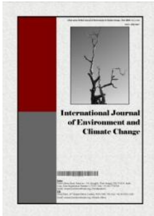

International Journal of Environment and Climate Change

10(2): 53-69, 2020; Article no.IJECC.54845
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Climate Change Impact on Agriculture and Related Sustainable Land Management Practices in Bangladesh – A Review

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Authors' contributions

This work was carried out in collaboration among all authors. The conception or design of this review article was initiated by authors MAH and MNAS. Author MAH conducted the literature searches and written the initial manuscript. Authors MNAS and MNA further drafted the manuscript and substantively revised and edited the manuscript before final submission. Author JS contributed in literature search, editing and proofreading the manuscript. All authors approved the submitted version.

Article Information

DOI: 10.9734/IJECC/2020/v10i230181
Editor(s):
(1) Dr. Anthony R. Lupo, University of Missouri, Columbia, USA.
Reviewers:
(1) Agu Eensaar, Tallinn University of Applied Sciences, Estonia.
(2) Ionac Nicoleta, University of Bucharest, Romania.
Complete Peer review History: http://www.sdiarticle4.com/review-history/54845

Review Article

Received 16 December 2019
Accepted 24 February 2020
Published 04 March 2020

ABSTRACT

Sustainable land management (SLM) is an effective climate adaptation technique in the present world. Bangladesh is listed in long-term Climate Risk Index 2019 due to its unicorn geographic features (e.g. low-lying riparian lands, big rivers, dense population and coastal settings). The livelihoods of Bangladesh are directly or indirectly linked to agricultural practices and or agribusiness. Many studies revealed that climate change-induced natural calamities (e.g. rainfall and temperature variability, sea level rise, flood, cyclone, drought, groundwater depletion, salt intrusion) unfavorably effect on agricultural production and livelihood activities and these are making critical food insecurity situation. Thus, identification and implementation of SLM practices to maintain food security of the bursting population are a prerequisite in Bangladesh. In this study, we have compiled the prospective SLM practices based on land management objective, land user

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requirements, crop and land suitability by reviewing peer-reviewed articles and grey literature. The potential SLM identified includes land resource conservation, erosion control, tillage technology, soil fertility management, vegetation management, efficient groundwater use, salinity-drought adaptations, land zoning and site-specific climate-smart agriculture. Among these SLM practices, the cultivation of suitable crop based on land quality and resource availability requires knowledge of decision support components involving the stakeholders for meaningful implementation of SLM. We proposed conceptual decision support components (e.g. land user, land quality, crop suitability, site-specific management, capital and governance) that would be the basis for the development and implementation of SLM towards land users and or farmers. The motivation of farmers through efficient extension activity and agri-governance for optimized land management can lead to minimizing the climate-induced vulnerability in agriculture. We concluded that the identified SLM practices, if implemented by adequate decision supports, SLM will help to achieve agricultural production as required by the sustainable Millennium Development Goals in Bangladesh.

Keywords: Land management; climate change; decision support; agriculture; food security.

1. INTRODUCTION

Bangladesh is perceived worldwide as a standout amongst the most defenseless nations to the effects of a worldwide temperature and rainfall alteration and climate change [1-5]. This is because of its unique geographic position, extensive floodplains and lower elevation from the ocean, high population density, persistence of poverty, sole reliance on natural resources (land, vegetation, water, biodiversity, etc.) and related services. The elevation of Bangladesh lies between 20 to 900 meters above the ocean level. A large portion of the land area is beneath 10 meters and in the middle of 10 and 20 meters of the sea level. Despite the weather and climatic vulnerabilities, this country continues to grow in agricultural sectors.

Bangladesh declared near self-sufficiency in rice production (self-sufficiency ratio 1.09) [6]. Maintaining this cereal-based agricultural production would be a challenge because of the high population growth rate (1.37) [7], key agricultural resource constraints and climate change effects [8]. Food production in contemporary years was able to achieve the target of national demands; still, national production was augmented by importing rice, wheat and other crops due to unexpected crop damage by uncertain climatic events. Moreover, the pressures on agricultural land management in Bangladesh are: the faster decline in arable lands, small landholdings, land degradation, shrinking groundwater in the northern areas, scanty choice of crops during fallow periods in the south and salinity affected areas, cropping in southern regions during winter, effects of sea-level rise and rise of cropping intensity [9,10]. In reality, the faster growth of the population is increasing the pressure for higher demands for food production despite climate change vulnerabilities. Agricultural lands, mostly in the highland area, are declining because of the settlements, urbanization, and industrialization, but the average production per hectare land targeted to be increased from 2.8 tons to 4 tons within 2030 for ensuring food security [11]. Minimization of the existing yield gap between potential and actual farm yield; higher production of other cereals (maize and wheat) and potato would play a significant role in maintaining food security in the future [12]. The current progression of agriculture demands for resource use efficiency, sustainability and further expectations of higher total production. Agricultural progress is evident throughout the country from the last few decades, mediated by high yielding and modern varieties, application of fertilizers, irrigation, pest and disease control by farmers and extension activities [10]. Although sustainability issues are not properly addressed in the farming systems of Bangladesh. Agriculture itself contributes approximately 12% of the gross domestic product (GDP) and employs 44% workforce of the country [13]. The contribution of agricultural sectors can still be higher than the present contribution to GDP if sustainable land management (SLM) and alternative livelihood strategy are adopted [14] with changing climatic scenarios.

