Climate-Resilient Agricultural Practices in Different Agro-ecological Zones of Bangladesh

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Abstract

Bangladesh is one of the most vulnerable countries to climate change due to its unique geographical position, the dominance of floodplains, low elevation, high population density, high levels of poverty, and overwhelming dependence on nature, its resources, and services. Increasing temperatures, irregular rainfall, drought, and cyclones are adversely affecting agricultural production, in turn creating a high risk to the food security of Bangladesh's large population. Large-scale climate-resilient practices (structural and nonstructural) are being implemented in different agro-ecological zones (AEZs) of Bangladesh, which have the potential to reduce the vulnerability and risks associated with climate change and contribute to sustainable agricultural development. This chapter explores the spontaneous and planned resilient practices and their possible contribution to food security in different AEZs of Bangladesh. We systematically classify and characterize agrarian adaptation options to climate change. To this end, first, we assess the impacts of climate change on the agriculture sector in Bangladesh. In addition, we analyze the determinants of farmer's choices between alternative adaptation measures available in different AEZs. Finally, we identify the gaps in the implementation of those practices and the way forward with policy recommendations.

Keywords

Climate change · Agriculture · Agro-ecological zones · Climate resilient · Practices · Bangladesh

Introduction

Bangladesh is one of the most vulnerable countries to the impacts of climate change in the world. According to the Global Climate Risk Index (GCRI), in 2017, Bangladesh was the sixth most climate-vulnerable country in the world (Kreft et al. 2017), though during 2010 it was the most climate-vulnerable country (Harmeling 2009). The Global Climate Risk Index (GCRI) 2010, covering the period 1990–2008, estimates that, on an average, 8241 people died each year in Bangladesh, while the cost of damages was around US $ 1.2 billion per year, and loss of gross domestic product (GDP) was 1.81% during the period (Harmeling 2009). Agriculture is the most vulnerable sector of Bangladesh due to climate-induced disasters which restrict the national food security. Different agro-ecological zones (AEZ) of Bangladesh suffer from different climate-induced disasters that affect agricultural production. Farmers introduced climate-resilient practices, through a large number of agricultural innovations by their own initiative and with the financial and technical support of various government and nongovernment organizations. It appears important at this stage to understand what climate-resilient agricultural practices are anticipated, based on current climate-induced disasters and knowledge of farmers, in each of the AEZs of the country.

Agroecosystem Versus Agro-ecological Zones

Though agroecosystems and agro-ecological zones are interrelated, agroecosystems are disaggregated into smaller crop suitability space based on some geographical and climatic characteristics such as land type, soil structure, soil texture, rainfall pattern, annual quantity of rainfall, incoming solar radiation, hydrometeorological disaster type, etc. Agroecosystems are an assembly of mutually interacting organisms and their environment, in which materials related to crop production are interchanged in a largely cyclical manner. An ecosystem has physical, chemical, and biological characteristics, along with energy sources and pathways of energy and materials interchange (Banglapedia 2014a). Bangladesh contains four main types of ecosystems: coastal and marine ecosystems, inland freshwater ecosystems, terrestrial forest ecosystems, and man-made ecosystems (Daniels 2003). The AEZs of Bangladesh are determined based on physiography, hydrology, cropping pattern, season, soil types, and tidal activity. There are 30 AEZs in Bangladesh. These 30 AEZs are subdivided into 88 agro-ecological subregions, which cover the whole country (Table 1). Again, these are divided into 535 agro-ecological units (Banglapedia 2014b).

Study Area

The study was conducted in five sub-districts of four agroecosystem as well as 10 agro-ecological zones based on different agroclimatic vulnerability. Shyamnagar Upazila in the Satkhira district, Tanore Upazila in the Rajshahi district, Khaliajuri Upazila in the Netrokona district, Rangamati Sadar Upazila in the Rangamati Hill district, and Chilmari Upazila in the Kurigram district are selected as the study area (Fig. 1), which covers the Ganges Tidal Floodplain for the Shyamnagar AEZ; the High Ganges River Floodplain, the Level Barind Tract, and High Barind Tract for the Tanore AEZ; the Northern and Eastern Hills for the Rangamati Sadar AEZ; the Active Tista Floodplain, Tista Meander Floodplain, and Active Brahmaputra-Jamuna Floodplain for the Chilmari AEZ; and the Old Brahmaputra and Sylhet Basin for the Khaliajuri AEZ (Table 2).

Shyamnagar Upazila (An administrative subunit of districts locally named Upazila or Thana) in the Satkhira district is located between 21°36′ and 22°24′ N and between 89°00′ and 89°19′ E and is a coastal settlement adjacent to the Bay of Bengal and the largest mangrove forest of the Sundarbans (Banglapedia 2015a). Tanore Upazila in the Rajshahi district is located between 24°29′ and 24°43′ N and between 88°24′ and 88°38′ E and is an area highly vulnerable to drought and displays Barind zone characteristic (Banglapedia 2014c).

Table 1 Agro-ecological zones of Bangladesh. (Source: BARC 1988)

Agro-ecological zones (AEZs)	Districts covered
1. Old Himalayan Piedmont Plain	Dinajpur, Panchagarh, Thakurgaon
2. Active Tista Floodplain	Gaibandha, Kurigram, Lalmonirhat, Nilphamari, Rangpur
3. Tista Meander Floodplain	Bogra, Dinajpur, Gaibandha, Joypurhat, Kurigram, Lalmonirhat, Naogaon, Nilphamari, Panchagarh, Rangpur, Rajshahi
4. Karatoya-Bangali Floodplain	Bogra, Pabna, Sirajganj
5. Lower Atrai Basin	Bogra, Naogaon, Natore, Rajshahi, Sirajganj
6. Lower Punarbhaba Floodplain	Naogaon, Nawabganj
7. Active Brahmaputra-Jamuna Floodplain	Bogra, Chandpur, Gaibandha, Jamalpur, Kurigram, Manikganj, Pabna, Sirajganj, Tangail
8. Young Brahmaputra and Jamuna Floodplain	Dhaka, Gazipur, Jamalpur, Kishoreganj, Manikganj, Munshiganj, Mymensingh, Narayanganj, Narsingdi, Netrokona, Sherpur, Tangail
9. Old Brahmaputra Floodplain	Gazipur, Jamalpur, Kishoreganj, Mymensingh, Narayanganj, Narsingdi, Netrokona, Sherpur, Tangail
10. Active Ganges Floodplain	Chandpur, Dhaka, Faridpur, Rajbari, Kushtia, Madaripur, Manikganj, Munshiganj, Natore, Chapai Nawabganj, Pabna, Rajshahi, Shariatpur
11. High Ganges River Floodplain	Bagerhat, Chuadanga, Jessore, Jhenaidah, Khulna, Kushtia, Magura, Meherpur, Naogaon, Narail, Natore, Chapai Nawabganj, Pabna, Rajshahi, Satkhira
12. Low Ganges River Floodplain	Bagerhat, Barisal, Dhaka, Faridpur, Rajbari, Gopalganj, Jessore, Khulna, Kushtia, Madaripur, Magura, Manikganj, Munshiganj, Narail, Natore, Pabna, Pirojpur, Shariatpur, Sirajganj
13. Ganges Tidal Floodplain.	Bagerhat, Barguna, Barisal, Bhola, Jhalakati, Khulna, Madaripur, Patuakhali, Pirojpur, Satkhira, Shariatpur
14. Gopalganj-Khulna Beels	Bagerhat, Barisal, Gopalganj, Jessore, Khulna, Madaripur, Narail, Pirojpur
15. Arial Beel	Dhaka, Munshiganj
16. Middle Meghna River Floodplain	Brahmanbaria, Chandpur, Comilla, Kishoreganj, Munshiganj, Narayanganj, Narsingdi
17. Lower Meghna River Floodplain	Chandpur, Lakshmipur, Noakhali
18. Young Meghna Estuarine Floodplain	Barisal, Bhola, Chandpur, Chittagong, Feni, Lakshmipur, Noakhali, Patuakhali
19. Old Meghna Estuarine Floodplain	Barisal, Brahmanbaria, Chandpur, Comilla, Dhaka, Feni, Gopalganj, Habiganj, Kishoreganj, Lakshmipur, Madaripur, Munshiganj, Narayanganj, Noakhali, Shariatpur
20. Eastern Surma-Kushiyara Floodplain	Habiganj, Moulvibazar, Sunamganj, Sylhet
21. Sylhet Basin	Brahmanbaria, Habiganj, Kishoreganj, Netrokona, Sunamganj

(*continued*)

Table 1 (continued)

