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Floating agriculture: a potential cleaner production technique for climate change adaptation and sustainable community development in Bangladesh

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ABSTRACT

Global climate change is anticipated to intensify the vulnerability of Bangladesh (a low-lying country formed by the alluvial plain of the Ganges-Brahmaputra river systems) to floods and waterlogging, and therefore, the country needs to be equipped with adequate adaptation strategies, particularly those based on traditional knowledge and locally available materials. In this paper, we present a systematic and in-depth review of existing literature to examine the possibilities of indigenous floating agriculture as a technique for climate change adaptation and sustainable community development in Bangladesh. Our review indicates that the indigenous floating agriculture holds enough potential to help farming communities in the flood prone regions of Bangladesh to sustain lives and livelihoods during floods and long-term waterlogged conditions. This technique has a unique quality of providing a wide range of agricultural, environmental, economic, social and cultural benefits, which ultimately render it as an environmentally sound, economically feasible, and socially viable practice. Case studies on a number of promotional and experimental floating agriculture projects in different regions of Bangladesh revealed that the floating agriculture greatly supported farming communities to adapt to adverse waterlogged conditions by allowing vegetable production for daily consumption, income generation, community mobilization, and by increasing land-holding capacity. Along with providing food and nutrition security, this technique also strengthened the community capacity to grow and sustain agricultural practices in the subsequent floods and waterlogging conditions. Although this technique has a number of sustainability challenges as highlighted in this study, many of these are possible to overcome through proper planning and long-term management initiatives. We recommend policy implications and future research needs that could be effectively utilized to render this technique as a suitable tool for climate change adaptation and sustainable community development in Bangladesh.

1. Introduction

Bangladesh is a highly vulnerable country to the adverse impact of global climate change (IPCC, 2001; IPCC, 2007; IPCC, 2012), and one of the most anticipated destructive consequences of global climate change in Bangladesh is flooding (IPCC, 2007; UNFCCC, 2013). Initial assessments by general circulation models have indicated that global climate change will cause Bangladesh to suffer from an increased frequency and extent of flooding (DANIDA and IWM, 2008). In a probabilistic analysis of 19 global climate model simulations by a generic binary decision model, Palmer and Raisanen (2002) estimated that over the next 50–100 years, the probability of extremely wet Asian monsoon seasons will rise with increased risk of flooding in Bangladesh. Using a sequence of empirical models and the MIKE11-GIS hydrodynamic model, Mirza et al. (2003) also assessed possible changes in the magnitude, extent, and depth of floods of the three major rivers, the Ganges, Brahmaputra and Meghna, under different climate-change scenarios. They observed that because of the increased peak discharge from these rivers, the flood-prone areas of the central and north-eastern regions of Bangladesh will be at a greater risk in terms of the depth and spatial extent of flooding. A number of other studies (Mirza, 2002; Ahmed, 2006; Rahman et al., 2007; Huq and Ayers, 2008; CCC, 2009; Walsham, 2010; MoEF Bangladesh, 2011;

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Kundzewicz et al., 2012) have also reported that global climate change will cause increased floods and waterlogging in Bangladesh in the future.

Bangladesh is a traditionally flood-prone country because of its geographic location. It includes the drainage channels for the enormous basins of the Ganges, Brahmaputra and Meghna Rivers, which are mostly located outside the country. During the monsoon period (usually June to October), the flow of these rivers and local runoff outstrips the capacity of the channels, and results in floods and waterlogging in the low-lying areas. Every year, approximately 20–25% of Bangladesh's total land area is inundated with normal flooding, which in extreme cases could reach up to 50–70% (Mirza, 2003; Rahman et al., 2007; BWDB, 2012). The severe floods of 1988, 1998, 2004, and 2007 inundated approximately 61%, 68%, 38%, and 42%, respectively, of Bangladesh (BWDB, 2008). All these floods caused enormous damages to life and property, and created substantial adverse impacts on the population's livelihood, health, and education (Mirza, 2002; Brouwer et al., 2007; Rahman et al., 2007; MoEF Bangladesh, 2011).