Agricultural system of Bangladesh is being affected and or altered by land resource degradation (low level of soil organic matter, soil fertility decline, salt intrusion, soil acidification, etc.), rainfall variability, extended drier periods, scarcity of irrigation water, extreme climatic events (e.g. floods, cyclone, unexpected heavy rainfall, hail storm etc.) and farmer choice towards particular cash crop(s) or cropping system [15-20]. These challenges are unfolding at different intensities throughout the country, whereas the country itself is already known for vulnerability to climate change due to its geographic location [21-24]. Farmers are variably adopting different land management practices to overcome these constraints of agricultural productivity. Therefore, to maintain agricultural productivity, efficient and sustainable production system along with optimized land system innovation is essential. The first and foremost step to make regional and national plans, and ensuring logical and profitable use of agricultural land, then to identify the most productive areas for different crops. The cultivation of certain crops (irrigated rice, wheat, maize, potato, mustard, pulses, tea etc.) in area(s) based on soil type, favorable weather, farming knowledge of farmers and their improved socio-economic condition would be the result of SLM and higher yields [25-28]. SLM is a land resource utilization approach, which involves land, water, livestock, crops and land users, to meet the agricultural production needs of the human and guaranteeing the long-haul profitable capability of these assets and the support of their ecological capacities. The association between land assets, atmosphere and human activities [29] controls the profitability and manageability of lands. Particularly even with environmental change and fluctuation, choosing the correct land should utilize given biophysical and financial conditions. The execution of SLM is fundamental for limiting land deterioration, restoring debased land and guaranteeing the reasonable utilization of land assets (e.g. soil, water, vegetation and biodiversity).

Climate change problems perceive to have its antagonistic effect on the total food production in Bangladesh [30,31,32]. Farming in the country often faces difficulties at various intensities due to climate change. For example, Bangladesh produces rice, i.e., dry winter season rice and monsoon rice; typically, the dry season rice is irrigation dependent but in some areas of Bangladesh cultivation of monsoon rice also requiring irrigation due to less rainfall or precipitation before/after growing period(s). The rice production cost shows a sharp rise due to the dependence of farmers on irrigation and agrochemicals. In addition, the infestation of new pest and disease also had been reported for some crops (such as the emergence of wheat blast) in Bangladesh [33]. The extraction of groundwater for irrigation also increased in the north of the country [34] due to lack of seasonal rainfall and moisture during cultivation, whereas salinity is rising in the south of the country due to flooding and irrigation [35]. All these events are interrelated with agricultural productivity and sustainability. In such situations, weather and climatic vulnerabilities are hypothesized to harm the agricultural productivity and food security progress of Bangladesh. Hence, this article attempted to review climate change impacts on agriculture and consequently discussed the need and options of SLM for Bangladesh with the necessary decision support components. In the first part of the article, we discussed the detrimental climate change variables that effect on agricultural production, which are likely to be augmented from rainfall and temperature variations, rise of sea level, drought, floods, cyclone etc. Consequently, we identified set of potential SLM practices and proposed various necessary decision support components for the development and implementation of SLM with land users and farmers.

2. METHODOLOGY

This study was done by reviewing peer-reviewed scientific journals, gray literatures and related reports, including information from different reliable websites, government documents (e.g. government documents from agricultural departments and Bangladesh Bureau of Statistics) and international reports (e.g. World Bank Report, World Food Summit, Germanwatch, Food and Agriculture Organization, United Nations). The keywords that were used for this review include temperature and rainfall, climate change, agriculture, production, food security, degradation, vulnerability, adaptation and mitigation, management and sustainability. The principal target of information was related to the consequence of climate change on crop agriculture and potential sustainable land management (SLM) practices. Information that are necessary as components for an intended decision support system and its development, transfer and adaptation of SLM are also identified. Information was further synthesized to examine the need for SLM and to identify potential SLM options in the changing climate situations of the country. In the first part of the result, we discussed the detrimental climate change effects on the agricultural production, which are likely to be augmented from rainfall and temperature variations, sea level rise, drought, floods, cyclone, etc. Consequently, we identified a set of potential SLM practices and proposed various decision support components for the development and implementation of SLM with the land users.

3. RESULTS AND DISCUSSION

3.1 Temperature and Rainfall Variability and Potential Impacts on Crop Agriculture

Bangladesh got a mild winter between the November to March and a sweltering, hotter summer between April to October months. The yearly normal temperature ranges from 22.4 and 26.4ºC. The most sizzling daytime temperature happens from April to May, particularly in Rajshahi region where the normal day temperature is around 35ºC or even more. The mean temperature is around 29ºC in the monsoon season (June to September) and the diurnal range is much lower at around 6ºC, with awkwardly warm and damp evenings. Long-term average monthly temperature and rainfall of Bangladesh for the periods 1991 to 2015 is presented in Fig. 1. In the midst of both the warm season (March to May) and the cool season (December to February), there have been far-reaching warming over Bangladesh since 1960. There was a reduction in the number of cool nights over the era 1970-2000 and an extension in the number of warm nights over the period. Complete rainfall over Bangladesh has increased slightly since 1960 but rainfall during the crop growing seasons, whether to remain short or excess affecting crop agriculture. However, rainfall variability and changes in wet and dry periods have been reported by Shahid [19]. Rahman and Lateh [36] conducted a spatial-temporal analysis of 34 meteorological station data of Bangladesh in 40 years (1971-2010) of time. They concluded that recent climate change in Bangladesh expected to cause 0.2ºC of mean temperature rise in each decade. While in case of rainfall, they reported upward annual trend of rainfall (+7.13 mm each year) but downward pre-monsoon (-0.75 mm each year) and post-monsoon rainfall (-0.55 mm each year) during the years 1971 to 2010. The variability of pre-monsoon and post-monsoon rainfall (44.84-85.25%) was found erratic and certainly, it will affect negatively on crop agriculture because pre-monsoon rain is important for land preparation of rainfed paddy cultivation. Likewise, post-monsoon rain and its reasonable intensity are important for moisture of winter crops. Besides, heavy rains can lead to flooding and logging of water that likewise prompts crop misfortune. Amin, et al. [37] saw that 1mm increment in precipitation at growth stages, reproductive and aging stages diminished monsoon rice production by 0.036, 0.230 and 0.292 ton separately. Then again, the excess or shortage of water is the points of confinement of crop agriculture. In 2016, arable lands for irrigation in Bangladesh was 5,500 thousand hectares (ha). Arable lands for irrigation with time expanded from 686 thousand ha in 1967 to 5,500 thousand ha in 2016 developing at a mean yearly rate of 5.01% [38]. Similarly, favorable temperature is another significant factor to consider in crop agriculture. Islam, et al. [39] revealed that 1ºC increment in the most extreme temperature at growth stage, reproductive and maturing stages, there was a decline in monsoon rice production by 2.94, 53.06 and 17.28 tons separately. The temperature alteration (by 2ºC and 4ºC) would seriously weaken the chance of producing wheat and potato. Misfortune in crop agriculture likely to exceed 60% of the feasible returns [40]. The effects of global warming, for example, loss in agricultural productivity, sea level rise, will impact on the GDP progress in future. For instance, [41] revealed that impacts of global warming (3ºC) on Bangladesh GDP (% change/year) can be −0. 854 (2027) and −2. 491 (2047), which would be −7. 591 in the long run.