Agro-ecological zones (AEZs)	Districts covered
22. Northern and Eastern Piedmont Plain	Brahmanbaria, Comilla, Habiganj, Jamalpur, Moulvibazar, Mymensingh, Netrokona, Sherpur, Sylhet
23. Chittagong Coastal Plain	Chittagong, Cox’s Bazar, Feni
24. St Martin’s Coral Island	Cox’s Bazar
25. Level Barind Tract	Bogra, Dinajpur, Gaibandha, Joypurhat, Naogaon, Natore, Chapai Nawabganj, Rajshahi, Sirajganj
26. High Barind Tract	Naogaon, Chapai Nawabganj, Rajshahi
27. North-eastern Barind Tract	Bogra, Dinajpur, Gaibandha, Joypurhat, Rangpur
28. Madhupur Tract	Dhaka, Gazipur, Jamalpur, Kishoreganj, Mymensingh, Narayanganj, Narsingdi, Tangail
29. Northern and Eastern Hills	Bandarban, Brahmanbaria, Chittagong, Comilla, Cox’s Bazar, Feni, Habiganj, Jamalpur, Khagrachhari, Moulvibazar, Mymensingh, Netrokona, Rangamati, Sherpur, Sunamganj, Sylhet
30. Akhaura Terrace	Brahmanbaria, Habiganj

Rangamati Sadar Upazila in the Rangamati Hill district is located between 22°30′ and 22°49′ N and between 92°04′ and 92°22′ E longitudes and is occupied by hills (Banglapedia 2015b). Chilmari Upazila in the Kurigram district is located between 25°26′ and 25°40′ N and between 89°38′ and 89°48′ E and is highly vulnerable to upstream floods and riverbank erosion. The area is adjacent to the entry point of the trans-boundary river Padma (Banglapedia 2014d). Finally, Khaliajuri Upazila in the Netrokona district is located between 24°36′ and 24°50′ N and between 90°00′ and 90°16′ E and is situated in the haor basin of Bangladesh (Banglapedia 2014e).

Methodology

The chapter aimed to increase the AEZ-based climate-resilient knowledge on agricultural interventions through field data collection and accumulated data from other secondary sources. Available scientific literature related to the impact of climate-induced sudden and slow onset disaster in agriculture has been reviewed and superimposed on a selected AEZ database on a geographical information system (GIS)-based platform to identify AEZ-based climate hotspots. The chapter incorporated both qualitative and quantitative information from secondary sources reviewing available literature related to climate-resilient agricultural practices in different agro-ecological zones of Bangladesh and primary information collection through household survey (HHS), focus group discussions (FGD), key informants interviews (KII), case studies, making use of the AEZ database and exploring climate-resilient agro-based innovations through ground truthing using case studies and field observation, and consultation with different stakeholders including the Department of Agriculture, local government institutions, farmers, livestock

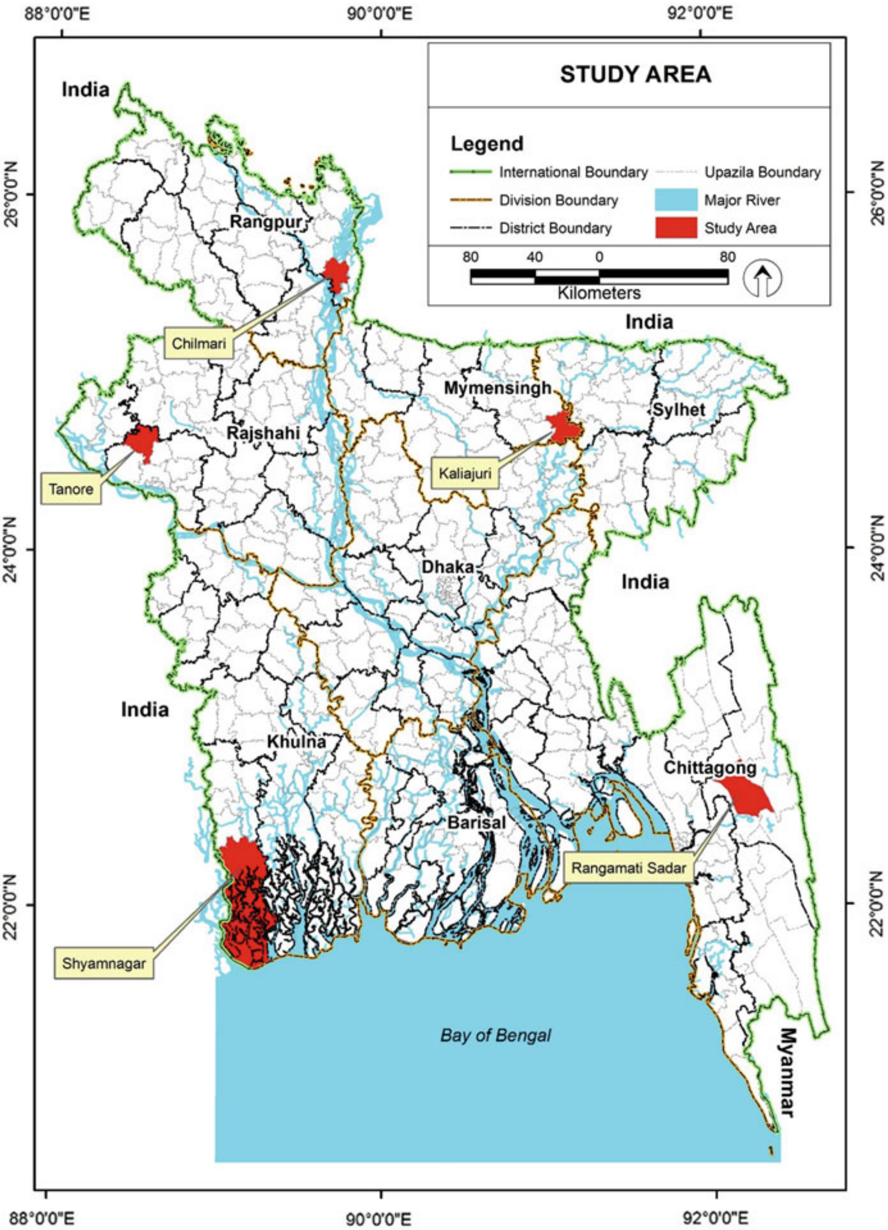

Fig. 1 Study area

department, the fisheries department, and NGOs involved in climate-resilient agricultural promotional activities in flood-, drought-, and salinity-prone areas and in hill ecosystems, as illustrated in Tables 2 and 3 and Fig. 1.

Table 2 Study area

Districts	Upazilas	Agro-ecological zones (AEZs)
Satkhira	Shyamnagar	Ganges Tidal Floodplain (13)
Rajshahi	Tanore	High Ganges River Floodplain (11), Level Barind Tract (25), and High Barind Tract (26)
Rangamati	Rangamati Sadar	Northern and Eastern Hills (29)
Kurigram	Chilmari	Active Tista Floodplain (2), Tista Meander Floodplain (3), and Active Brahmaputra-Jamuna Floodplain (7)
Netrokona	Khaliajuri	Old Brahmaputra Floodplain (9) and Sylhet Basin (21)

Table 3 Primary data collection tool and sample size for the target people

Sl.	Data collection tool	Target people	Sample size
1	HHS	Climate-vulnerable people	100 in each study area
2	FGD	Climate-vulnerable people	
3	KII	Department of Agriculture, local government institutions, Department of Livestock, Department of Fisheries, NGOs	8 in each sub-district
4	Case studies	Best practice documentation on resilient interventions related to agriculture, livestock, fisheries	3 in each sub-district

Result and Discussion

Impact of Climate Change on Agriculture

Due to climate change, precipitation patterns changed in Bangladesh, causing more intense rainfall on rainy days and more dry days in the summer season (in a year). As a result, agricultural production, the critical sector in Bangladesh, is suffering. The impacts of climate change have significantly reduced agricultural production in flood-, drought-, and salinity-prone areas. Climate-induced hazards related to agricultural damage in our study area are illustrated in Table 4.

Shyamnagar (Ganges Tidal Floodplain AEZ)

The coastal Shyamnagar Upazila AEZ, which is in the Satkhira district, is adjacent to the Bay of Bengal and the mangrove forest of the Sundarbans. Being in the nearby Bay of Bengal, the Upazila, like the other Upazilas of the Ganges Tidal Floodplain AEZ, is highly vulnerable to salinity intrusion into agricultural land (Fig. 2), cyclone, storm surge and tidal surge, the impact of

Table 4 Existing climatic hazards in the study areas. (Source: Authors)

District	Upazila	Climatic Hazards
Satkhira	Shyamnagar	Salinity intrusion, tidal surge, cyclone and storm surge
Rajshahi	Tanore	Drought, storm/hailstorm
Rangamati	Rangamati Sadar	Landslide, flash flood
Kurigram	Chilmari	Flood, riverbank erosion, storm/hailstorm
Netrokona	Khaliajuri	Flash flood, storm/hailstorm

sea level rise, drainage congestion and flooding, and storm surges and tidal inundation. Every year, about 500 ha of land are converted to saline land. In 2000, the level of salinity was about 23.93 dS/m, and in 2009 about 28.64 dS/m in the Shyamnagar Upazila (Islam et al. 2015).

