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Climate Change and Coastal Agriculture: Impacts and Adaptation

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Climate change is a reality as evident by sea-level rise, high frequency of weather extremes, surface temperature rise and glacier melting. It impacted the vulnerable coastal agriculture both in negative and positive ways. High frequency cyclone and salinity enhancement due to climate change negatively impacted irrigated wheat, maize, sugarcane and rice along with fish-spawning and aquaculture in the coastal region of South-East Asia. However, some positive impacts on coconut and rice (at few locations) have also been recorded. Rainwater harvesting, interlinking drainage network, introduction of salt-tolerant cultivars, crop diversification and modified irrigation system are effective adaptation strategies to cope up the climate change vagaries in the coastal region. Contingent planning, real-time weather forecasting with agro-advisory and crop insurance could increase the resilience of the system. Climate-smart village with the three components, *viz*., sustainable food production, resilience and mitigation should be promoted in the vulnerable coastal region through national and international funding by interlink the line departments and NGOs.

(**Key words:** *Climate change adaptation, Coastal agriculture, Rainwater harvesting, Salt tolerant cultivars)*

Climate change impacts have been witnessed throughout the world. It is threatening world's coastal regions with a range of impacts including increased flooding, permanent inundation of low-lying coastal areas, increased erosion of beaches and cliffs, degradation of coastal wetlands and salinization (Burden *et al*., 2020; Haer *et al*., 2013; Kumar *et al*., 2011; Nicholls *et al*., 2007). Coastal areas are characterized by high concentrations of human settlements; population density is on an average three times the global mean population (McGranahan *et al*., 2007; Small and Nicholls, 2003). There are 136 major port cities hosting more than one million inhabitants each, thirteen of which are in the top 20 most populated cities in the world (Bosello and De Cian, 2014; Kebede and Nicholas, 2012). Owing to their geographical location, the coastal regions of the world are inherently under constant threats of climate change vagaries like cyclones, tidal surges, sea-level rise, frequent flood events, sudden sedimentation, water-erosion, etc. The effects of climate change are already being felt in many coastal areas. Further, the expected effects of climate change including warming of air temperatures, rising sea levels, high frequency of extreme weather events (hurricanes, tropical cyclones) would have larger impacts on coastal regions, which have low and flat terrain, high population density, low awareness of communities towards improved livelihood-technologies, and inadequate response as well as preparedness towards forecasting to combat the damaging impacts of extreme events.

The Indian subcontinent has a coastline of around 7500 km, out of which the mainland is having 5400 km, Andaman & Nicobar Islands is about 1900 km and Lakshadweep coast covers 132 km. Almost 250 million people live within a distance of 50 km from the coast. There are 14, 44 and 162 major, medium and minor rivers respectively that discharge huge amount of sediments and water to the seas and oceans (Singh, 2006). Major rivers include the Ganges, Brahmaputra, Godavari, Krishna, Mahanadi and Cauvery on the east coast and Tapti and Narmada on the west coast. The east coast supports activities such as agriculture and aquaculture while a number of industries are supported by the west coast. The Indian coastal region accounts for fragile ecosystems of estuaries, mangroves, coral reefs, seagrasses, etc. Overall, Indian coastline represents one of the most comprehensive biodiversity with about 15042 species followed by Indonesian coastline (10855 species) (Carlton *et al*., 2018; Walther *et al*., 2016). Estimates suggest that 3,959 species of flora and fauna are associated with the mangrove habitats in India alone (Hussain and Badola, 2008).