3.2 Impact of Sea Level Rise on Crop Agriculture and Productivity

The Intergovernmental Panel on Climate Change (IPCC) figures that a worldwide temperature alteration will result in ocean level rise in Bangladesh somewhere in the range of 0.18 and 0.79 meters by the most recent decade of the 21st century [42]. A global assessment of sea level rise and coastal inundation indicated range of future coastal hazards between the years 2030 and 2060 and emphasized on adaptive management for resilient coastal communities [43]. However, the rise of sea level influences agricultural crops by the increase of salt-affected area and flooding of more arable lands due to expanding cyclones and typhoon occurrences. Consolidated impacts of these phenomenon decline farming returns in the coastal front zone. Salinity intrusion because of the rise of sea level will diminish farming profitability by scarcity of fresh water and arable lands. Ali [44] explored the loss of rice production in the Satkhira region of Bangladesh, rice production in 2003 was reported to be 1,151 metric tonnes lower than in 1985, with a production loss of 69%. The total production decrease was augmented as 77% shift of paddy field to shrimp lake and 23% was due to yield misfortune. Ascension of the ocean level causes flooding of more agricultural fields, which demonstrates that there will be more damage to agricultural returns in the future. Around one-third of Bangladesh or 49,000 square kilometers regions are expected to be impacted by the tides in the Bay of Bengal. The seaside inundation areas will obviously be extended by the rise of sea level in the future with an unfavorable impact on various agricultural crops. Butzengeiger and Horstmann [45] reported that normal waves of floods likely to rely on to increase from current 7.4 meters to 9.1 meters if the ocean level rises to 1 meter. Salinity-influenced areas of the coastal front have been accounted for expanding from 0.83 million ha in 1990 to 1.05 ha in 2009. Soil salinity boundary has been expanded into more areas of the coastal zone and beyond since the years between 1973 to 2009 [35] (Fig. 2). Karim and Iqbal [46] reported that in eastern Bangladesh alone would have lost 14,000 tonnes of grain production by 2030 and 252,000 tonnes by 2075. The OECD referred to a study evaluating a decline in GDP from 1 m sea level by 28% to 57% [47]. As more area under arable lands were found to be affected by salinity between 1973 to 2009, it is likely that crop agriculture and related productivity will be affected by the scarcity of fresh water and rise of salinity levels.

3.3 Impact of Floods and Cyclone on Crop Agriculture

Flood is one of the most damaging events for the crop production in Bangladesh, e.g. 45% agricultural production damaged by the flood in the year 1988 [48]. Monsoon rice transplantation was postponed by prolonged flooding, leading to an important loss of prospective monsoon production during the flooding of 1998. In recent years, the loss of irrigated rice due to flash floods has become a frequent and persistent occurrence in the low land areas and haor basin areas (i.e. a haor basin area is marshy wetland and frequently waterlogged ecosystem in Bangladesh's northeastern region) [49]. In fact, flash flood due to heavy rain and water from upstream not only cause damage of dry season rice, but also standing crop damage occurs during pre-monsoon and monsoon seasons in Bangladesh. This certainly affects negatively in the total agricultural production in Bangladesh due to various intensities of flash floods by drainage congestion and heavy rains from April to May and September to November and monsoonal river flooding from June to September and coastal floods in the southern regions of the country. If flooding depth is higher than normal, it can damage substantially paddy fields during the monsoon season. Thus, targeted production of rice may not be possible to achieve every year. Fig. 3 shows the flooding depth of Bangladesh, it is evident from that considerable arable areas can be flooded under 0.30 to 0.91 M in Bangladesh.

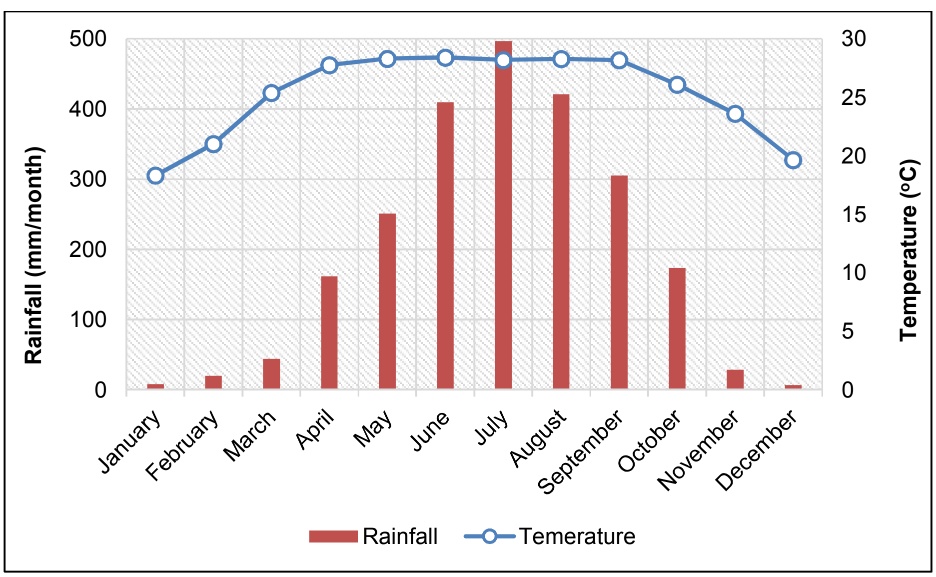

Fig. 1. Average monthly temperature and rainfall in Bangladesh (1991-2015)