Rangamati Sadar

The Rangamati Sadar Upazila is an ecologically and economically constrained area due to the prevalence of hilly ecosystem. The Upazila is characterized by climatic hazards including flash floods (Fig. 3), landslides, and medium-level droughts. Climatic hazards result in increased ecosystem fragmentation, depletion of wildlife, the decline in forest resources, and changes in the livelihood patterns of indigenous people in Rangamati (Huda 2013).

Chilmari

Floods, flash floods, and riverbank erosion are the most common climate-induced disasters for the Chilmari Upazila in the Kurigram district (Fig. 4). Climate change is contributing to a reduction of cultivable land through erosion and agricultural land loss due to the seasonal floods in the area. In the last 10 years, sandstorms and the sand wave (the storm which washes away the sand with strong wave) have been observed in the Chilmari Upazila, as related by respondents during the community consultation. Climate-induced disasters restrict the accessibility of common property resources sectors like forestry and fisheries, because of their depletion, due to cold waves, dense fog, groundwater depletion, heavy rainfall, and untimely and irregular rainfall in these areas (Rahaman 2018).

Tanore

The Tanore Upazila in the Rajshahi district, which is located in the Barind Tract region, is a highly drought-prone area (Fig. 5). The area also suffers from cold waves during winter. Farmers face frequent extreme weather events in the area, like in other areas of the High Ganges River Floodplain, Level Barind Tract, and High Barind Tract. The impacts were noticed mostly in the form of erratic rainfall and distribution patterns, changes in temperature, droughts, depletion of

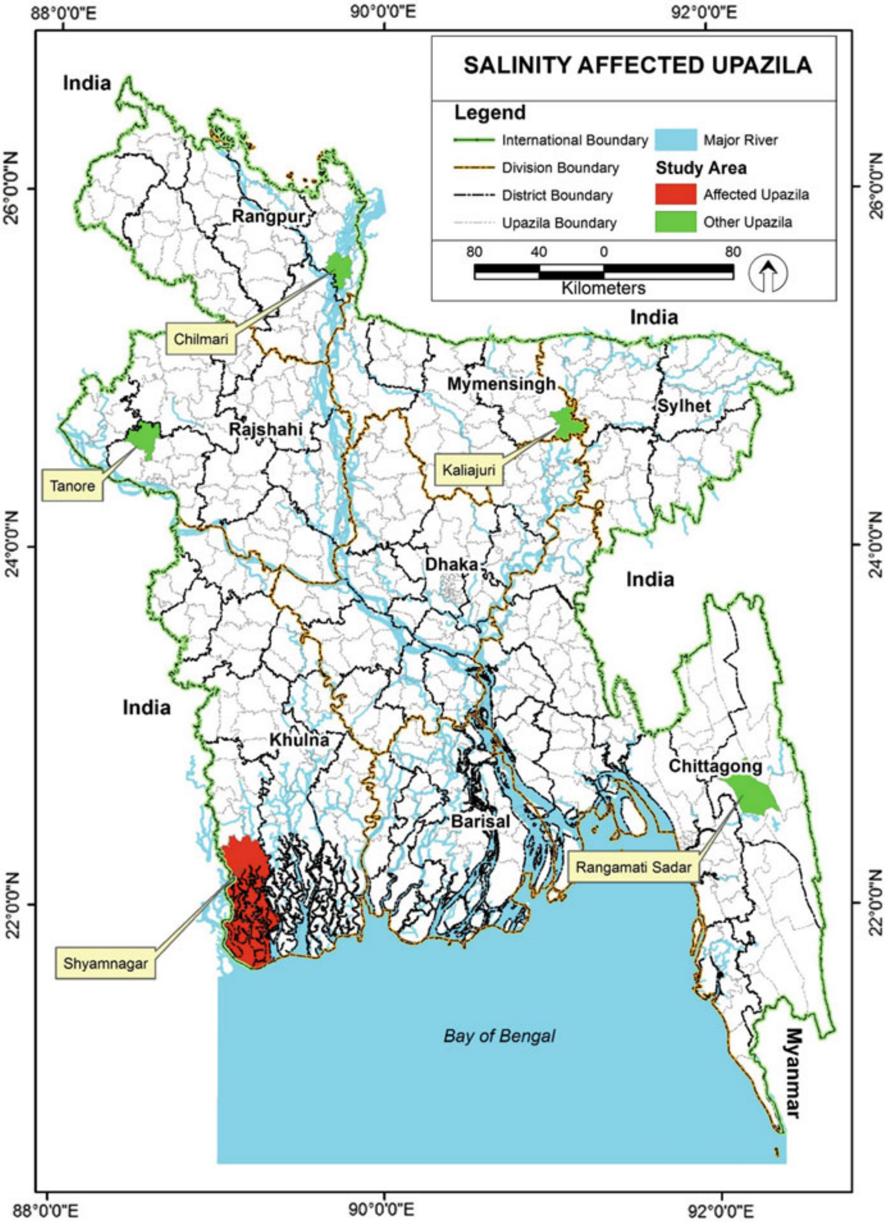

Fig. 2 Salinity affected Upazila in the overall study area

groundwater reserves, more pest and disease problems, and water scarcity. Some of these are of course only indirectly linked to climate change and variability (Nagothu et al. 2014).

Khaliajuri

Like other areas of the Old Brahmaputra and Sylhet Basin AEZs in the haor basin, flash floods (Fig. 6) are a common climate-induced disaster in Khaliajuri. Along with flash floods, the high-intensity wave action which is locally known as *afal* is an

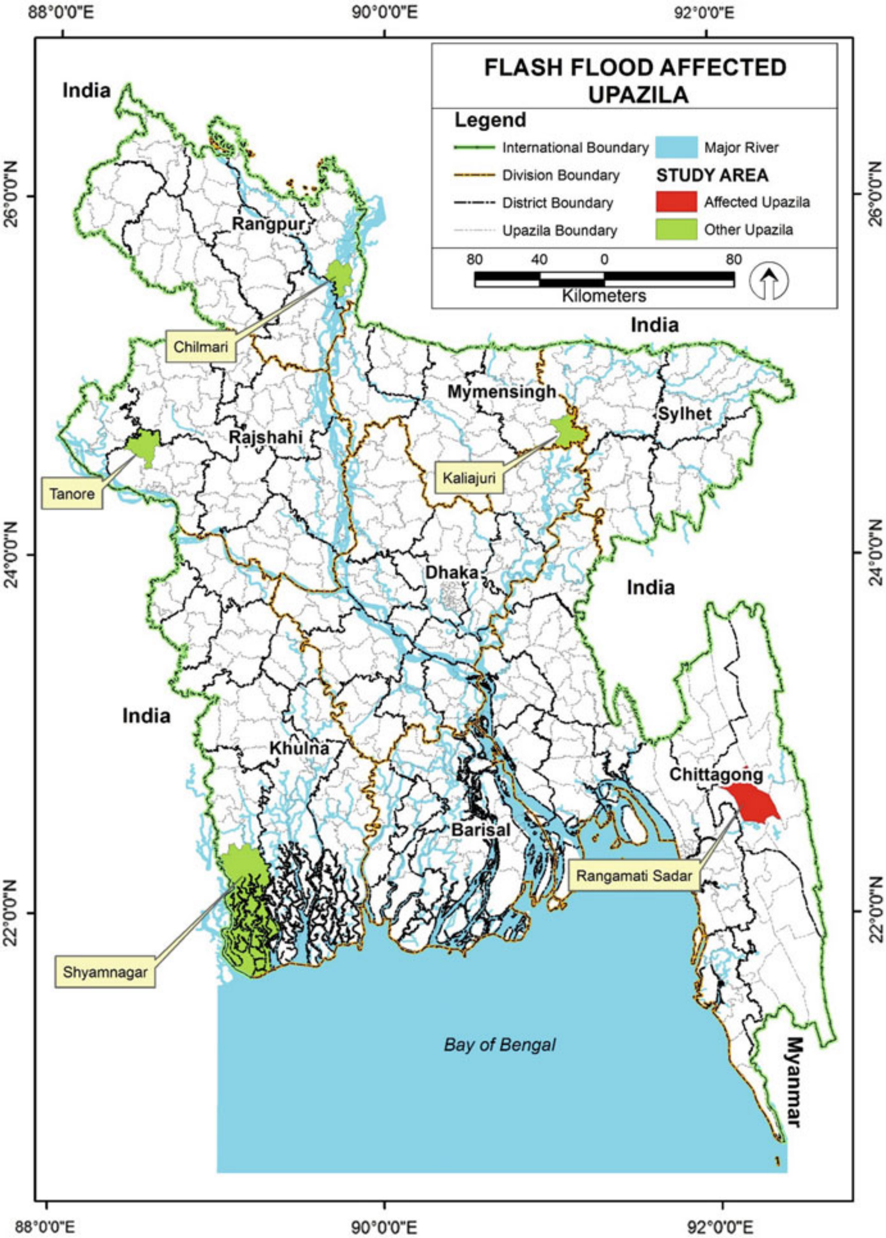

Fig. 3 Flash flood-affected Upazila in the overall study area

extreme climate-induced event in the area. During summer, water crises also hamper irrigation in the area, which restricts crop production. Each year, flash floods damage huge crop surfaces in the area.