Although all vital sectors of Bangladesh are more or less affected by the adverse impacts of annual floods and long-term waterlogging, the most severely damaged is the agricultural sector (Ericksen et al., 1993; Brouwer et al., 2007; MoEF Bangladesh, 2011), which contributes approximately 18% to its GDP (Global Finance, 2012). Along with providing a continuous food supply in the rural areas, the agricultural sector employs approximately 54% of Bangladesh's rural population that comprises approximately 80% (World Bank, 2011) of its total 143 million people (BBS, 2011). Bangladesh experienced significant damage to its agricultural sector from a number of floods over the last three decades. For instance, the floods of 1987 caused a total loss of approximately 1 million metric tons (MMT) rice crops (Rahman et al., 2007), and in 1988, floods caused a 45% reduction in the annual agricultural production (Karim et al., 1996). The catastrophic flood of 1998 also damaged approximately 4 MMT of agricultural products in which the loss of rice crops alone accounted for more than half (2.04 MMT) of the total loss, with vegetables (25% of the total) and fibers (19%) constituting the remaining loss (Ninno et al., 2001). In addition, the recent devastating flood of 2007 destroyed approximately 1.12 million hectares of cropland, and resulted in a loss equivalent to US$ 620 million (DMB Bangladesh, 2007). Even in the normal flooding years, floods cause a substantial impairment to the agricultural sector by creating permanent (4–5 months) waterlogged conditions in many parts of the country, particularly in the low-lying floodplains (CEGIS, 2003; Haq et al., 2004; Irfanullah et al., 2011). In the backswamp areas (locally known as haors) that are located between the natural river levees and occupy approximately 2.04 million hectares in Bangladesh, the flood water may be retained for seven to eight months out of a year.

Long-term waterlogging makes it too difficult for the farmers to continue normal land-based agriculture practices. Therefore, the farming communities that solely depend on the land-based agriculture to sustain their lives and livelihoods are severely affected from waterlogged conditions. Problems such as hunger, malnutrition, depression, disease, unemployment, and social conflicts become apparent and eventually result in economic and social instability in the farming communities (Mirza, 2003; Haq et al., 2004; Brouwer et al., 2007; Rahman et al., 2007; Poncelet, 2009). Without the ability to sustain themselves, farmers ultimately leave their dwellings and migrate to urban areas in search of food and livelihood (Ullah, 2004; MoEF Bangladesh, 2005; Kelkar and Bhadwal, 2007; Rayhan and Grote, 2007; Walsham, 2010). As a result, Bangladesh is consistently losing potential farmers who have played a key role in supporting its long-term agricultural and economic development. The unplanned migration of the farmers to cities also creates a burden on the urban environments because the majority of these displaced people live in the slums, on footpaths, near rail-lines, rail stations and bus stations, or in other open places that do not offer safety, health or sanitation facilities (Afsar, 2003; Hossain, 2006; Kelkar and Bhadwal, 2007; World Bank, 2007; Huq and Ayers, 2008; Angeles et al., 2009; Walsham, 2010). This condition eventually leads to a number of urban problems such as overcrowding, health and sanitation crises, waste management burdens, environmental pollution, traffic jams, esthetic impairments, and various social conflicts. Therefore, it is evident that flooding and waterlogging is a greater threat, not only to the agricultural sector but also to the overall economic, social, and environmental development of Bangladesh.