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In India, majority of the costal districts are fed by the rivers, river deltas and back-water streams. In those areas, main agricultural output comes from crop production, aquaculture and fisheries supporting livelihood. A number of crops like rice, jute, pulses, sugarcane, oilseeds, vegetables, spices and fruits are grown in those regions of India. Rice is the staple crop in the coastal region of India. In addition to rice, horticultural crops and particularly coconut plantation is predominant in coastal agriculture. Aquaculture is also a significant activity in those regions having significant economic impacts on supporting ecosystems. Further, the aquaculture is growing rapidly in the food production sector of the world with 8.6% average annual growth rate since the 1980s (FAO, 2014). India has become the second largest producer in aquaculture, globally after China and contributes to 6.3% of the world's production (FAO, 2014). In general, the number of people employed or engaged in aquaculture and fisheries has increased at a rapid rate than global population increase, and the highest employment levels are found in Asia itself (FAO, 2014). However, coastal fisheries are affected by the change in flow patterns and reduced water flows negatively affects the fish habitats and breeding patterns. The interactions between the inland and the ocean waters affect the natural shrimp breeding that usually takes place in the inland coastal waters. Overall, it could affect the habitat availability for fish and hence the fisheries-water productivity. Climate change along with agro-chemical contamination also adds to the deleterious, often lethal, effects of water pollution on fisheries at the coastal regions (Haynes and Michalek-Wagner, 2000). High sediment loads and silt deposition changes in streamflow and river-bank architecture that could also damage fish-spawning grounds and coastal habitats. Moreover, the current productivity of the farming systems including aquaculture and agriculture in coastal areas are far below the inherent potential of the region (Mandal *et al.*, 2015). This paper deals with the impacts of climate change on coastal agriculture and the adaptation strategies.

Climate change and coastal agriculture

Global mean surface temperature has increased by 0.87°C over the period from 1880 to 2016 (IPCC, 2018). More precisely, the warming of the ocean was highest near the upper 75 m surface by 0.11°C per decade over the period from 1971 to 2010 on a global scale (Kumar *et al.*, 2012; Heron *et al.*, 2016). However, the warming was generally higher over the land surface than over the ocean. The human-induced global warming reached around 1°C (±0.2°C) above the pre-industrial levels during 2017. During the same period, the acidification of the ocean has been increased by 26% and the pH of ocean water surface layer has reduced by 0.1 scales. The Arctic sea-ice reserve decreased @ 3.5 to 4.1% per decade from 1979 to 2012 and the glaciers have shrunk almost worldwide. Very importantly, the global mean sea level rose by 0.19 m during the period from 1901 to 2010. The rate of rise since the mid-19th century has been higher than the mean rate during the previous two millennia (Omondi *et al.*, 2014). An analysis of the extreme events indicates that the occurrence of very intense tropical cyclones has increased over recent decades. Moreover, hundreds of fish species have been moving towards the north to cooler water in the oceans and disrupting coastal economies.

The intensity and extent of climate change risk affect various aspects of crop production including growth, life cycle and related field management. The direct impacts are on plant physiological processes and physical damage, while indirect effects are caused by impacting the conditions and timing of field practices. For example, the above-threshold air temperatures and lower precipitation lead to drought and heat stress and it adversely affects the crop growth and development (Porter and Semenov, 2005). It may also increase the incidence of pest and diseases (Bale *et al.*, 2002). Similarly, the heavy rainfall, flooding and hail storms could lead to crop loss by physically damaging the crop canopies or via creating an anoxic soil environment that limits plant and root respiration (Kimball, 2008). Extremely wet conditions many a time put obstacles in field operations like planting, fertilizer application and harvesting. The food quality is also negatively affected by climate change issues. Crops generally respond non-linearly to alteration or changes in their growing environments and they are usually affected by the combinations of stresses that ultimately affect their performance and yield.

Effect of sea-level rise on coastal ecosystems

Global average sea-level has risen at a rate of 1-2 mm yr^{-1} since 1900 (Church *et al.*, 2004; IPCC, 2013), however, during the past 30 years, it has been changing at a rate of 30 mm yr^{-1} (Cazenave and Nerem, 2004; Church and White, 2011; Menendez and Woodworth, 2010; Woodworth and Blackman, 2004). The eleven GCMs (including, bcc-csm1-1, CanESM2, CCSM4, GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-MR, MIROC5, MPI-ESM-LR, NorESM1-M; both for mid-century and end century climate under the RCP4.5, and RCP8.5 emission scenarios were considered), projected ("medium confidence") that the global mean sea levels could increase by 44-74 cm by 2100 (IPCC, 2018). Alternative estimates based on the huge ice sheet melt suggest ("low confidence"), that sea level could even rise up to 1.9 m by 2100 (Jevrejeva *et al*., 2014). However, the above mentioned projections, primarily reflect the effect of thermal expansion of seawater only and did not consider the instability and large discharges from the Greenland or West Antarctica ice sheets that might add a further 10 to 20 cm to sea-level rise projections by the end of this century. Overall, a similar trend of sea-level rise has been noticed throughout the world (IPCC, 2018; Lewis *et al*., 2013; Woodworth *et al*., 2011). Therefore, the message is clear from the analysis that the relative mean sea-level around the world is rising, at a spatially varying rate, that would have significant consequences on estuarine systems in the coastal region in general and coastal crop production in particular (Sibanda *et al*., 2015).