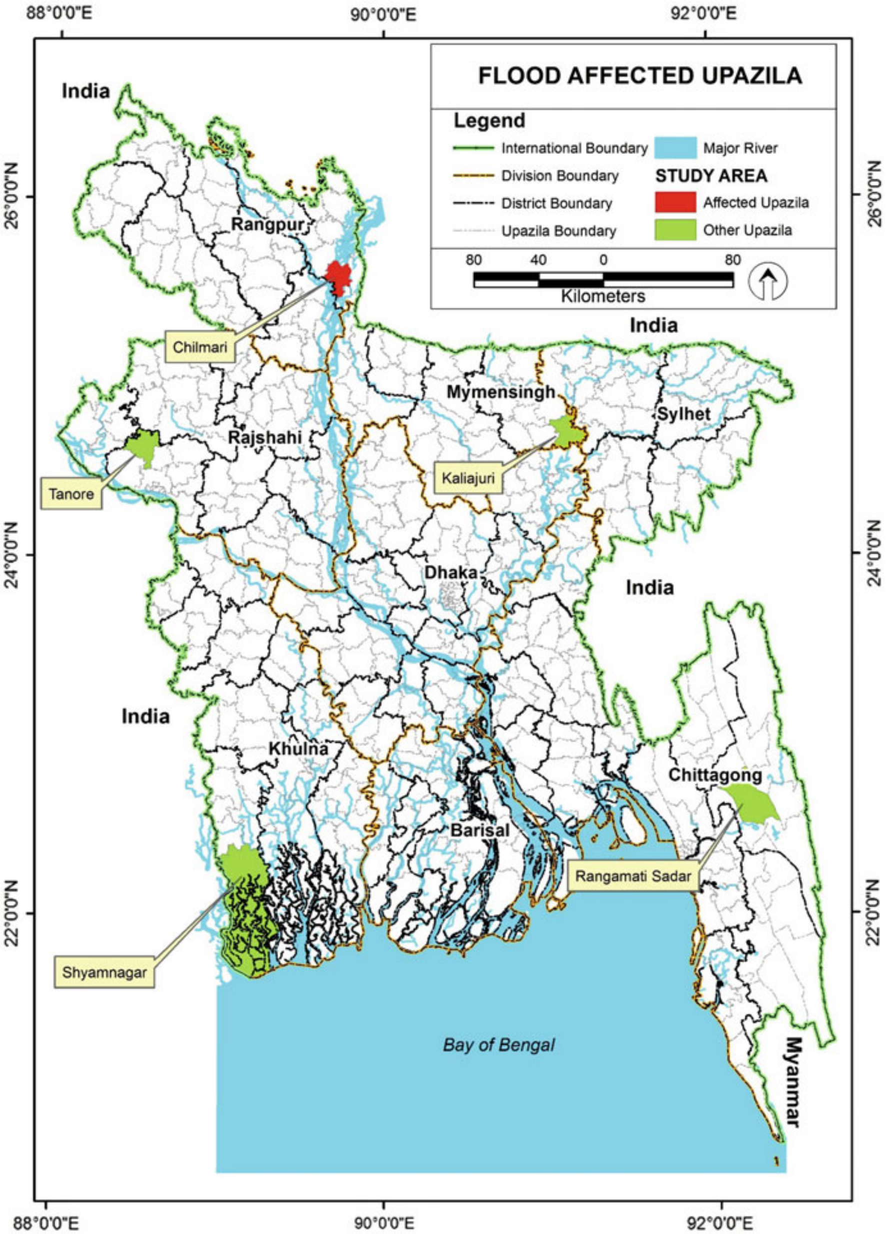

Fig. 4 Flood affected Upazila in the overall study area

Resilient Agricultural Options

Agriculture is the principal livelihood option of Bangladesh. But it is the most vulnerable to the increasing frequency and intensity of extreme events such as floods, cyclones, storm surges, hailstorms, erratic and heavy rainfall, and salinity intrusion (Mainuddin et al. 2011). Climate change and climate variability are affecting the land use patterns, crop systems, productivity, and optimum agriculture output (GOB 2009). Many forms of adaptation practices such as hard and soft adaptation are being implemented throughout the world to reduce the loss and damage from extreme climate events and climate variability (ADB 2011). Many agricultural adaptation options are being practiced in Bangladesh to adapt to climate-induced agricultural disasters like salinity, flood, waterlogging, drought, etc. To ensure climate-resilient agricultural development in Bangladesh, many structural and nonstructural soft and hard interventions are being practiced all over the country in different agro-ecological zones. Some of these innovations are devised by local communities through their indigenous knowledge, and some are planned interventions promoted by different government and nongovernment organizations. Nelson et al. (2007) and Alam et al. (2013) mention that floating bed crops/vegetables in the south-central and southern areas, plant bed raising, and dyke cropping at the shrimp *ghe*r (Water bodies which are artificially generated through raising dyke around the lowland) is an old but effective practice used nowadays.

Adaptation procedures can be autonomous, planned, or natural (Chambwera et al. 2014). Autonomous activities are those which are undertaken by private actors, prompted by climate change-induced market or welfare changes. Planned actions are those which are carried out by both private and public actors. These actions mainly include deliberate policy decisions based on the awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve the desired state (Carter et al. 1994). Natural actions appear within the ecosystem as a reaction to climate change (Chambwera et al. 2014). The agriculture sector adaptation in Bangladesh is triggered by autonomous, planned, and natural adaptation in different agro-ecological zones by the government and nongovernment sector. The following are the key resilient agricultural practices in the Ganges Tidal Floodplain, High Ganges River Floodplain, Level Barind Tract, High Barind Tract, Northern and Eastern Hills, Active Tista Floodplain, Tista Meander Floodplain, and Active Brahmaputra-Jamuna Floodplain AEZs of Bangladesh (Table 5).

Shyamnagar Upazila (Ganges Tidal Floodplain AEZ)

To cope with climate-induced disasters like salinity intrusion, tidal surges, and waterlogging and ensure resilient livelihoods, multidimensional resilient options are being implemented in the Shyamnagar Upazila. Our research indicates that, at present, 31.3% (Fig. 7) of the farmers of the Shyamnagar Upazila have adopted alternative land use practices like shrimp farming instead of crop production

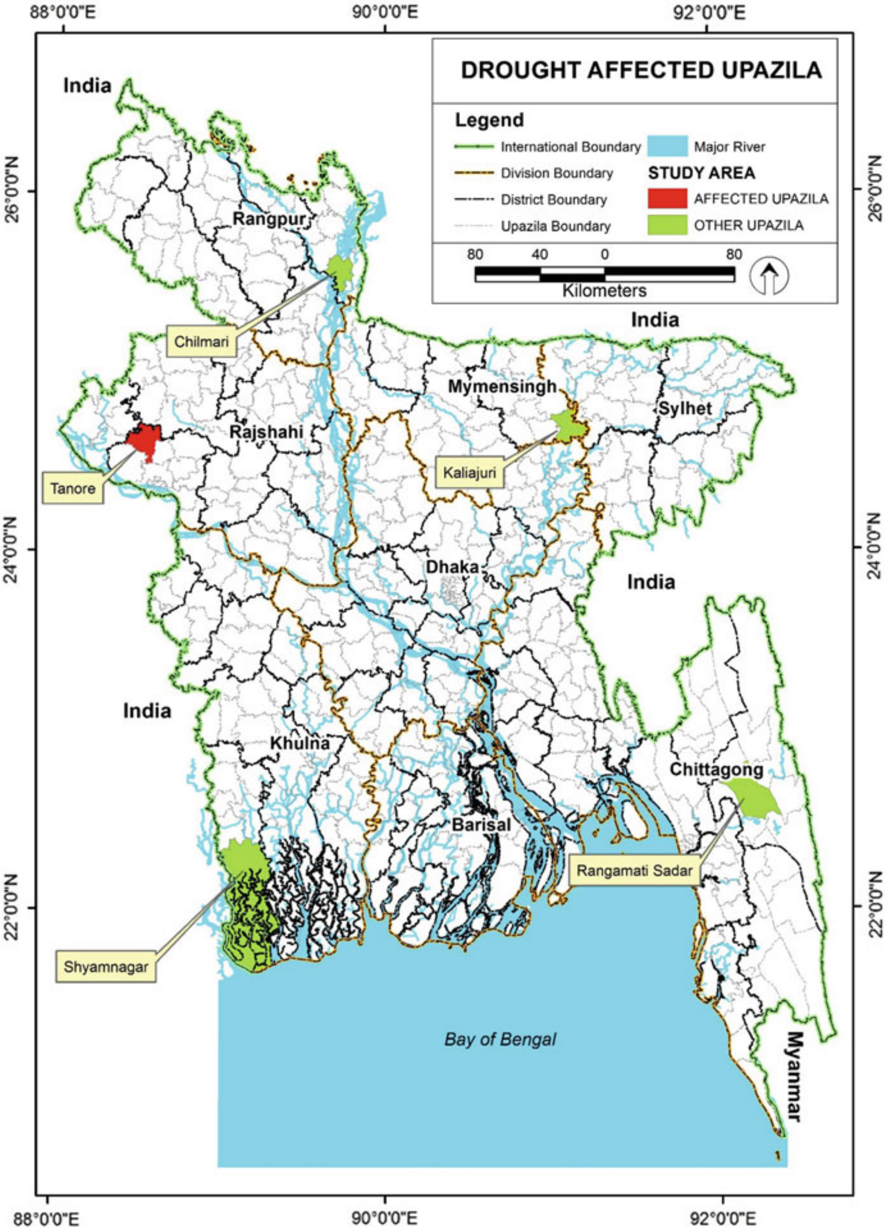

Fig. 5 Drought affected Upazila in the overall study area

(Field Survey 2017). Though the use of land for crop farming is decreasing gradually, there are some alternative options for agriculture emerging, such as embankment cropping, plantation of mangrove trees, cultivation of saline-tolerant grass,