In some regions of Bangladesh, farmers have been attempting to sustain their lives and livelihoods in flooded and long-term waterlogged conditions by utilizing a self-innovated farming technique. This technique is known as ‘floating agriculture’ and is a practice in which crops and vegetables are grown in soilless floating platforms (beds) constructed of locally available materials such as water hyacinth and other aquatic weeds. Although this unique technique of Bangladesh is based on the native knowledge of farmers, the scientific term for it is ‘hydroponics,’ which is a method of growing plants without soil by using inert growing medium, such as gravel, sand, perlite, vermiculite, clay pebbles, etc., where plants receive essential nutrients for their growth either from a nutrient solution or organic materials added to the medium (Winterborne, 2005). Floating agriculture is an indigenous technique of farming in the southern floodplains of Bangladesh, particularly in the Barisal, Gopalganj and Pirojpur districts, where the farmers have been practising this method for more than 100 years (Asaduzzaman, 2004; IUCN Bangladesh, 2005; Islam and Atkins, 2007; Irfanullah, 2009; Haq and Nawaz, 2009). Over the last decade, this technique were introduced and promoted to other flood-prone regions of Bangladesh. Thus far, 14 (of 64 total) districts, including Barisal (Irfanullah, 2009; MoA Bangladesh, 2015; Hutton et al., 2015), Gopalganj (IUCN Bangladesh, 2005; Irfanullah, 2009; UNEP, 2009; IPS, 2012; MoA Bangladesh, 2015), Pirojpur (Islam and Atkins, 2007; Alam, 2011; The Daily Star, 2013a; The Daily Observer, 2015), Madaripur (IUCN Bangladesh, 2005; IUCN Bangladesh, 2008), Satkhira (Islam and Atkins, 2007), Habiganj (Irfanullah et al., 2008), Kishoreganj (IUCN Bangladesh, 2009; Irfanullah et al., 2011), Sunamganj (IUCN Bangladesh, 2009; Irfanullah et al., 2011; Anik and Khan, 2012; HSI BD, 2013; Pavel et al., 2014), Netrokona (IUCN Bangladesh, 2009; IUCN Bangladesh, 2012a), Jessore (Haq et al., 2004; Haq and Nawaz, 2009; Haq, 2009; IRIN, 2010), Gaibandha (Practical Action, 2010; Brown, 2013; Choudhury and Bepary, 2014), Khulna (Dhaka Tribune, 2013; The Daily Observer, 2014), Faridpur (AKK and IGES, 2011), and Lalmonirhat (The Daily Star, 2012; Practical Action, 2014a), were reported to be using floating agriculture either extensively or at least to some extent.

Based on a systematic and in-depth review of the published literature, in this study, we present an overview of the available knowledge relating to floating agriculture practices in different regions of Bangladesh, which is thus far lacking in the available literature. With this overview, we then examine the possibilities of indigenous floating agriculture as a technique for climate change adaptation and sustainable community development in Bangladesh. In addition, we attempt to determine the knowledge gaps to highlight the requirements for future research so that this practice can be considered a sustainable adaptation to flooding and long-term waterlogged conditions in Bangladesh. The key facts explained so far in this section are summarized in Fig. 1.

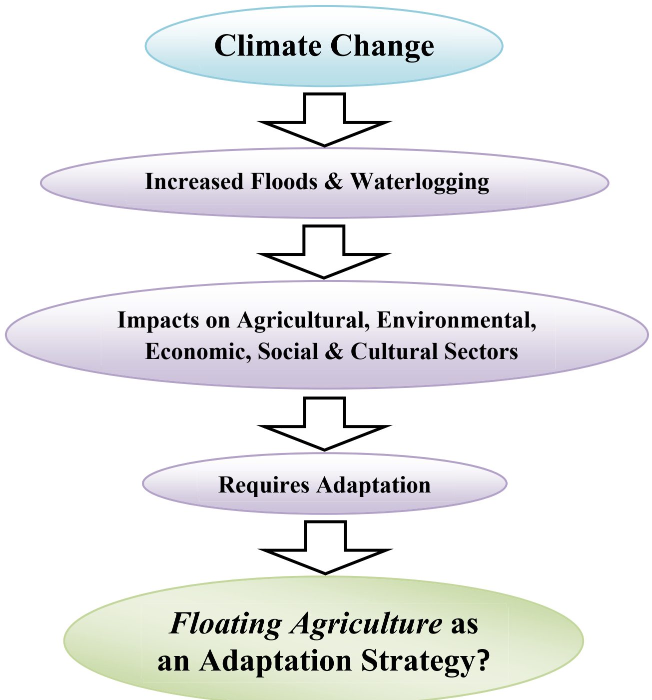

Fig. 1. Conceptualizing the linkage between climate change and floating agriculture.