Further, the climate change impacts on coastal erosion and sea flooding in densely populated and infrastructure-rich coastal regions have received a lot of attention by environmental scientists and literature on climate change issues in recent times. A significant number of population and assets are already damaged due to coastal flooding. Moreover, the sea-level rise might lead to the loss of coastal wetlands, which filter the nutrients, microbial-agents, and chemical-toxicants (McMichael *et al*., 2006). However, the direct and indirect effect of sea-level rise on the fate of microbial diversities, nutrient and chemical-agents and their interactions in the coastal ecosystem is still partly understood and needs special attention (Nicholls, 2002).

Effect of storm surges on coastal ecosystem

Most of the climate models and atmospheric observations suggested that after the second half of 20th century there has been a pole-ward shift of majority of storms in the coastal region of the world (Weisse *et al*., 2012). However, there might be a decrease in frequency and an increase in the intensity of (tropical) cyclones in the future (Paciorek *et al*., 2002; Geng and Sugi, 2003). Although the storm surges are not directly related to the changes to extratropical cyclones, higher water levels are generally driven by a rise in the mean sea-level, and indirectly affects the cyclonic paths (Woodworth *et al*., 2011; Menendez and Woodworth, 2010). The mean sea-level rise would also change the dynamics of storm surge generation and propagation (McInnes *et al*., 2003) having higher estuarine flood-risk and inundation (Nicholls, 2002) in the coastal region.

Effect of river flow on coastal ecosystem

River-flows are the resultant of integrated interaction of hydro-meteorological processes both act at catchment and command area, and river flow is an important indicator of potential impacts of climate change on estuaries and coastal ecosystem (Hannaford, 2015). Global warming has been intensifying the hydrological cycle; changing precipitation patterns and thereby affecting the river flow responses (Hannaford, 2015; Talling *et al*., 2015). Historical data showed that the annual mean rainfall has not changed since the 1960s, but winter precipitation has intensified (Burt and Ferranti, 2012; Jones *et al*., 2013; Talling *et al*., 2015). During the same period, river-flows have also increased in winter and autumn and decreased during spring (Hannaford, 2015; Hannaford and Buys, 2012; Talling *et al*., 2015). River-flows are spatially variable and dependant on catchment characteristics and intensities of precipitations (Keef *et al*., 2009). The future predictions on river-flows that took into consideration the "wetter winters and drier summers" signal (Arnell *et al*., 2003; Christierson *et al*., 2012), suggested a reduction of summer flow by 42-80% and increase in winter-flow by up to 25% (Christierson *et al*., 2012; Prudhomme *et al*., 2012). Although uncertainty exists in the amount and intensity of river flow in estuaries and coastal-delta, it is certain that there would be a shift in the season of crop-growth period in coastal regions with spatially variable-windows.

Impact of climate change on coastal agriculture

The coastal crop production/agriculture has been severely affected by climate change vagaries and continues to do so due to its inherent problem and higher vulnerability (Table. 1).

Table 1. *Impact of climate change on crop production and coastal agriculture*

Climate change consequences	Direct/ indirect effects on crop production and coastal agriculture
Sea level rise	Loss of land, coastal erosion, flooding, soil salinization
Rainfall and river flow	Coastal agriculture by impeded drainage, aquaculture damage
Storm surges	Estuarine region affect, coconut crop and aquaculture damage
Soil erosion	Soil degradation, nutrient loss, low productivity
Wetland loss and change	Low C sequestration, high GHGs emission
Frequent flooding	Estuarine soil salinity, aquaculture damage, sedimentation
High frequency drought	Moisture stress, low yield, low productivity
Cold wave	Desiccation, low yield
High temperature	Estuarine region affected, coconut crop and aquaculture damage
Heat wave	Desiccation, low yield

Problems of coastal agriculture

Crop production under the vulnerable environment in the coastal region faces multiple problems like high salinity during *rabi*, waterlogging during *kharif* and cyclonic devastation during autumn. Moreover, the natural calamities in those regions further ponder risk to farming communities and their livelihood. The higher salinity in coastal region due to presence of saline-ground water at lower depth, excessive withdrawal of groundwater (good quality) from aquifers and frequent tidal movement with the intrusion of saline-ocean water and finally the poor water and land management.