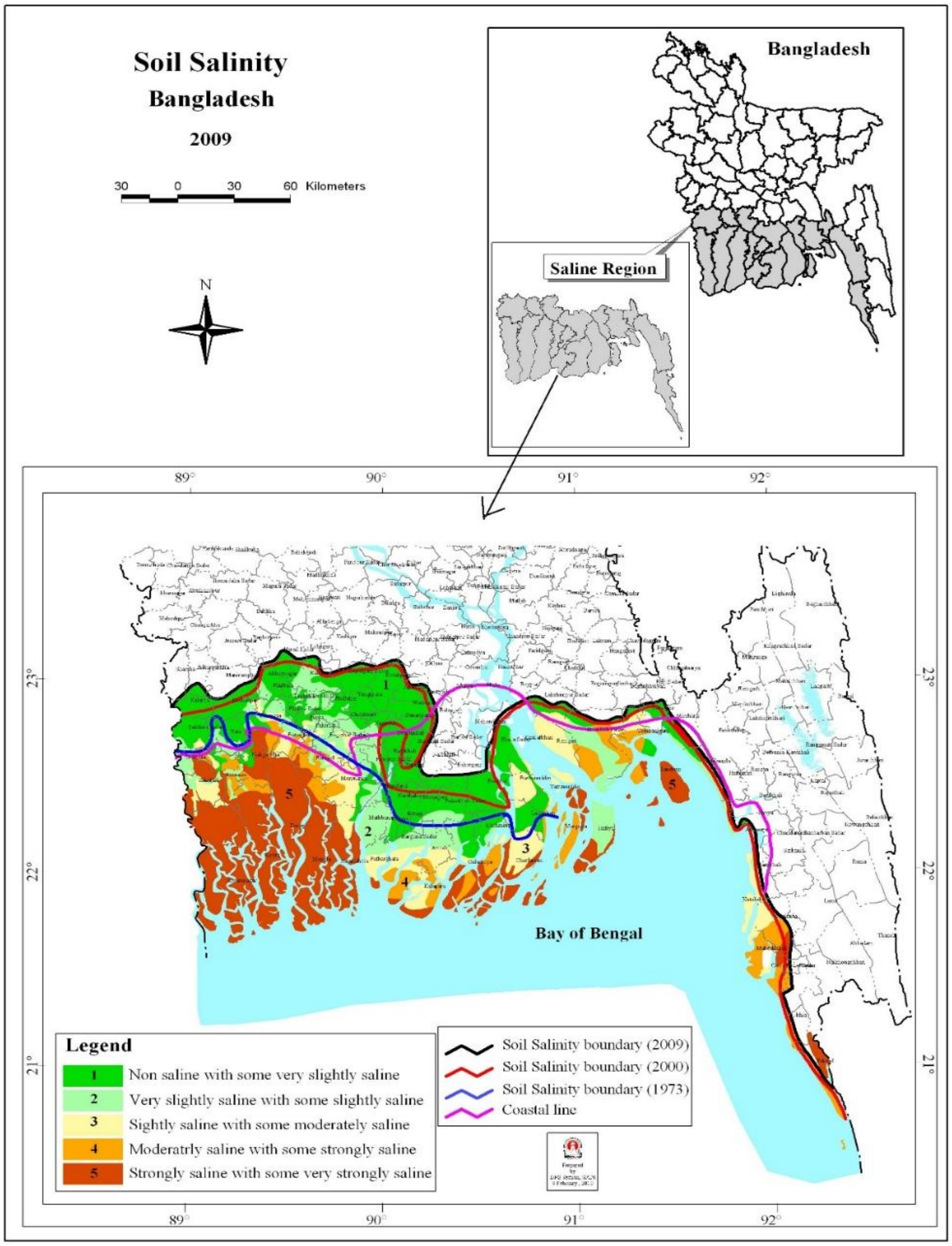

Fig. 2. Salinity boundary expansion from 1973 to 2009

3.4 Impact of Drought on Crop Agriculture

For most occasions, dry spells and periods affect agricultural crops in Bangladesh during the months before and after monsoon due to variations in temperature and rainfall. Bangladesh has suffered about 20 dry season circumstances over the last 50 years. In the early 1990s, the dry season situation in northeastern Bangladesh had led to a reduction of rice production by 3.5 million tonnes, which eventually forced farmers to go to groundwater irrigation with the surge of cropping intensity. If other agricultural losses are regarded as part from major cereals, such as other rotational crops in between the rice-rice systems (all winter crops, tomato, sugar cane, tobacco, jute, corn, etc.), In addition, plantations, bi-annual and perennial farm resources, including fruits (litchi, mango, jackfruit, banana, guava, papaya), also bamboo, betel nut and melons. Then there will be substantial loss and impact on crop agriculture due to the drought of various intensities. Drought prone areas in Bangladesh are likely to be affected by drought spells. The arable lands of Barid tract (i.e. Terrace land areas) in the greater Rajshahi district will be most affected by drought conditions (Fig. 4). This can lead to more fallow lands, poor crop yields due to inadequate moisture and more groundwater extraction for irrigation. These will lead the potential production capacity to be reduced, thus endangering food security of the northern regions [50]. In addition, other adverse ecosystems that are likely to be affected further by climate change include Haor and Bills, Charlands, Hills and Saline area including the Barind Tracts of Bangladesh (Fig. 4). Therefore, SLM is essential for these areas to offset land degradation and to continue agricultural productivity and safeguard livelihood of these areas in Bangladesh.