2. Method

For this review, information from almost all of the available published literature on floating agriculture practices in Bangladesh have been thoroughly studied and systematically utilized. In order to find scientific articles on floating agriculture, we have carried out an extensive Internet search using the most common and relevant search engine (for instance; Google Scholar, Web of Science, AGRIS, SCOPUS, Academic Search, WorldWideScience etc.). For grey literature search on floating agriculture, we have utilized Google Web, Google Images, Science.Gov etc. We have also thoroughly checked the list of references of each of the primarily identified floating agriculture literature, websites of relevant national and international organizations working on floating agriculture, and personal website and professional networks (e.g. ResearchGate, Linkedin) of the main author and co-authors of floating agriculture articles to find further literature. In addition, we have utilized our personal and professional network to find and get access to floating agriculture literature. It is observed that peer-reviewed journal publications on this indigenous technique of Bangladesh are scarce, which indicates, this area of research has received limited attention from the international scientific community. Thus, the literature we considered for this review are mostly dominated by 'grey literature,' which includes official reports of the government, non-government, and international organizations; conference and symposium papers; case studies published in magazines and newsletters; local and international newspaper articles; blog posts; and video documentaries. Although the number of peer-reviewed scientific articles on this technique is quite small, the availability of a considerable number of grey literature could provide a sufficient knowledge base for a review. However, considering the fact of dominancy of grey literature, we have performed a bibliometric analysis to indicate the types and number (in each category) of literature used, and the extent to which each of the literature has been utilized in this study (Table 1). This analysis provides a basis for a general understanding of the quality of the literature and the reliability of the information utilized in this review. Our analysis indicates that the reports of international organizations (for instance; IUCN, UNFCCC, UNEP, ADB, FAO, and Practical Action) constitutes the highest proportion (18 out of 67, or 27%) of total floating agriculture literature we utilized, while the number of peer reviewed international journal paper, book chapter/section, and magazine/newsletters are 6, 7, and 8 respectively, and the number of literature in each of the remainder categories are less than 6. The literature that have been highly (total number: 15) and moderately (total number: 6) utilized in this review as indicated in Table 1 are mostly comprised of the findings of field surveys and case studies that collected primary information on various aspects of floating agriculture practice in different regions of Bangladesh. However, the majority (46 out of 67, or 69%) of the literature that we have used only in 1–2 instances, include a brief description/report on the floating agriculture practice, in most cases, based on secondary information. While reviewing the literature on floating agriculture practice of Bangladesh, we focused mainly on assessing information relating to its environmental and economic productivity, its suitability a as technique for climate change adaptation and sustainable community development, and challenges to its sustainability.

In this study, we have also attempted to review the floating agriculture practices of other countries of the world, and as stated above, put substantial efforts to find relevant literature in this regard. Although we have found some literature on floating agriculture practice of few other countries for instance, Inle Lake in Myanmar (Sidle et al., 2007; Leah, 2013), Dal Lake of Kashmir in India (Mushatq et al., 2013; Gupta, 2014), and Xochimilco in Mexico (Popper, 2000; Onofre, 2005); in most cases, the literature are of insufficient number, inconsistent, and lacking sufficient information and scientific quality, and therefore, are not considered for this review. This review focuses exclusively on the case of floating agriculture practices of Bangladesh.

3. An overview of the procedure of floating agriculture practices in different regions of Bangladesh

In Bangladesh, floating agriculture is locally known by different names such as Baira (Haq et al., 2004; IUCN Bangladesh, 2005; Rahman, 2011; Awal, 2014), Dhap (Haq et al., 2005; Islam and Atkins, 2007; Hossain, 2010; Rahman, 2014; MoA Bangladesh, 2015), Gaota (Sen and Zaid, 2010; Kuria, 2010), Geto (Haq et al., 2004), and Vashoman Chash (Asaduzzaman, 2004). Although the people of different regions of Bangladesh have modified this practice according to their local conditions and available materials, the basic method of floating agriculture is more or less similar in all of the regions. A thorough understanding of the procedure of floating agriculture is essential to effectively assessing its suitability as a technique for climate change adaptation.

3.1. Materials necessary for floating agriculture

The type and availability of raw materials required to construct floating beds may vary from one region to another. In most of the regions, water hyacinth (*Eichhornia crassipes*) is used as the main component to construct the floating platform, whereas in other regions, aquatic weeds, paddy straw, and coconut fiber are used either alone or in combination (Table 2). Aquatic creepers such as dulali lata (*Potamogeton alpinus*) or durali (*Hygroryza aristata*) are used (IUCN Bangladesh, 2005) to prepare seed balls for raising seedlings. The sufficient availability of these raw materials is crucial for determining the quality of the floating bed and the subsequent sustainability of floating agriculture.

Table 1
A bibliometric analysis of the available published literature on the floating agriculture practice of Bangladesh utilized for this review.