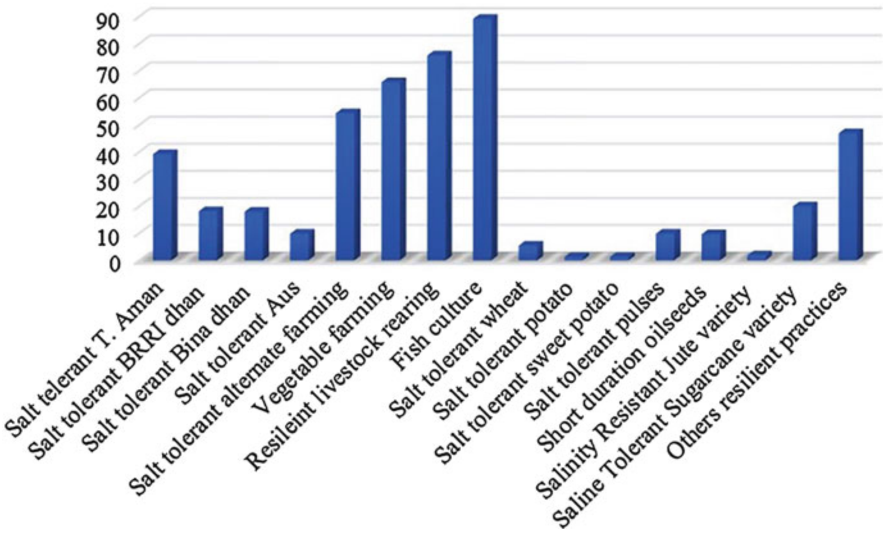

Fig. 6 Climate-resilient agro-based practices in Shyamnagar Upazila. (Source: Field Survey 2017)

using flood- and saline-tolerant rice, etc. The major climate-resilient agro-based practices of the Ganges Tidal Floodplain AEZ are illustrated in Table 6.

Farmers of the Shyamnagar Upazila under the Ganges Tidal Floodplain AEZ have introduced a number of climate-resilient practices in different agro-based farming, like the introduction of salinity-tolerant rice varieties such as T. Aman: BR-22 and BR-23; Bina shail flash flood; BRRI dhan 33, 56, 57, and 62; Bina dhan 7 and 16; BRRI dhan 47, 61, 67; Bina dhan-8 and 10; T. Aman: BRRI dhan 40, 41, 53, 54; and Aus: BRRI dhan 65; T. Aman: BR-22 and BR-23; cage fishing, mele (reed) cultivation, floating dhap (The practice of growing vegetable saplings on water bed, locally known as “dhap”) cultivation, shifting planting time, short-duration rice varieties, integrated farming, crab patenting, semi-scavenger housing for goat, duck, and hen rearing, net fishing, dyke farming, salt-tolerant wheat like Bijoy, BARI Gom-25, BAU-1059 line; salt-tolerant potato: BARI Alo-22 CIP Clone −88.163; salt-tolerant sweet potato: BARI Mishti Alo-8,9, salt- and heat-tolerant pulses: BARI Mug-2,3,4,5,6, BM-01, BM-08 BARI Falon-1, BARI Sola-9; short-duration and salt-tolerant oilseeds: BARI Sharisha-14,15; BARI Chinabadam-9, BINA China badam-1, BINA China badam-2, BARI Soyabean-6 BARI Til-2,3,4; salt-resistant jute varieties by Bangladesh Jute Research Institute (BJRI): (i) HC-2, (ii) HC 95, (iii) CVL 1; salt-tolerant sugarcane varieties by Bangladesh Sugarcane Research Institute (BSRI): (i) ISWARDI-40 (Table 5).

Figure 6 illustrates that 39.2% of farmers use salt-tolerant T. Aman varieties BR-22, BR 23, BR 22, and Bina shail; 18.1% of farmers use salt-tolerant BRRI dhan varieties BRRI 33, BRRI 56, BRRI 57, BRRI 62, BRRI 40, BRRI 41, BRRI 53, and BRRI 54; 17.9% of farmers use salt-tolerant BINA dhan varieties BINA 7, BINA 16, BINA 8, and BINA 10; and only 9.8% of farmers use the salt-tolerant Aus variety

Table 5 Climate-resilient agricultural practices in different AEZs. (Source: Authors)

Agro-ecological zones (AEZs)	Study area	Climate stress	Adaptation options
Ganges Tidal Floodplain (13)	Shyamnagar	Salinity intrusion, tidal surge, cyclone, and storm surge	Shifting planting time, short-duration rice varieties, increasing the height of the mud wall, using flood-tolerant rice varieties, floating bed agriculture, improved flood warning system and communication, T. Aman: BR-22 and BR-23 (rice varieties developed by the Bangladesh Rice Research Institute (BRRI)); Bina shail flash flood, BRRI dhan 33, 56, 57, and 62 (rice varieties developed by the Bangladesh Rice Research Institute (BRRI)); Bina dhan 7 and 16 (rice varieties developed by Bangladesh Institute of Nuclear Agriculture (BINA))
High Ganges River Floodplain (11) Level Barind Tract (25) High Barind Tract (26)	Tanore	Drought, storm/ hailstorm	Short-duration rice varieties, surface water-based irrigation, shifting planting time, drought-tolerant rice varieties, rainwater harvesting, (wheat) BRRI dhan 56, 57, and 66
Northern and Eastern Hills (29)	Rangamati Sadar	Landslide, flash flood	Replantation, early crop harvesting, short-duration varieties, shifting planting time
Active Tista Floodplain (2) Tista Meander Floodplain (3) Active Brahmaputra-Jamuna Floodplain (7)	Chilmari	Flood, riverbank erosion, storm/ hailstorm	Rice-prawn/shrimp farming, cultivating saline-tolerant varieties, rainwater harvesting, desalinization, Boro, BRRI dhan 47, 61, 67 and Bina dhan-8 and 10; T. Aman, BRRI dhan 40, 41, 53, 54; and Aus, BRRI dhan 65, (wheat) Bijoy, BARI Gom-25, BAU-1059 line
Old Brahmaputra Floodplain (9) Sylhet Basin (21)	Khaliajuri	Flash flood, storm/ hailstorm	Excavating the canals of surrounding fields, digging drains, excess water is withdrawn by pump from the field, BRRI dhan 51 and 52, Bina dhan-11 and 12

BRRI 65. On the other hand, 54.3% of farmers practice alternate cropping including mele (reed) cultivation and salt-tolerant grass farming in the study area (Fig. 6). Salt-tolerant grass (fodder) farming is increasing day by day, as found during the community consultation. Resilient livestock farming, including semi-scavenger housing for livestock (hen, duck, sheep, and goat), is practiced by 75.6% of households to protect the livestock from climate-induced salinity and flood-oriented

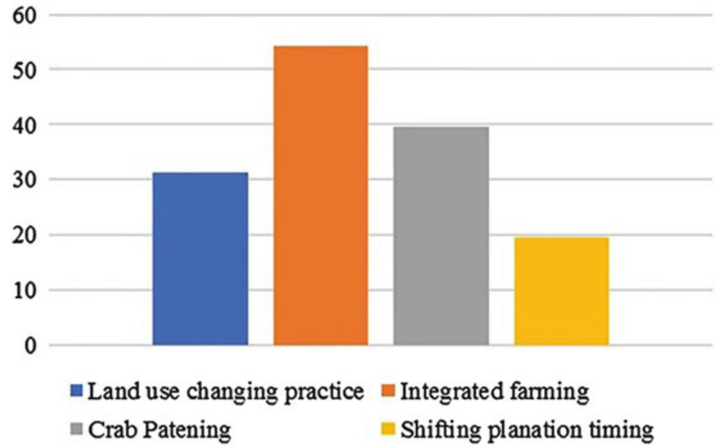

Fig. 7 Alternate climate-resilient practices in Shyamnagar Upazila. (Source: Field Survey 2017)

Table 6 Agro-based resilient practices in Ganges Tidal Floodplain AEZ (Shyamnagar). (Source: Authors)