Impacts of climate change on coastal estuaries

The flood risks of coastal estuaries are primarily caused by sea-level rise and the incidence of high river flow events (Lewis *et al*., 2013; Quinn *et al*., 2014). Estuarine flooding could also be caused by the combinations/ interactions of extreme river flow and storm surge which could drastically enhance flood hazard (Maskell *et al*., 2014). Precisely, if we see that both the river-flow and sea level have been changing and going to be changed due to climate change that could potentially enhance flood risk to estuaries in coastal regions (Yang *et al*., 2015). And more so, the potential adverse impacts of estuarine flooding on the coastal ecosystem would happen if proper mitigation/ adaptation strategies are not taken into account (Nicholls *et al*., 2011). Estuaries floods could cause an increase in erosion and loss of land to sea; pollution and increased human health risk; and significant loss to wetland habitats and ecosystems (Day *et al*., 1995; Nicholls *et al*., 1999).

The projected increase in average air temperature would increase evapotranspiration in many catchments that might alter vegetation types and reduce soil moisture, all of that can reduce runoff into estuaries and potentially dampen the flood risk in the coastal region (Boorman, 2003). The uncertainty (high spatial variability) is high in the prediction of rainfall pattern even in warmer climate change scenario which affects the physical drivers of coastal regions. The hydrodynamics and mixing are equally important that is impacted by the rainfall and estuarine flow along with air temperature and rainfall. Most of the estuaries are shallow and affected by tidal behaviour (Prandle and Lane, 2015). Climate change induced sea-level rise coupled with low water flow during summer (droughts) and saline water intrusion would affect the up-estuary and could lead to more salinity in up-estuaries command area during summer or dry months. On the other hand, enhanced river flow during *kharif* (wet sown) may pollute the down estuaries with toxicants/ nutrients (Prudhomme *et al*., 2012; Sibanda *et al*., 2015).

Climate change impacts on coastal crop production

There are nine predominant climate change induced factors that limit the crop production in the coastal region (Fig. 1). Among them, high soil and water salinity are the most critical. Periodical inundation of coastal areas with saline sea/ocean water due to tidal movement, presence of narrow brackish water table, impeded drainage and shortage of good quality-irrigation water are the associated factors. Salinity affects crop production drastically (Fig. 2). Heavy cyclonic disturbance during crop maturity, prolonged monsoon, intensive high

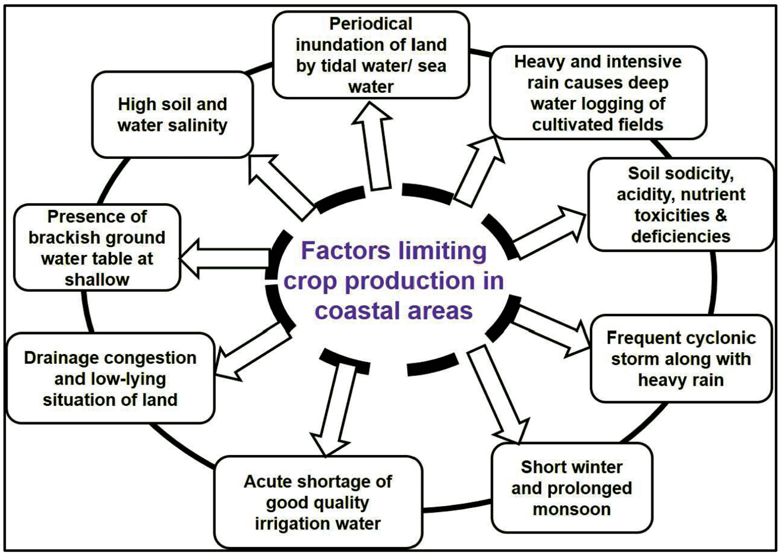

Fig. 1. *Various climate change factors impacting coastal crop production.*

Table 2. *Different input parameters required by InfoCrop model for a typical simulation*