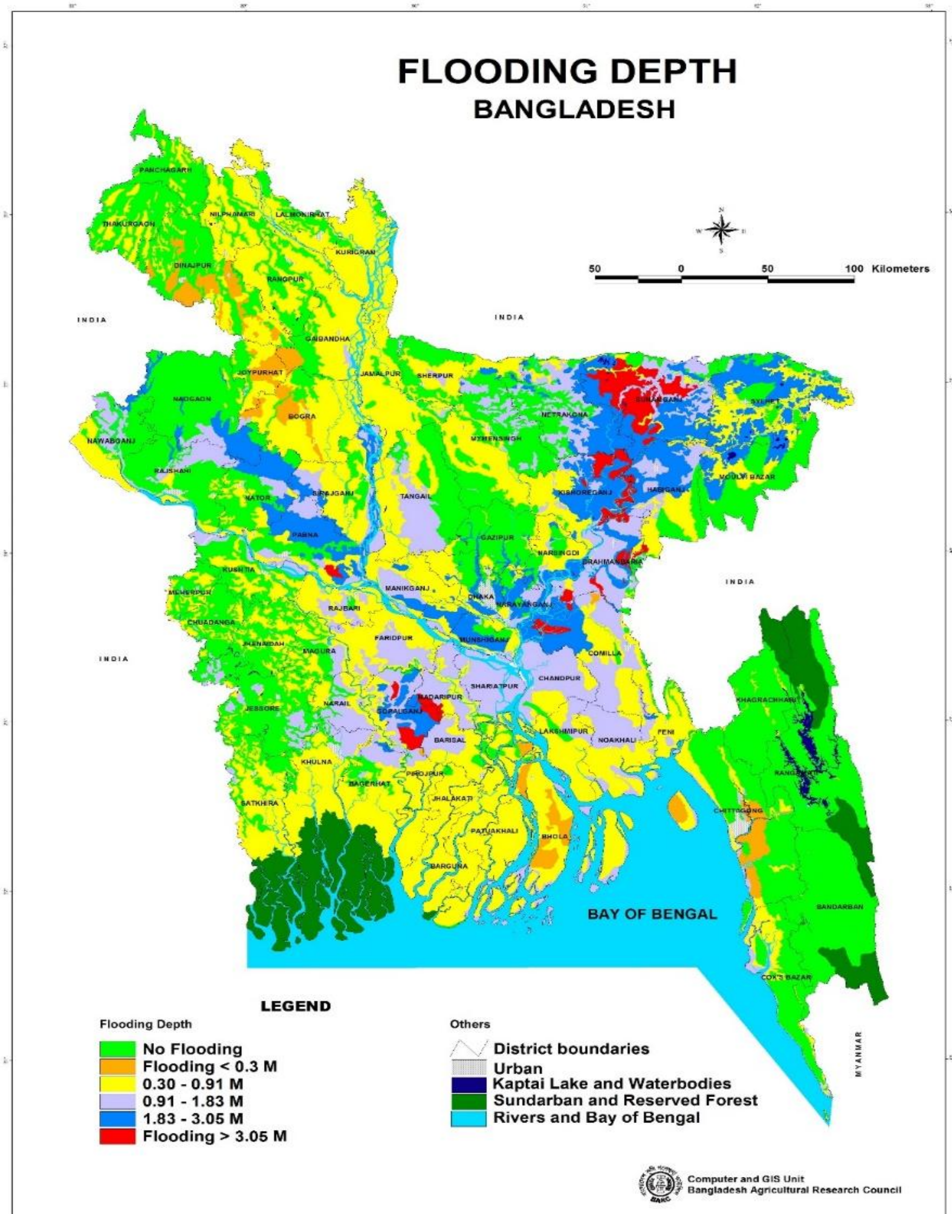

Fig. 3. Flooding depths of Bangladesh

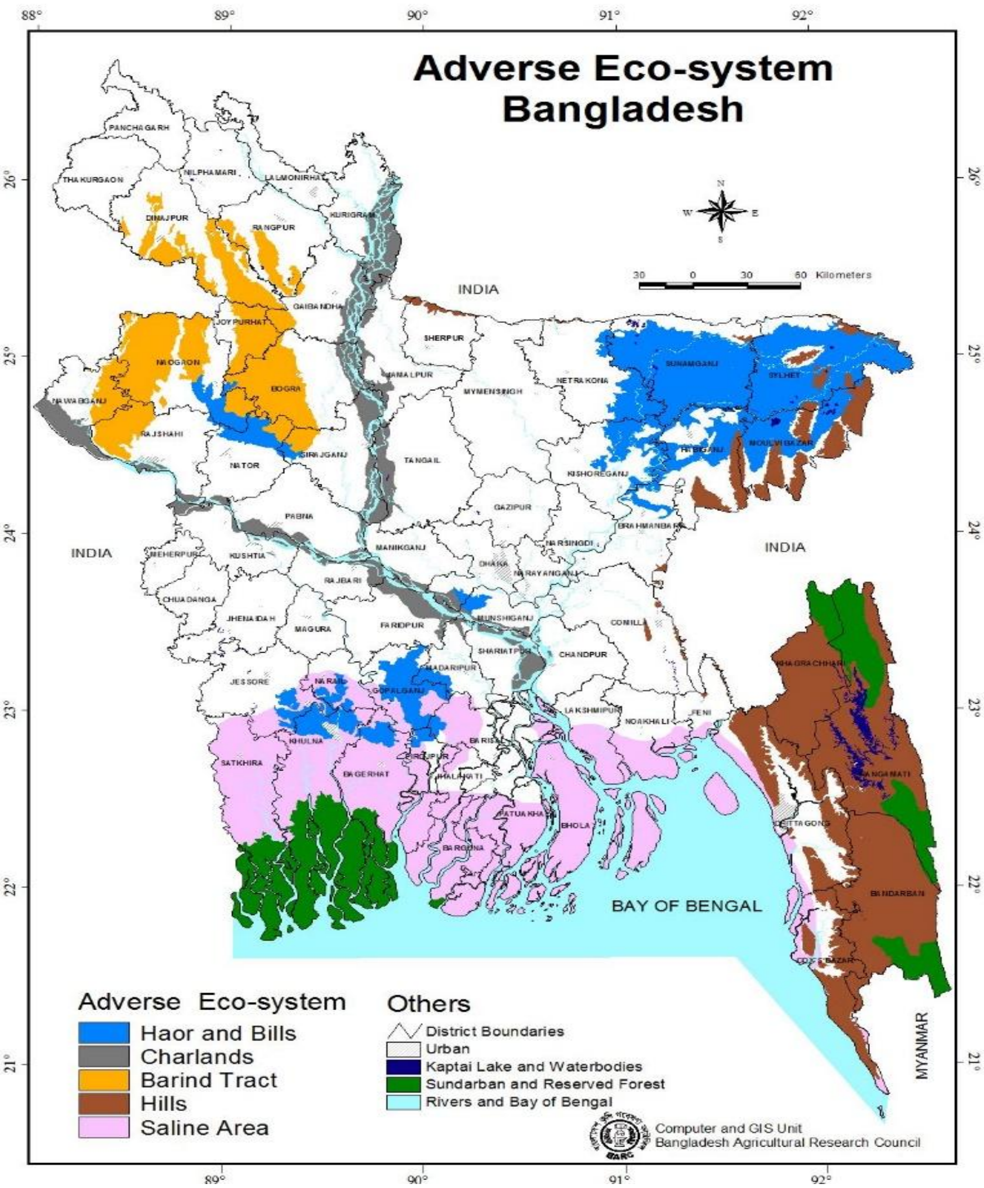

Fig. 4. Adverse ecosystems of Bangladesh

3.5 Impact of Climate Change on Groundwater and Irrigation Aspects

Groundwater is the main source of the water system in many countries, including Bangladesh, for dry winter paddy fields irrigation. In any case, this significant asset is being excessively misused and drained past regular renewal of aquifers from precipitation and river stream is inadequate [51]. Groundwater extraction for irrigation during rice cultivation (especially in dry season irrigated rice) has been increased sharply in Bangladesh since the expansion of area under cultivation through irrigation. A downward layer of groundwater level has been already reported in the northern parts of the country; climate change certainly influencing groundwater availability in Bangladesh [52]. Indeed, even with a 30% lower groundwater discharge rate, the average month-to-month level of groundwater would diminish by up to 14M in the northwestern regions of Bangladesh. The groundwater discharge in the northwestern parts of Bangladesh needs to reduce by 60% of the flow to guarantee practical utilization and or sustainability of groundwater. But given the fact that the area under irrigation-based paddy cultivation has been increased throughout the country, the judicial abstraction of groundwater for irrigation is much challenging, because 60% less groundwater abstraction would immediately affect the productivity of irrigation-based dry season paddy crops. This challenge needs to address with proper planning, efficiency and administration in groundwater abstraction. Change of land use could be a solution if adopted by land users and meet their expectations. However, faster groundwater abstraction and climate change are affecting groundwater levels, the groundwater level would decrease 5 to 6 times quicker in 2026–2047 than in the baseline era (1985–2006) if the present growing trend in groundwater abstraction continues. In addition, it has been reported by Mustafa, et. al. [52] that the extraction of groundwater needs to restrain by more than 50% of the present usages to ensure the sustainability of groundwater in the northwestern regions of Bangladesh (Fig. 5). Nevertheless, Crosbie, et al. [53] and Mustafa, et al. [52] concluded that monthly groundwater recharge because of climate change effect is highly uncertain, but continuously under climatic and anthropogenic pressure. Thus, with this uncertainty and huge abstraction of groundwater for irrigation would lead groundwater levels far-reaching for further abstraction due to agriculture. For example, the groundwater abstraction rate was reported by Mustafa, et al. [52] far higher in the year 2010 than actual recharge potential.

3.6 Sustainable Land Management (SLM): Present Approach and Practice