Resilient sector	Options
Salt-tolerant T. Aman	BR-22 and BR-23, Bina shail
Salt-tolerant BRRI dhan	33, 56, 57, and 62 BRRI dhan 40, 41, 53, 54
Salt-tolerant Bina dhan	7 and 16 Bina dhan-8 and 10
Salt-tolerant Aus	BRRI dhan 65
Salt-tolerant alternate farming	Mele (reed) cultivation, salt-tolerant grass farming
Vegetable farming	Floating dhap cultivation, dyke farming, homestead farming
Resilient livestock rearing	Semi-scavenger housing for goat, semi-scavenger housing for duck, semi-scavenger housing for hen, semi-scavenger housing for sheep
Fish culture	Net fishing, cage fishing
Salt-tolerant wheat	Bijoy, BARI Gom-25, BAU-1059
Salt-tolerant potato	BARI Alo-22, CIP Clone -88,163
Salt-tolerant sweet potato	BARI Mishti Alo-8,9
Salt-tolerant pulses	BARI Mug- 2,3,4,5,6, BM-01, BM-08 BARI Falon- 1, BARI Sola-9
Short-duration oilseeds	BARI Sharisha-14,15 BARI Chinabadam –9, BINA China badam-1, BINA China badam-2, BARI Soyabean-6 BARI Til-2,3,4
Salinity-resistant jute variety	HC-2, HC 95, CVL 1
Saline-tolerant sugarcane variety	ISWARDI-40
Others resilient practices	Land use changing practice, integrated farming, crab patenting, shifting plantation timing

diseases. Fish culture is the common practice of coastal Bangladesh, but due to sea level rise, tidal inundation, storm surges, and flood, this practice is being restricted for the recent time (Field Survey 2017). Most of the farmers stopped fish culture in open pond, and now 89.1% of farmers are practicing net fish in their *gher* to protect shrimp and other fishes from flood and tidal inundation and some of the homestead level cage fishing; crab farming is observed in the study area which is being practiced by almost 89% of farmers (Fig. 6).

Vegetable farming is restricted by high salinity, waterlogging, and flood in the study area. But in the last 20 years, through the initiative of government and nongovernment organizations, some climate-resilient practices like homestead farming, dyke farming, *gher/dhap* farming, or integrated farming have been introduced in the study area, and 65.7% of farmers are practicing such farming for their household needs (Fig. 6). Commercial vegetable farming is not possible in the study area, as found from the community survey. Salt-tolerant wheat, jute, sugarcane, oilseed, pulse, etc. cultivation are practiced at a small scale.

Land use changing practice, integrated farming, crab patenting, and shifting plantation timing are introduced as climate-resilient practices in the study area. 31.3% of crop producers are farming shrimp instead of crop in their paddy fields, and some farmers changed crop calendar following seasonal crop suitability in the study area (Fig. 7).

Tanore Upazila (High Ganges River Floodplain, Level Barind Tract, and High Barind Tract AEZ)

Tanore (in the High Ganges River Floodplain, Level Barind Tract, and High Barind Tract AEZ) is vulnerable to drought, groundwater depletion, and hailstorms. Drought and groundwater depletion were the most damaging disasters for agricultural crop production, according to respondents during community consultations. The farmers of Tanore Upazila under the High Ganges River Floodplain, Level Barind Tract, and High Barind Tract AEZ are involved in climate-resilient agricultural practices like short-duration rice varieties, surface water-based irrigation, solar irrigation, rainwater harvesting for irrigation, canal re-excavation, shifting planting time, and use of drought-tolerant rice varieties like BRRI dhan 56, 57, and 66, short duration: BRRI dhan 33, 56, 57, and 62; Bina dhan 7, 16, and 66, and drought-tolerant wheat varieties like BARI Gom-26; salt- and heat-tolerant pulses: BARI Mug-2,3,4,5,6, BM-01, BM-08, BARI Falon-1, BARI Sola-9 oilseeds (Table 7). A small portion of farmers introduced conservation farming and mulching as experimental farming practices.

Field consultations revealed that 21.3% of farmers are practicing short-duration rice varieties of BRRI dhan 33, 56, 57, and 62 and Bina dhan 7, 16, and 66 and that 49.9% of farmers are practicing drought-tolerant rice varieties BRRI dhan 56, 57, and 66 as climate-resilient practices in the study area (Fig. 8). Although being a drought-prone area, wheat is a suitable crop for the area, and 11.6% of farmers are cultivating drought-tolerant wheat varieties like BARI Gom-26 in the area. Groundwater depletion is the major crisis in the drought-prone Tanore as well as the High Ganges River Floodplain,

Table 7 Agro-based resilient practices in High Ganges River Floodplain, Level Barind Tract, and High Barind Tract AEZs of Tanore Upazila. (Source: Authors)

Resilient sector	Options
Short-duration rice varieties	BRRI dhan 33, 56, 57, 62; Bina dhan 7, 16, 66
Drought-tolerant rice varieties	BRRI dhan 56,57, 66
Drought-tolerant wheat farming	BARI Gom-26
Heat-tolerant pulses	BARI Mug- 2,3,4,5,6, BM-01, BM-08 BARI Falon-1, BARI Sola-9
Other resilient practices	Conservation farming, mulching, shifting planting time

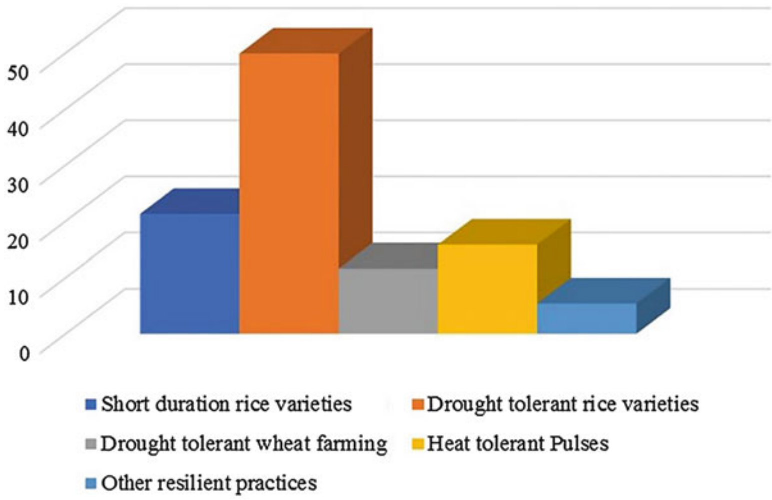

Fig. 8 Climate-resilient agro-based practices in Tanore Upazila. (Source: Field Survey 2017)

Level Barind Tract, and High Barind Tract AEZ, and inhabitants of the study area are managing water for irrigation and domestic purposes through surface water-based irrigation (17%), solar irrigation (14%), rainwater harvesting for irrigation (6%), and canal re-excavation (9%), and the intensity of water management options are shown in Fig. 9 (Field Survey 2017). A very small number of farmers are using conservation farming, mulching, and shifting planting time to adapt to drought in the study area.

Rangamati Sadar Upazila (Northern and Eastern Hills AEZ)

Hill ecosystems are not suitable for farming. Previously, Jhum was the only crop production option for the hill people. But due to climate change, Jhum farming is restricted. In recent times, through the initiatives of government and nongovernment organizations, the hill farmers have started practicing climate-

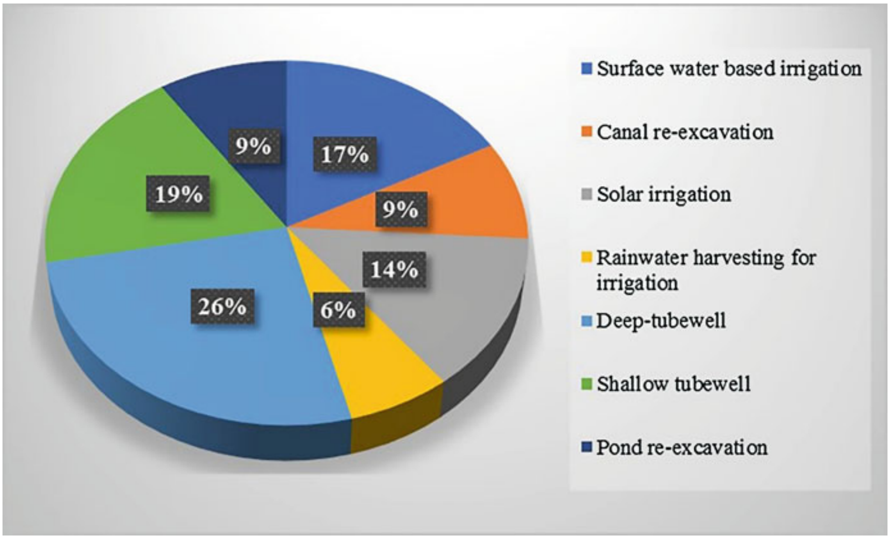

Fig. 9 Drought-resilient water management options in Tanore Upazila. (Source: Field Survey 2017

resilient zero tillage farming, terrace farming, rainwater harvesting for irrigation, replantation, early crop harvesting, short-duration varieties, and shifting planting time.

