).

Finally, Bell *et al*. (2019) summarizes the main research findings of these papers.

The CPWF (Challenge Program on Water and Food) Ganges Basin Development Challenges (GBDC) Program conducted (2011-2014) significant work on characterising the surface water resource of the Bangladesh coastal zone (river levels, flows and salinity) as well as demonstration of improved (more intensive and diversified) cropping systems (Humphreys *et al*., 2015, which includes a series of papers on different aspects). The present Special Issue reports on the next steps for better integration across scales, improved understanding of salt and water dynamics, a better understanding of the ground water resources and sustainable levels of extraction, and an exploration of reduced tillage crop establishment methods (for most timely establishment).

Cropping intensification in the coastal zone will depend on the local / farm level response to the polder level maintenance and rehabilitation programs. In part, this is a matter of the water management and cropping opportunities that are the subject of this Special Issue. In part, it is also a matter of institutional response (addressed separately by the sister project 'Promoting socially inclusive and sustainable agricultural intensification in West Bengal and Bangladesh' funded by ACIAR). BWDB (2012) notes the tension between sluice gate operation for agricultural production systems (which aims to get excess water out of polders during the rainy season and prevent entry of saline water into polders in the dry season) and shrimp farming (which aims to get brackish water in during the dry season), and suggests that the creation of water-user associations at different levels (village, sub-polder, whole polder) to operate sluice gates for community benefit (rather than leaving them in the hands of a powerful few) is necessary.

Climate change is an important issue for the coastal zone of Bangladesh and West Bengal [for example, a large economic impact is projected due to greater coastal inundation in Bangladesh by the end of this century, Dasgupta *et al*. (2014a)]. Earlier work in the Bangladesh shows that climate variability is likely to dominate climate change in the region at least up to 2050 (Moors *et al*., 2011; CSIRO, 2014; Jeuland *et al*., 2013). CSIRO (2014) point out that coping with climate variability (*i.e*. coping with the extreme floods, storm surges and droughts already experienced) is likely to prepare the country for climate change at least until 2050.

The World Bank (2010b) points out that investments in the last 50 years have increased the resilience of Bangladesh to climate-related hazards, and significantly reduced damage and losses from extreme climatic events. Notwithstanding the gains made, such events still cause large economic losses and slow progress in reducing poverty. Thus, the outcomes of the research reported in this Special Issue will further aid Bangladesh, and by extension West Bengal, India, to cope with climate variability and climate change.

One of the main impacts of sea water intrusion into the river, and the consequent increases in river salinity in the dry season in Bangladesh, is to limit the availability of fresh surface water in the dry season, which is highly dependent on the flow of water in the Ganges and Brahmaputra rivers, particularly the Ganges River (Mainuddin *et al*., 2013). The Bangladesh Integrated Water Resources Assessment Project (IWM, 2014) and the CPWF GBDC Program (Khan *et al*., 2015) studied the impact of upstream withdrawal, sea level rise and climate change on the coastal zone water resources in Bangladesh (IWM, 2014). Papers in the Special Issue are informed by this background knowledge.

This Special Issue aims to report techniques for reducing the impacts of salinity in the coastal zone of the Ganges Delta. Studies in Bangladesh show that sea level rise and increased storm surges will expose an additional 9 million people to inundation and result in an additional $5.5 billion damage (approximately) to the Bangladesh economy (Dasgupta *et al*., 2014a). Declines in crop yields of up to 16% and in income of up to 11% in the absence of coping strategies are projected by Dasgupta *et al*. (2014b). The potential for the findings reported in the following papers to counteract the projected declines in current incomes could be as important as the potential increase in farm level income. Such income losses would be particularly difficult for people who are already poor, and the potential to counteract such losses is potentially a huge benefit. We are not aware of similar studies for the coastal areas of West Bengal and so cannot enumerate the potential economic impact of additional inundation there.

Chandna *et al*. (2015) estimated that about 0.5 Mha could be brought under high-yielding varieties (HYV) during *aman-rabi* in Barisal Division, using extrapolation domain analysis. A modest increase of 10% in rice yield (from the 2 t ha^{-1} average yield) due to better water management on 10% of 0.5 million ha after 5 years, would increase production by about 10,000 tonnes per *aman* season: the farm-gate value of the extra grain is about 2.8 million US dollars.

There are about 800,000 ha of fallow or underutilized land in the poldered coastal zone (Schulthess *et al*., 2015). If 5% of this land can be brought under cultivation of *rabi* crop in the Bangladesh portion (for example, wheat) in the next 5 years, the total wheat production will be about 100,000 tonnes per season, generating a farm-gate value of 28 million US dollars. Similar benefits can be expected in West Bengal. Farming of high value crops such as tomato, chilli, etc. by marginal and women farmers will generate additional income for them. Sarker *et al*., (2019) showed that farmers can gain benefit of 87,955 Taka ha^{-1} (1,050 US$ ha^{-1}) by growing sunflower, T. *aus* and T. *aman* rice at Amtali. Sarangi *et al*. (2018) showed that farmers can get net return of ₹ 46,260 (~750 US$ ha^{-1}) by growing zero tillage potato that was standardised under this project. So, a household that has 0.10 ha of land could derive a net benefit of about US$ 75 by growing zero tillage potato. This represents a large income boost for many households where the average income is less than US$ 1.25 $person^{-1}$ day^{-1}.

Access to supplementary irrigation can provide opportunities for intensification on the one hand and risk mitigation on the other. Farm wheat yield is expected to increase from about 2.5 t ha^{-1} to 3.5 - 4.0 t ha^{-1} due to supplementary irrigation (Mainuddin *et al*., 2013). Considering the vast area in the coastal zone affected by salinity and perceived water scarcity, the total economic benefit could be enormous. Bangladesh consumes more than twice, as much wheat as it grows, and importing the shortfall is eroding foreign currency reserves. Bangladesh is also a big net importer of pulses and oilseeds, which has a similar impact on the foreign currency reserve. Therefore, there will be additional flow-on benefits to other sectors of the economy. Social and economic analyses could also consider the opportunity cost of any activities replaced in the *rabi* season, such as grazing of ruminants.

Increased agricultural productivity resulting from better water and salinity management will enhance the income of farming communities in the Ganges Delta, and significantly reduce the government and donor investment required for livelihood improvement.

This Special Issue on *Cropping System Intensification in the Salt-Affected Coastal Zone of the Ganges Delta* contains invited papers on (1) The coastal environment of the Ganges Delta, (2) New technologies for cropping system intensification and (3) Out-scaling and social inclusion of cropping systems intensification

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