Any SLM approach, preferably should start-up from the land user or farmer realization and the requirements based on land quality and expected returns. Throughout the country for crop agriculture, application of farmyard manure and cow dung has been practiced variably for many years before the cropping seasons. Although farmer generated manure application depends on the availability of yard manures from animal and livestock sources. However, this practice certainly helps to improve land quality by improving organic matter status of arable lands. In this regard, the Department of Agriculture Extension (DAE) and the Soil Resource Development Institute (SRDI) through their advisory services (such as farmer meeting, fertilizer and manure recommendation, advice for mitigation of land degradation) are motivating land users further for manure application. In addition, DAE suggests some farmers throughout the country during the cultivation season with a set of advice for growing crop management. While SRDI distributes Upazila Land and Soil Resources Utilization Guide (LSRUG) (commonly known as *Upazila Nirdeshika*) for 459 upazila's of the country that will assist farmers and extension workers (including researchers) with applying fertilizers and composts as indicated by the soil test value of arable lands [54]. In addition, the Ministry of Agriculture is in collaboration with the Ministry of Land to authorize the suggested 2011 Agricultural Land Conservation and Land Use Act to protect agricultural land from the development of settlements and industrial infrastructures. Several other organizations, for example, Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI) and Bangladesh Water Development Board (BWDB) are working in different capacities for crop agriculture and land management. Academic research and practical understanding of SLM is inadequate in the country, therefore universities can work further on the development of SLM options and implication strategy. While the policy makers can strengthen the implications of SLM through land administration and decision support for the land users.

Farmers also change and or adapt their land utilization patterns by the choice of a particular crops and systems such as guava production in wetland areas, floating cultivation, conservation tillage, manure application and sustainable crop intensification (Fig. 6). In addition, farmers may choose to cultivate maize, wheat, potato and also in some area’s jute, vegetables, etc. for their higher returns and demands. This farmer choices can be mediated by land-user self-motivation, land and water related limitations such as temperature, moisture, flooding (including waterlogging and wet conditions), length of dry months and land capability. As for example, floating vegetable cultivation in the south regions of Bangladesh, cultivation of the pulse and legume as a rotational crop in high Barind areas of Rajshahi division, higher cropping intensity in the greater Dinajpur district due to more highland and medium highland areas, salinity tolerant rice and other crop cultivation in the south districts etc. These practices are being continually promoted and adopted by the farmers of Bangladesh. However, SLM in Bangladesh is getting more and more complex due to various pressures on lands for multiple demands, but the farmers (and or land users) are the key driver and actor of the land management system in Bangladesh.