Figure 10 shows that zero tillage farming is the most practiced climate-resilient agricultural system in Rangamati Sadar as well as Northern and Eastern Hills AEZ. It is practiced by 54.9% of the total farmers in the study area. Terrace farming is practiced by 39.2% of farmers to adapt to landslide and flash flood in the hill areas. During summer, not only irrigation water but also drinking water crises affect the hill dwellers, and the farmers harvest rainwater for agricultural irrigation; 40.5% of farmers introduced the water system as climate-resilient irrigation system (Fig. 10). Short-duration crop varieties are adopted by 23.4% of the farmers to harvest early in the rainy season. Crop calendars changes as well as shifting planting time are practiced by 37.3% of total farmers. Mulching is the most prominent water conservation agricultural technology, and 28.6% of farmers are using it as a water conservation technique as well as a climate-resilient farming practice in hill tracts areas (Fig. 10).

Chilmari Upazila (Active Tista Floodplain, Tista Meander Floodplain, and Active Brahmaputra-Jamuna Floodplain AEZ)

Chilmari is affected by flash floods, regular floods, and riverbank erosion. Access to agriculture and natural resources including forestry and fisheries are restricted in the area. The farmers are implementing some climate-resilient practices. Flash flood- and submergence-tolerant rice varieties such as BRRI dhan 51 and 52; Bina dhan-11

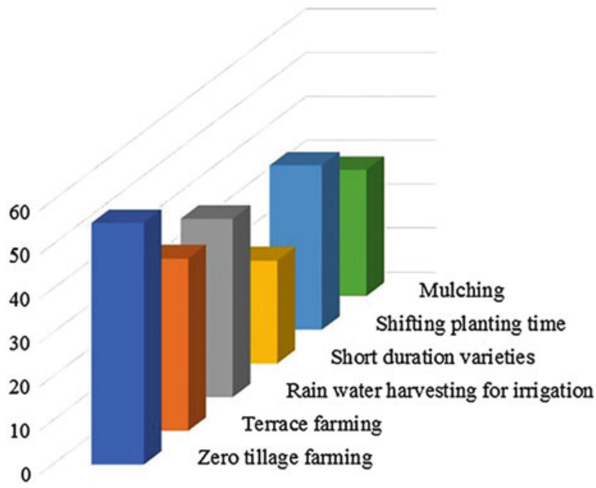

Fig. 10 Climate-resilient agro-based practices in Rangamati Sadar Upazila. (Source: Field Survey 2017)

and 12, T. Aman BR-22 and BR-23, Bina shail flash flood, BRRI dhan 33, 56, 57, and 62, Bina dhan 7 and 16, BRRI dhan 47, 61, and 67; Bina dhan-8 and 10, T. Aman BRRI dhan 40, 41, 53, and 54, Aus BRRI dhan 65, T. Aman BR-22 and BR-23; floating dhap cultivation, shifting planting time, semi-scavenger housing for goat, duck, and hen rearing, net fishing, dyke farming, embankment cropping, roadside plantation, agroforestry, homestead farming, *SORJAN*, dyke farming, etc., are the most innovative climate-resilient practices in these AEZs.

Figure 11 illustrates that homestead farming is the most widely used resilient agro-based practice in the study area of the Active Tista Floodplain, Tista Meander Floodplain, and Active Brahmaputra-Jamuna Floodplain AEZ; it is practiced by 72.4% of households of the Chilmari Upazila to meet their household vegetable demand around the year, especially in the rainy season when floods hit the area. The most used resilient agro-based interventions are using flash flood- and submergence-tolerant rice varieties, including BRRI 51, BRRI 52, BRRI 33, BRRI 56, BRRI 57, BRRI 62, BRRI 40, BRRI 41, BRRI 53, BRRI 54, BRRI 47, BRRI 61, BRRI 67, BINA 11, BINA 12, BINA 7, BINA 16, BINA 8, BINA 10, BR 22, BR 23, Aus BRRI 65, and T. Aman BR 22 and BR-23, which are being used by 47.1% of farmers of the study area (Fig. 11). Agroforestry is another popular and widely practiced climate-resilient intervention in the study area, being practiced by 39.4% of farmers for fuelwood, fruits, and timber (Fig. 11). 24.6% of households also practice roadside plantation as climate-resilient intervention; 11.8% are involved in embankment cropping; 11.4% are practicing plantation time shifting as well as crop calendar changes to harvest early crops before the floods (Fig. 11). 32.6% of households are involved in semi-scavenger housing for goat, semi scavenger housing for duck, and semi-scavenger housing for hen rearing as climate-resilient practice for livestock rearing in the study area (Fig. 11). Net fishing is found as climate-resilient fish culture at the household level as the resilient fish culture which is being practiced by only 5% of households in their pond (Fig. 11). Fish culture is hardly an intervention

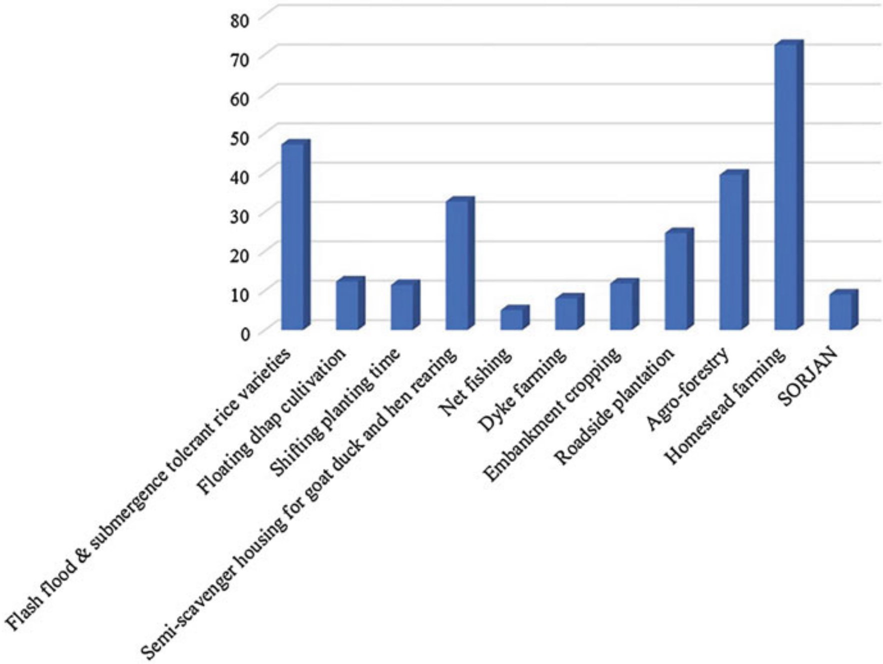

Fig. 11 Climate-resilient agro-based practices in Chilmari Upazila. (Source: Field Survey 2017)

in the study area because during the rainy season, all the waterbodies become submerged and on the other hand, during winter and summer, the area suffers from water deficit. During the field study in 2017, it was found that dyke farming and *SORJAN* farming, as a climate-resilient vegetable, are being practiced by 8% and 9% of households in the study area, respectively (Fig. 11).

Khaliajuri (Old Brahmaputra Floodplain and Sylhet Basin AEZ)

The area is flash flood prone. In response, the farmers of of Khaliajuri Upazila under the Old Brahmaputra Floodplain and Sylhet Basin AEZ have introduced excavation of the canals of surrounding field, *SORJAN*, submersible dykes, digging drains, withdrawal of excess water from the fields by pump, BRRI dhan 51 and 52; Bina dhan-11 and 12, submersion-tolerant rice varieties BRRI dhan 51 and 52, Bina dhan-11 and 12, T. Aman BR-22 and BR-23; Bina shail flash flood, BRRI dhan 33, 56, 57, and 62, Bina dhan 7 and 16, BRRI dhan 47, 61, and 67, Bina dhan-8 and 10, T. Aman BRRI dhan 40, 41, 53, and 54, Aus BRRI dhan 65, T. Aman BR-22 and BR-23, floating dhap cultivation, shifting planting time, semi-scavenger housing for goat, duck, and hen rearing, net fishing, dyke farming, embankment cropping, roadside plantation, agroforestry, and homestead farming as climate-resilient

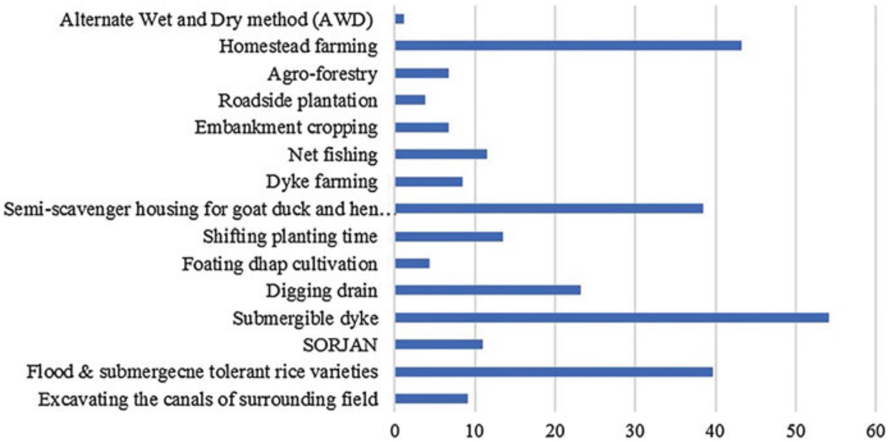

Fig. 12 Climate-resilient agro-based practices in Khaliajuri Upazila. (Source: Field Survey 2017)

agricultural practices. The alternate wet and dry (AWD) method toward conserving irrigation water is introduced as an experimental irrigation technology for the water-stricken summer season, in order to provide adequate water to irrigate all the Boro lands in haors, in the absence of reliable and economically exploitable groundwater aquifer systems.