Types of literature	Reference	Total number
Journal paper (peer-reviewed international)	[a] Islam and Atkins, 2007; [a] Irfanullah et al., 2008; [a] Irfanullah et al., 2011; Anik and Khan, 2012; Awal, 2014; [b] Pavel et al., 2014	6
Journal paper (local)	Saha, 2010	1
Book (international)	[a] IUCN Bangladesh, 2005; Linham and Nicholls, 2010	2
Book chapter/section (international)	[a] Irfanullah, 2009; Padmavathy and Poyyamoli, 2011; Rahman, 2011; Alam et al., 2013; DEV, 2013; Habiba et al., 2013; Abedin and Habiba, 2015	7
Conference/Symposium paper (international)	Haq et al., 2005; [a] Hossain, 2010	2
Magazine/Newsletter (international)	[a] Haq et al., 2004; Pender, 2008; [a] Haq and Nawaz, 2009; Kuria, 2010; Mallorie, 2010; [b] Sen and Zaid, 2010; Irfanullah, 2013a; Choudhury and Bepary, 2014	8
Reports (international organizations)	UNFCCC, 2006; [a] IUCN Bangladesh, 2008; [a] IUCN Bangladesh, 2009; [a] Practical Action, 2010; AKK and IGES. 2011; Clements et al., 2011; Practical Action, 2011; IUCN Bangladesh, 2012a; IUCN Bangladesh, 2012b; [a] Irfanullah, 2013b; ADB, 2014; Practical Action, 2014a; Practical Action, 2014b; Rahman, 2014; SATNET Asia, 2014; UNEP, 2014; Anglican Alliance, 2015; Hutton et al., 2015	18
Reports (local non-government organizations)	[a] Asaduzzaman, 2004; [a] Haq, 2009; [b] BARCIK, 2010	3
Reports (government organizations)	[b] MoEF Bangladesh, 2005; [a] MoA Bangladesh, 2015	2
News article (international)	IRIN, 2010; IPS, 2012; The New York Times, 2014	3
News article (local)	[b] The Daily Star, 2012; Dhaka Tribune, 2013; The Daily Star, 2013a; The Daily Star, 2013b; The Daily Observer, 2014; The Daily Observer, 2015	6
Blog post (international)	Alam, 2011; Brown, 2013; Irfanullah, 2013c; Alauddin, 2014	4
Video documentary (international organizations)	IIED, 2008; UNEP, 2009; Alam, 2012; [b] HSI BD, 2013; ANEP, 2014	5

References not marked with 'a' or 'b' have been utilized only in 1–2 instances in this paper.
[a] Highly utilized (5 or more instances).
[b] Moderately utilized (3–4 instances).

Table 2
Bed geometry and raw materials used for floating agriculture practice in different regions of Bangladesh.

Studies	Location	Size of the bed *L = Length* *W = Width* *H = Height* (meter)	Materials used for making floating bed		Typical bed size suggested in this study (meter)
			Water hyacinth and other aquatic weeds	Other materials and equipments	
Haq et al., 2004	Village Chandra of Jessore district	L: 15 – 50 W: 1.5–2.5 H: 1	Mainly [1]water hyacinth (*Eichhornia crassipes*). But other aquatic weeds i.e. [2]water lettuce (*Pista stratiotes*), [3]duckweed (*Lemna minor*) are used	Aman paddy stubs, straw, coconut husk, bamboo and rope	L: 20–30 W: 1.5–2 H: 1
Islam and Atkins, 2007	Nesarabad thana of Pirojpur district	L: 50 – 60 W: 1.2 – 1.5 H: 0.25 – 0.5	Mainly water hyacinth. But water lettuce, [4]blady grass (*Imperata cylindrica*) and [5]noll grass (*Hemarthria protensa*) are also used	Wood ash and dissected coconut fibers	
Irfanullah et al., 2011	Villages of Kishoreganj and Sunamganj districts	L: 4.5 W: 2 H: 1	Mainly water hyacinth	Bamboo and country boat	
IUCN Bangladesh, 2005	Chanda beel of Gopalganj district	L: 4.56–13.7 W: 1.5–2.74 H: 1.83	Mainly water hyacinth but other aquatic weeds like water lettuce, duckweed, [6]hydrilla (*Hydrilla verticillata*), [7]morning glory bush (*Ipomoea fistulosa*) are also used	Aman paddy stubs, bamboo, boat, chopper and other gardening tools	

Local name of the aquatic weeds in Bangladesh: [1]Kochuripana, [2]Topapana, [3]Khudhipana, [4]Shon ghash, [5]Noll ghash, [6]Kanta shaola, [7]Dholkolmi.