Category of inputs	Details of required inputs
Crop/variety	Coefficients of different growth parameters
Weather	Solar radiation, maximum and minimum temperatures, wind speed, vapour pressure, rainfall, and climate change scenario (CO_2, maximum and minimum temperatures and rainfall), if applicable
Soil	Texture, water content at saturation, field capacity, wilting and air dry levels, initial soil moisture, NO_3 and NH_4 content at the start of simulation, bulk density, saturated hydraulic conductivity, organic carbon, pH by layers (3 layers are considered)
Sowing	Dates of planting, seed rate and depth of planting
Irrigation	Amount, time and depth of irrigation by soil layer
Inorganic nitrogen fertilization	Amount, time and depth of placement of different N fertilizers by soil layer
Organic matter addition	Amount, time and depth of placement of different organic matters, N (also its type) and irrigation by soil layer
Pests	Population/severity of pests and their timing of presence, if applicable

frequency rainfall and soil related problems (acidity, toxicity, sodicity, nutrient deficiency, etc.), which are aggravated due to climate change consequences can negatively impact the crop production in coastal regions. The impacts of climate change on crop production in coastal areas of some of the countries are described with specific examples below.

Impacts of climate change on crop production in coastal Australia

Sugarcane production in the coastal region of northern Australia would be negatively affected by sea-level rises and higher tidal intrusion of flood plains. Sugarcane production would also be impacted by salinity, increase in extreme rain events and high erosion-risk caused by sediment loading in the Great Barrier Reef. Specifically, the higher risk of extreme winds and intense tropical cyclonic activity is likely to increase the damage of sugarcane crop. On the contrary, in eastern Australia, a reduction in rainfall might increase sugarcane yields due to increased solar radiation. However, a decrease in rainfall might increase the pressure on available water for irrigation. Further, increased temperatures would increase the length of the growing season and subsequently, would enhance the pressure on land-use for horticultural crops. In southern Australia, increased temperature might affect the fruit quality of viticulture as the fruits would ripen earlier and at the same time shortening of the harvest period due to phenological changes would require an increased processing capacity. Moreover, decrease in rainfall would become an issue of that coastal region for irrigation. In southern Australia, an increased temperature may cause phenological shifts of horticultural crops. For example, reduced mean temperatures in the winter would affect the choice of species and variety to be grown there. However, the increase in frost occurrence might nullify the negative impact of high temperatures (Williams *et al*., 2015).

Impacts of climate change on crop production in coastal India

Impact assessment of climate change on major crops in the Western Ghats (WG) and coastal districts of India was done using the InfoCrop model. InfoCrop is a generic crop model developed to meet some specific requirements *i.e*. integrated assessment of the effects of variety, pests, soil, weather and management practices on crop yields, water, nitrogen and carbon dynamics, and greenhouse gas emissions in aerobic as well as anaerobic conditions, especially for tropical regions where the problems of food production and sustainability are more intense (Table 2).

The impacts were projected based on prevalent-climate, location, projected climate-scenarios, type of crops grown/dominant cropping systems and their management. In general, areas under rice in the east-coast and coconut in the Western Ghats are likely to increase, while areas under irrigated wheat, maize, and mustard in coastal regions, and rice, sorghum and maize in the WG might decrease. However, changes in crop management and introduction of stress-tolerant variety could offset the negative impacts of climate change (Kumar *et al*., 2011).

Another experiment conducted by Hebbar *et al*. (2008) in major cotton producing states of India from Hisar to Coimbatore during 2000-2001 and 2004-2005, respectively using InfoCrop-cotton model revealed that the total biomass and seed cotton yield prediction showed an accuracy of 86 and 89%, respectively. The prediction of cotton production was more accurate for partially irrigated or irrigated districts as compared to rainfed districts. Boomiraj *et al*. (2013) presented the results of InfoCrop model evaluation in terms of its validation and impact of climate change on Indian mustard (*Brassica juncea*), sorghum (*Sorghum vulgare*) and maize (*Zea mays*), for six different regions of India (Akola, Anantpur, Coimbatore, Gwalior, Bijapur and Kota). Simulated results of mustard model showed a spatial variation in yield among all regions in both irrigated and rainfed conditions. Kumar *et al*. (2017) simulated the impact of varying levels of maximum and minimum temperature, seasonal rainfall and CO_2 on three varieties of mustard using Info Crop model. Change in Tmax and Tmin by -1 to 1°C, rainfall by 10 to 20% and CO_2 between 415 to 490 ppm showed a beneficial impact on the crop and increased the seed yield considerably. Similarly, Kumar *et al*. (2018) conducted a field experiment on mustard and results revealed that the model emphasis on all the parameters to be within the acceptable range (10%) with significant accuracy.