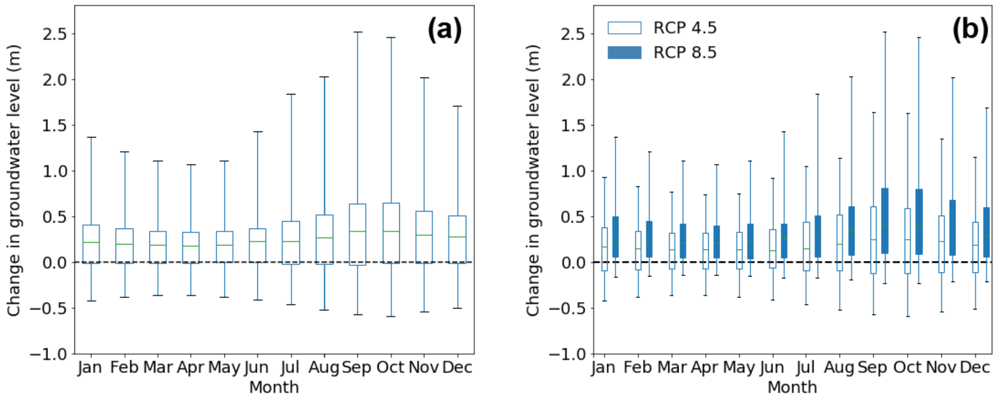

Fig. 5. Average monthly change in groundwater levels in the simulated future years (2026–2047) compared to baseline years (1980–2006): (a) all greenhouse gas combined, and (b) as a function of greenhouse gas. RCP means Representation Concentration Pathway. Details can be found at https://www.hydrol-earth-syst-sci.net/23/2279/2019/ [52]

A

B

C

D

E

F

Fig. 6. SLM practices; floating fruit and vegetables production (A-C), conservation tillage (D), manure application in arable lands (E) and crop intensification (F)

3.7 Sustainable Land Management (SLM): Options

SLM technology and options related to crop agriculture and consequent land degradation restoration tools can be broadly sub-divided into soil erosion control, minimization of soil disturbance, integrated soil management, land resource management, pest and disease control, efficient water use and related SLM based climate smart activities. These SLM techniques are broadly consistent with land-based mitigation alternatives that can be suitable for land quality, and limitation, which should be driven by agricultural demands and resource availability. Adapted potential land management options are presented in Table 1. Cropland management primarily consisted of sustainable land preparation, inputs, soil and plant management and farming system management [55], nutrient management [56,57], manures and fertilizer application, crop protection [58], crop residue management [59] and crop water management [15]. Soil disturbances through inversion tillage and puddling during the land preparation can be optimized by minimum or no-tillage technology [55], conservation agriculture, crop residue retention and avoidance of land conversion for industrial and non-agricultural purposes. Integrated soil fertility management would sustain soil health for the future as well as the recommended application of inputs (fertilizers, insecticides, and pesticides) will increase resource use efficiency in agriculture. Land zoning and conservation of resources accordingly will contribute to agricultural productivity, protection of biodiversity and the environmental protection. Subsequently, improved physical and chemical soil conditions (i.e., water retention, organic matter, soil fertility and carbon sequestration) of arable lands would be feasible. This would put the beneficial impacts on soil degradation prevention while improving climate change mitigation and adaptation strategy for any agro-ecosystem of the developing countries including Bangladesh [59,60].

3.8 Sustainable Land Management (SLM): Decision Support Components

A decision support system with the necessary components for sustainable land management should address the decision-making contexts and processes of the land users. It also requires the driving knowledge base categories (i.e., land quality, crop suitability, user requirement, climate) and whose integration together can lead SLM approach with the actors (i.e., land zoning, resources, governance, extension) involved. The prospective SLM practice (Table 1) requires decision support components so that land management can be convenient to develop and viable transfer for targeted land users. It is also equally important that the land resource availability and land user capability be taken into consideration so that the end-users can be able to implement SLM. SLM practice can be significant in relation to sustainability, but whether the land users and or farmers are adopting it or not depends on several drivers and actors involving land issues, crop suitability, weather, resource and governance policy. The drivers and actors are needed to identify for SLM specifically, unless land management objectives (Table 1) would not be achievable. Each SLM practice should be primarily driven by land quality (e.g. land evaluation, land quality indicators), and limitations (e.g. moisture, land type), and crop suitability and potential, which in turn reflect the land user requirements (e.g. preference of crops, land user goals, adaptability). As the weather and climatic condition is another key issue for crop agriculture in Bangladesh in contempt of climate change, this is also driving farmer decisions and present agricultural practices. These drivers of SLM can only end up into sustainable management options if land zoning (e.g. land information system, site-specific management) is conducted for whole Bangladesh arable lands and comes under practice by the policy makers and consequently by the land users [61]. Resource and capital availability (e.g. access to arable lands, water, external subsidies, and funding) is another key concern unless SLM would not be possible by the end-users. Nonetheless, actors such as good governance and adequate extension is a prerequisite, so that an SLM practice can be underway with substantial effects on land productivity and ecosystem services. Therefore, various necessary decision support components are shown in Fig. 7 involving the drivers and actors. These components can serve as a basis for the development and implementation of SLM at land user's level in Bangladesh. This proposed decision support components would be useful tool for decision-makers to buildup on different components, understand the complex climate variables in spatial and temporal contexts with necessary land (i.e. land resource quality database for soils), and land user information (i.e., local practice, change adoption and expectation of farmers).

Table 1. Prospective SLM options in relation to climate change, land and vegetation management for cropland mitigation in Bangladesh

Options	Objectives	Proposed adapted SLM practices
Land resource conservation	Minimize soil disturbance and arable land restoration	Restraint conventional land preparation and inversion tillage, Erosion measure and aggregate stability of arable lands, Residue retention after harvest, Minimum and conservation tillage, No-tillage technology, Avoidance of land conversion
Integrated management of soil fertility	Plant nutrients and soil amendments	Fertilizer recommendation, Integrated nutrient management, Soil acidity amelioration, Soil salinity monitoring, Farm-yard manure and organic amendments, Green manuring and biofertlizer application
Vegetation management/ land resource conservation	On-farm better land management and farming system	Land zoning, Inclusion of pulse and legume in cropping systems, Choice of crop (i.e., salinity and drought-tolerant variety) for the southern region lands during the fallow periods, Sustainable agricultural intensification in same piece of land, Agricultural disaster management and land recovery, Adapted practices (i.e. cover crops, mulching) to the drought prone northern terrace lands, Agro-adaptations in Haor basin areas, Floating cultivation in wetlands
Pest and disease	Crop protection	Biological control instead of chemical prevention, Integrated pest management
Water harvesting and utilization	Water management	Water-saving irrigation, Rainwater use during rice transplanting, Alternate wetting and drying irrigation, Monsoon water harvesting
Climate smart agriculture	Sustainability and productivity	Resilience to climate change by productivity, Adaptation and mitigation