The AWD is a newly tested climate-resilient water management option in the Khaliajuri haor area, which at present is used by only 1.2% of farmers to cultivate rabi crops during winter when the haor becomes dry (Fig. 12). In this area, the submersible dyke is the most widely used resilient intervention for the farmers to mitigate floods during the rainy season. Submersible dykes support multi-dimensional services for the haor dwellers in cropping and communication during summer and rainy season. It was found that 44.1% of farmers depend on submersible dykes for farming (Fig. 12). Homestead farming is a common practice, which has become a major climate-resilient farming practice for the haor people where 43.2% of households are involved in homestead farming in order to restore rural agro-based economy and cope with climatic stress in terms of vegetable supply and food security (Fig. 12) (Field Survey, 2017). Rice cultivation is difficult and somewhat restricted in the study area due to regular flash floods, regular floods, and submergence. The people of the study area use flood- and submergence-tolerant rice varieties. 39.6% of farmers in Khaliajuri Upazila are practicing this with the varieties BRRI dhan 51 and 52; Bina dhan-11 and 12, BRRI dhan 51 and 52; Bina dhan-11 and 12, T. Aman BR-22 and BR-23; Bina shail; BRRI dhan 33, 56, 57, and 62; Bina dhan 7 and 16, BRRI dhan 47, 61, and 67; Bina dhan-8 and 10, T. Aman BRRI dhan 40, 41, 53, and 54, Aus BRRI dhan 65, and T. Aman BR-22 and BR-23. Semi-scavenger housing for hen, duck, and goat rearing is another climate-resilient household level intervention found in the study area, which is being practiced by 38.4% of households. 23.2% of farmers dig drains around the agricultural land during the rainy season to drain flooded water, which is also a flood mitigation intervention for the paddy farmers. *SORJAN* (11% of farmers), floating dhap cultivation (4.3% of farmers), and dyke farming (8.4% of farmers) are climate-resilient vegetable farming practices in the area. A small number of households are involved in net fishing and climate-resilient fish cultures, in order to meet the households' needs; only 11.5% of households use this practice in the study area (Fig. 12). Agroforestry, embankment cropping, and homestead farming are other climate-resilient farming practices used by 6.7%, 3.8%, and 43.2% of farmers, respectively. During the field survey, 13.5% of farmers were found to change crop calendars in order to cope with early flash floods (Fig. 12).

Reshaping Policy to Promote Climate-Resilient Agriculture in Bangladesh

According to the official data from the Soil Resource Development Institute (SRDI) (Rahman and Hasan 2013), in 2010, crop agriculture land covered 9.5 million hectares in Bangladesh, though the Bangladesh Bureau of Statistics (BBS 2016) estimated that 8.52 million hectares were under crop in 2010–2011 and the Department of Agricultural Extension (DAE) stated in the Krishi (agriculture) Diary (DAE 2011) that the crop area is about 9.1 million hectares. Moreover, due to population growth, the share of land per capita is shrinking every year, which is threatening the land resource base for agriculture, forest, and wetlands. For example, in 1983–1984 (BBS 1985), there were 21,442 thousand acres of total cultivable crop area, which dropped to 19,133 thousand acres in 1994–1995 (BBS 1997). On average, Bangladesh is losing nearly 82,000 ha of arable land each year. This is mainly due to the conversion of land into urban, peri-urban, industrial uses. Agriculture is also responsible for some conversions (e.g., Chakaria Sundarbans of Cox's Bazar district and its adjacent areas). Agricultural land has decreased to 12,742,274 ha with the loss of 23,391 ha in 2000, and again with the loss of 56,537 ha in 2010, it reached 12,176,904 ha (Rahaman 2016). The annual loss of agricultural land during the study period (1976–2010) was 33,140 ha. The availability of agricultural land was in a decreasing trend, with much higher rates during the period from 2000 to 2010 (Rahaman 2016). Agriculture accounts for 20% of Bangladesh's gross domestic product and employs 65% of the country's labor force. However, more than 50% of Bangladesh's arable land has been affected by saltwater intrusion, submergence, or drought (IFC 2011). Bangladesh urgently needs support in developing a climate-resilient agriculture if its people are to survive and prosper in the long term. Climate change is affecting the country in many ways. For instance, rising sea levels are causing some agricultural land in coastal areas to become more saline, reducing both the quality and quantity of the products available. The impact of climate change on agriculture is undeniable and will most certainly worsen if climate-resilient farming practices are not adopted. In southern districts, where land is only centimeters higher than the brackish estuarine water, large swathes of agricultural land are becoming arid. Crop yields are shrinking because of increased salinity due to rising water levels in the Bay of Bengal. In coastal areas, coconut and betel nut trees do not yield half of what they did two decades ago, while banana groves are dying out in their hundreds. At the same time, vegetables sold in the urban markets of Dhaka, Khulna, and Rajshahi are deemed tasteless and fetch low prices compared to produce from salt-free regions. In a country where almost 80% of the population lives in rural areas (Hossain 2001), this is bad news. Bangladesh needs support for climate-resilient agriculture. Support for sustainable climate-resilient agriculture is the key trigger to enabling farmers to increase food security and adapt. In order to address this, farmers must raise their vegetable beds, maintain the soil's moisture by covering the seed-beds (and the manure around plants) with straw and leaves to prevent excessive evaporation and erosion, increase the amount of organic material in the soil, and modify cropping patterns.

The National Agriculture Policy was finalized in 2013, and it has also taken cognizance of the Environment Policy of 1992, Forest Policy of 1994, Fisheries Policy of 1998, Agricultural Land Use Policy of 2001, National Jute Policy of 2002, Livestock Resources Policy and Action Plan 2005, National Livestock Development Policy of 2007, National Food Policy of 2008, and National Poultry Development Policy of 2008. One of the stated objectives of the Policy is to make Bangladesh's agriculture sustainable and climate resilient such as to deal with climate change-related threats. It has put an emphasis on research, extension services, technology transfers, and information in order to make this happen. But there are no specific action plans based on agro-ecological zones.

Although the National Food Policy Plan of Action (2008–2015) has recognized the threats of climate change and emphasized the development of long- and short-term forecasts or the development of climate change-related early warning system (EWS) to deal with risks to food production, the policy does not reflect agro-ecological zone-based climate-resilient action plans, research, and strategies. From this point of view, reshaping agricultural policies and strategies in climate-smart agriculture in Bangladesh is urgently needed.

Conclusion

Bangladesh is one of the most climate-vulnerable countries in the world due to the combination of frequent natural disasters, high population density, and low resilience to economic shocks. Bangladesh has a primarily agrarian economy. Agriculture is the single largest producing sector of the economy since it makes up nearly 30% of the country's GDP and employs around 60% of the total labor power. The operation of this sector has a significant impact on major macroeconomic objectives like job creation, poverty mitigation, human resources development, and food security (Chowdhury and Chowdhury 2011). However, the agriculture sector is largely impacted by the adverse impact of climate change-related extreme events including cyclone, flooding, drought, salinity intrusion, etc. As a result, the food security of the people, especially the people living in the climate change hotspots, is in a precarious condition. Despite all these climatic stressors, people are trying to cope with the adverse situation, both through their traditional knowledge of agrarian adaptation and through newly emerged technologies in the agricultural sector. These adaptation options vary with geographic location, extent and type of climatic impacts, etc. The people of Bangladesh are using those practices since they are well-known adaptation options for those climate-induced disasters and extreme events. They are trying their level best to build their resilience in combating climate change impacts in the agricultural domain. These efforts need to be more organized and developed, based on improved technologies existing in the world. The government should consider recognizing the local and indigenous agrarian adaptation practices in its relevant policies and should move forward with new strategies for better implementation of those adaptation techniques.

Cross-References

► Assessment of Information on Successful Climate-Smart Agricultural Practices/ Innovations in Tanzania
► Drought-Tolerant Crops in Kirinyaga County, Kenya: Climate-Smart Agriculture Adaptation Strategies
► Effect of Mulching on Soil Temperature and Moisture for Potato Production in Agro-ecological Zones of Central Highlands of Kenya
► Local Knowledge of Climate Change Among Arable Farmers in Selected Locations in Southwestern Nigeria

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