Specifically, a majority of the areas in the WG is projected to lose the crop yields by 4% in 2030 scenario. The yield of *kharif*-irrigated rice, in the WG region, is projected to change by +5% to –11% while in rainfed-rice the projected change in yield would be in the range of ±35%, with a majority of the region is going to lose the rice yields up to 10% in spite of beneficial effects of CO_2 fertilization in few locations. However, the farmers in the northern part of Kerala, northwest part of Tamil Nadu, and in some parts of Karnataka could reduce the negative impacts of climate change by adopting the measures such as soil moisture conservation, providing proper drainage-network, adopting stress-tolerant cultivars and increasing water and nutrient use efficiencies. The reduction in yields of maize and sorghum could go up to 50% primarily due to spikelet sterility. However, in the WG, the yield of coconut is projected to increase by up to 30% in a majority of the regions due to climate change (due to an increase in rainfall by ~10%; plus CO_2 fertilization and relatively less increase in temperatures) (Table 3).

Overall, the west coast usually experiences high frequency rainfall-events and sea-water intrusion, while the east coast suffers from the threats of frequent cyclones, floods and heavy winds. All these along with increased atmospheric temperature, change in rainfall pattern and elevated CO_2 could cause severe damage to crop production. The irrigated rice yield is going to reduce by 10% in a majority of the coastal districts in India (Climate change in the 2030 scenario). In contrast, rainfed rice yields are projected to enhance by 15% in many districts on the east coast. Impacts of climate change on irrigated as well as rainfed maize in the coastal districts are likely to be higher than inland areas (yield loss 15-50%) (Table 3).

Impacts of climate change on agriculture in coastal Bangladesh

Coastal agriculture of Bangladesh experiences a yield reduction or in some cases devastation due to tidal inundation and salinity (Table 3). Climate change associated hazards like sea-level rise, cyclone and storm surge have been contributing to aggravate the problem. Most of these lands remain fallow in the dry (*rabi/boro*) and pre-monsoon (*aus*) seasons due to perceived high soil and water salinity and lack of good quality irrigation water (Karim *et al*., 1990).

Islam (2006) found that 1°C increase in maximum temperature at vegetative, reproductive and ripening stages caused a reduction in rice (*kharif*) production by 2.94, 53.06 and 17.28 tons, respectively. With the change in temperature (by 2°C and 4°C), the prospect of growing wheat and potato would be severely impaired. Ali (2006) reported the loss of rice production in a coastal village of Satkhira district in Bangladesh during 2003 (69% of yield loss compared to 1985) due to development of coastal salinity. He also reported that 19 of the 40 local rice varieties have become extinct, and 4–5 varieties have become rare (Ahmed, 2003). Besides rice production, salinity declines the yields of vegetables, coconuts, betel nuts, and fruit. Salinity also enhances food insecurity through the deterioration of milk productivity and reproductive health of cattle by the destruction of pasture land. In fisheries, native fish species disappear. For instance, Miah *et al*. (2004) reported that native freshwater fish species, such as *rohu, katla, boal, tengra, koi, shing,* etc., have been disappearing gradually due to increased salinity in

Table 3. *Impact of climate change on coastal crop production*

Country	Sea level rise	High temperature	Cyclone and flooding	Reference
India	1.0 m rise in sea level; Krishna-Godavari deltas affecting the cropland over 839 km^2; aquaculture over 805 km^2 and plantations over 430 km^2, along the entire AP coast.	Rise in temperature by 10°C; Reduction in yield occurred *i.e.* irrigated rice- 10%, irrigated maize -15-50%, rainfed maize-35 %; A temperature increase of 1, 2, and 3°C from present-day conditions, would reduce grain yield of wheat by 8.1%, 18.7%, and 25.7%, respectively.	Cyclone (2009, Gosaba, WB) resulted in high salinity and increased pH of soil; rice, wheat, sugarcane, chilli and pulses production were highly affected; Before cyclone, average production of *boro* rice was 3.5 t ha^{-1} in 2008-09, which was reduced to 2.1 t ha^{-1} in 2012-13.	Kumar *et al*. (2011) Sinha and Swaminathan, (1991) Debnath (2013); Rao *et al*. (2011)
Bangladesh	9.2% reduction in national production.	High temperature and salinity (20-40%) loss in rice; and 1°C rise in temperature would reduce the rice yield by 69%.	Cyclone (2007): 1.6 million acres crop land damaged; >25% winter-rice destroyed; Due to excessive rainfall and water logging 40-60% yield loss occurred in vegetables.	Gornall *et al*. (2010) Hoque and Haque (2016) Ruane *et al*. (2013)
Myanmar	Saltwater intrusion detrimentally affects the wet season crop, which accounts for 85% of the national rice production.	-	Cyclone (2008): The soil salinization affected 50,000 acres of rice cropland and made it unfit for planting.	Gornall *et al*. (2010) Wassmann *et al*. (2009)