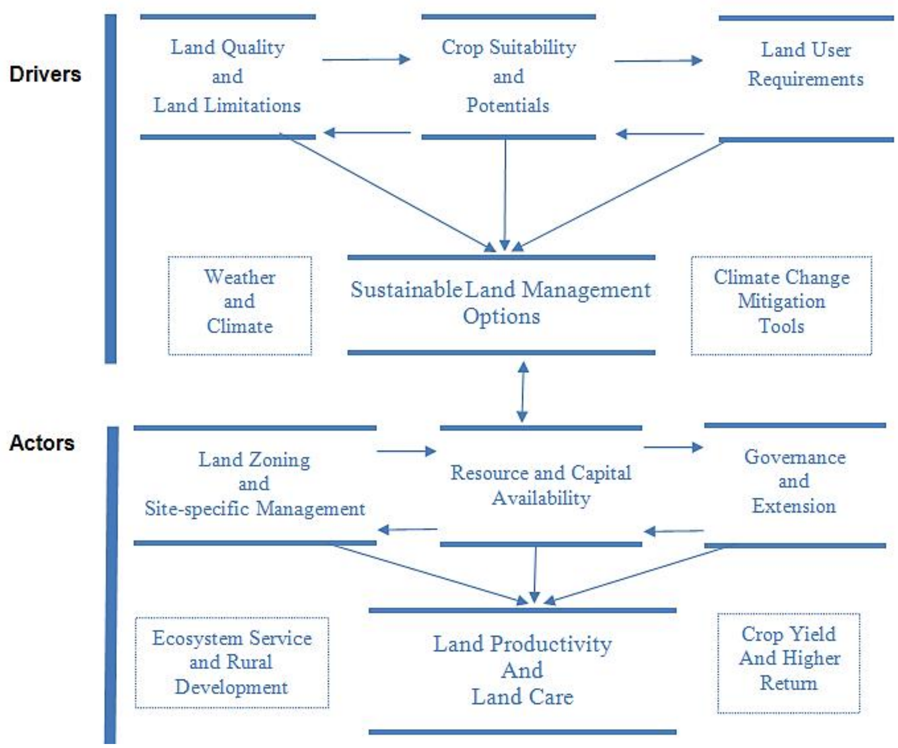

Fig. 7. Proposed decision support components for SLM

3.9 Barriers of Sustainable Land Management (SLM)

There can be many reasons behind the choice of the land user for not adopting a certain practice and innovation related to SLM. Firstly, the adoption process involving land user is important, then the SLM approach itself and issues involving it and eventually the transfer process is expected to be augmented by the extension workers [62]. The decision support system components that can help the implementation of prospective SLM practices (Table 1) require collaboration and interactivity of land user with other stakeholders and issues during the adoption and transfer process of SLM. The role of extension agent is also equally important for adopting SLM, whose advice to change or adapt with certain practice also depends on land use preference in crop agriculture. While the evaluation of existing efforts of present technology transfer and its effectiveness (such as rate of adoption) with stakeholders related to SLM can help future practice adoption. Land user goals and objectives, risk and uncertainty, and socioeconomic conditions require to investigate and identify specifically so that extension workers can disseminate the SLM approach with the acceptability of end-users (namely farmers). However, understanding the constraints during the adoption process of SLM is imperative for land-based perspective SLM practices to be successful. Limited access and lack of interest to potential SLM technologies (including services and farm machinery) and scarcity of resources (i.e., arable lands, labor force, farm inputs, biological resources, power/energy, water, and suitable crops) are the key barriers to implement SLM in Bangladesh. Biophysical imperatives and financial settings are also important because certain land management practice, which is suitable for one region or site, might not be the desired option for the various regions. Thus, SLM practices need to develop site-specifically and based on local land user's demands; hence, land zoning can be a significant option [61]. While on the other hand, success and failure of a land management practice will depend on site-specific land and environmental characteristics, such as soil quality, climate, topography, and sources of water. Nevertheless, institutional and governance issues can play a significant role in the implementation of SLM. There is a significant need for well-prepared and successful extension activities to encourage and implement, monitor and evaluation of the effect of localized SLM initiatives or services. Last but not the least, monetary contemplations and motivational plans are two of the land users' essential inspirations for choosing SLM innovations and services, including a solid reliance on outside sponsorships (such as governmental subsidies) for the execution and viable implementation. Provision of decision support tools (Fig. 7) for land users and or farmers can be immensely helpful for the development and implementation of SLM.

4. CONCLUSION

It is evident that there are certain vulnerabilities of climate change on agriculture of Bangladesh due to variability of temperature and rainfall, sea-level rise, flood, cyclone, drought and land degradation. To overcome this and continue the growth in agriculture SLM is essential. Therefore, SLM options, mainly land resource conservation, erosion control, management of soil fertility, vegetation management, tillage technology, crop protection, efficient water use and climate-smart agriculture are immensely demanding in Bangladesh. These identified prospective SLM requires to focus on land user requirements to overcome the barriers of SLM. Moreover, we identified components that are necessary (e.g. land quality, crop suitability, capital, governance, extension) for a decision support system to develop and transfer SLM towards the land users and farmers. In the small landholding system of Bangladesh, adaptation and implementation of SLM involving all the actors and drivers would be certainly challenging with the changing climatic scenario. Interactivity between the land user and extension worker, acceptance of SLM options, farmer motivation and assistance, decision support and the local governance can lead different prospective SLM practices into reality through the effective transfer process to ensure food security and combat the impacts of climate change in the years to come.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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