the coastal districts of Bangladesh. Flood has the most deleterious effect on crop production on coastal Bangladesh. The 1988 flood caused a reduction in agricultural production by 45% (Karim *et al*., 1996).

A number of climate risk factors like increased temperature, frequent droughts, changes in seasonal rainfall pattern, long dry spells, increase in soil salinity and increase of tidal surges affect crop production. Mahato (2014) reported that in the context of climate change the main reasons of yield reduction (20-40% yield loss) in wet season (*aman*/ wet) crop was erratic rainfall, increased intensity and frequency of drought, salinity, floods, cyclone, use of local varieties, increased incidences of pests and diseases. On an average, the yield level of HYV-boro rice was more affected (20-40% yield loss) by high temperature and salinity during *kharif* (wet season). Vegetables, pulses and oilseed crops were also affected (40-60% yield loss) by soil wetness, excessive rainfall and water-logging in the coastal areas.

Adaptation strategies

Climate change consequences and its impact have made crop production vulnerable in coastal regions. Therefore, livelihood as well as food security in those regions is under threat (Abedin and Shaw, 2013). Therefore, climate change adaptation strategies and their effective implementation are the needs of the hour (Fig. 2).

High salinity, flood, extreme temperature, drought and cyclone are the main climatic stresses to crop cultivation in coastal regions. Many stress-tolerant varieties are now available for potential adaptation of abiotic stresses caused by climate change in the coastal region. Salinity is the main problem in coastal crop production due to frequent intrusion of tidewater in the main cropland. Lunasankhi, Luna burial are the prominent salt-tolerant rice varieties developed by Indian Council of Agricultural Research (ICAR)-National Rice Research Institute (NRRI), Cuttack for coastal saline soil. Likewise, submergence-tolerant rice varieties (Swarna Sub-1, IR-64 Sub-1) are now becoming popular in the flood-prone coastal areas in India. Multiple stress-tolerant varieties, which can withstand both flood and drought (e.g., CR Dhan 801, 802) could serve as another option for coastal rice growing farmers.

Rainwater harvesting is one of the cost-effective and eco-friendly technologies for freshwater conservation in coastal areas. Rainwater harvesting can be an effective alternative to water supply solution, not only in drought but also in salt-affected areas. Conserved freshwater in water harvesting structure (WHS) can be used for various agricultural purposes in future (irrigation, livestock and other domestic uses). Capturing rainwater also helps in recharging the aquifers; reduce flooding and overcoming the scarcity of water during summer/ dry season. For example, the "*Kattas* and *Madakas*": a traditional water conservation method, which is predominantly found in the Udupi and Dakshina Kannada districts of Karnataka and Kasaragod district of Kerala may be adopted in the coastal region. Rapid and deep tillage reduces soil salinity by breaking the capillary continuity for upward movement of saline groundwater. Therefore, mechanized tillage could be used to break the soil-capillaries so that salinity development in the dry season might be restricted in the coastal region. In slightly and moderately saline areas, cultivation of dry season rice and fresh-water-shrimp could help in reclaiming soil salinity (salts of the soil could be leached out easily in a short time). This technique is popularly known as "Lockpur model" and has been adopted by a number of farmers in Khulna-Bagerhat region in Bangladesh. In this technique of cultivation, where both rice and fish are grown together also helps in increasing the farmer's profit.

In case it becomes extremely risky to continue agricultural activities under an altered climate change scenario in the coastal region, alternative land use should be considered. Improved crop management along with site-specific land-use-change are the key adaptation-cum-mitigation strategies to climate change in coastal agriculture. Some important production technologies such as raised bed planting, mulches with drip irrigation (good quality irrigation water), introduction of high-value horticultural crops like watermelon, chilli, cucumber and tomato in salt-affected soils (4.5-11.0 dS m^{-1}; Islam, 2006) could be the options to overcome climate change consequences. In seasonally flooded areas, floating garden for vegetable cultivation is one of the suitable options. It is an inventive floating raft with a bamboo base, upon which water hyacinth is piled and then covered by other aquatic plants or coconut husk to form a seedbed ready for planting (Fig.3). This technique is universally adopted by the farmers in the coastal region. These floating gardens are known as

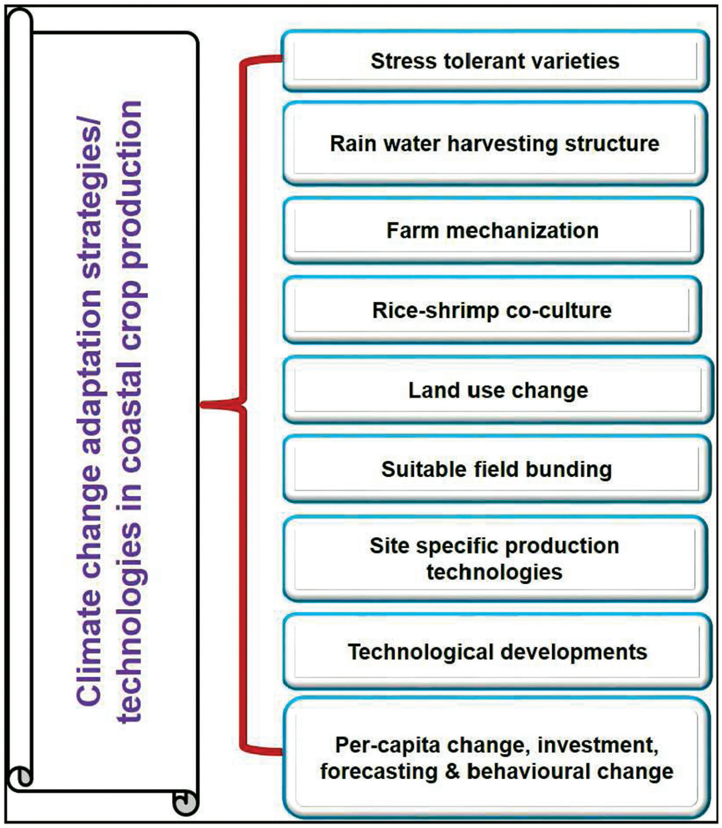

Fig. 2. *Climate change adaptation strategies/ technologies in coastal crop production*

Fig. 3. *A farmer working in a floating vegetable garden (Source: Pender, 2008)*

"*baira*", in Bangladesh. Sorjan system of cropping, rice-fish dual culture, utilization of bunds as vegetables/ spices, and floating bed agriculture with introduction of salt- and drought-tolerant varieties have been identified as potential adaptation options for the development of coastal agriculture for increased agricultural production in Bangladesh under climate change scenarios.

However, whatever adaptation strategy is adopted, it should start with and be led by the local community/ people wherever possible as they are the real experts to deal with climate change- vagaries; rather than implementing highly technical, expensive and outsider-led interventions that are often untried in field conditions. Therefore, a priority also must be given to using and modifying traditional coping mechanisms developed in the communities in the coastal region.

Climate has been changing and it affects crop production in coastal regions of the world. The coastal regions are considered as one of the most vulnerable areas in the context of climate change scenarios. Sea-level rise, river-flow, estuarine floods, tropical cyclones are the climate change consequences which affect the coastal crop production. The crop production in coastal plains of India, Bangladesh, south-east Asia, Australia and China was already impacted negatively by climate change consequences in the last 3-4 decades. Future predictions have also shown the threats of reduction in yield of irrigated maize, wheat, sugarcane and rice in those regions. Although few positive impacts of climate change have happened and also are predicted in crop production particularly rice and coconut in the coastal region, those are sporadic and not consistent. Largely coastal agriculture including aquaculture and fish-spawning are under threat. Site-specific adaptation and adaptation lead mitigation approaches must be followed to cope up with this situation. The strategies include the introduction of salt-tolerant cultivars, raised-bed plantation, micro-irrigation with good quality irrigation water in drier months, field levelling and bunding, alternative land-use-management and crop diversification are few effective options. Hence, sound forecasting and real-time crop insurance scheme along with technological intervention in coastal areas are the three pillars that should be looked into for making the coastal agriculture climate-smart.

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