Water hyacinth is considered as an invasive aquatic weed in many countries including Bangladesh because of its rigorous growth and adverse effects, such as congestion of channels or streams, reduction of the carrying capacity of water bodies, deterioration of water quality and eutrophication, biodiversity loss, pest infestation, and obstruction of fish production and water supply for human consumption (Tellez et al., 2008; Patel, 2012). Because of the high availability, water hyacinth is commonly used for constructing floating beds in different regions of Bangladesh (Haq et al., 2004; Islam and Atkins, 2007; Practical Action, 2010; Irfanullah et al., 2011). A picture of the availability of water hyacinth along with some freshly made floating beds is presented in Fig. 2. The utilization of water hyacinth in constructing floating beds and growing crops in these beds could be a useful means of recycling vital nutrients such as phosphorus and nitrogen that are lost from agricultural fields to water bodies through surface run off water or by other processes. Excessive phosphorus and nitrogen in water bodies can lead to eutrophication (Chowdhury et al., 2014; Conley et al., 2009). In an experiment, Kutty et al. (2009) observed that water hyacinth (*Eichhornia crassipes*) removed approximately 67% of phosphorus, 81% of ammonia and 92% of nitrate in municipal wastewater. Therefore, floating agriculture could help to control invasive aquatic weeds and minimize water pollution and eutrophication problems. In some regions of Bangladesh, straw of Aman (a local species of rice) paddies had been used in the past for making floating beds because of its high abundance. However, after the introduction of HYV (High Yielding Varieties) rice, people lost interest in growing local varieties such as Aus and Aman. Therefore, the production of straw became low, and farmers began to using water hyacinth instead of paddy straw (BARCIK, 2010). Like the availability of raw materials, the size of the floating bed also varies from one region to another (Table 2). Generally, to prepare a 1 m^2 (area) sized floating bed, approximately 5 m^2 of growing water hyacinths are required (Haq et al., 2004). The net benefit from

Fig. 2. Availability of water hyacinth and other aquatic weeds, and freshly made floating beds (*Image Source:* Pender, 2008).

floating agriculture may increase with the enhancement of bed size (Pavel et al., 2014).

3.2. Procedure of floating bed preparation and crop cultivation

A number of available papers present detailed descriptions of the method of bed preparation and crop cultivation in floating agriculture practices of different regions in Bangladesh for instance, Gopalganj (IUCN Bangladesh, 2005; Hossain, 2010), Pirojpur (Islam and Atkins, 2007), Jessore (Haq et al., 2004; Haq and Nawaz, 2009), and Gaibandha (Practical Action, 2011; Brown, 2013). Irfanullah et al. (2008) also depicted a brief and clear picture of a traditional floating agriculture method of Bangladesh. Moreover, the video documentaries of IIED (2008) and HSI BD (2013) present a visual demonstration of the method of floating bed preparation and crop cultivation in some regions of Bangladesh. Based on a review of all of these published sources, in this paper, we summarize the method of a typical floating agriculture practice in Bangladesh, which is shown in Fig. 3. Floating beds are generally prepared in the monsoon season when land gets flooded and waterlogged. Water hyacinths are collected and compacted according to the method presented in Fig. 3 to prepare floating beds. Once the beds are ready, seeds and seedlings of suitable monsoon crops are planted. Maintenance of growing crops in floating beds is also required for better crop productivity (Fig. 4). The monsoon cultivation commences in June–July and ends in September–October. During October–November, when the flood water recedes, the monsoon beds are dismantled and mixed with soils as organic fertilizer to prepare winter plots for the cultivation of winter crops (Fig. 3).

3.3. Suitable crops for floating agriculture

A range of monsoon and winter crops have been found suitable for floating agriculture (Table 3). The selection of crops depends on the personal preference, local conditions, and availability of seeds and seedlings. Although all types of the crops that are listed in Table 3 could be grown in the floating beds, certain tuber crops that require a soft medium for root penetration, such as potato, ginger, turmeric, and arum are much more suitable (BARCIK, 2010). During the monsoon of 2006, the participants in the project of Habiganj district cultivated 18 different crops, where bottle gourd, amaranth and pumpkin were the main crops cultivated on 70% of the beds; while tomato, spinach, potato and chilies were the major cultivated crops in the subsequent winter (Irfanullah et al., 2008). Irfanullah (2009) reported that farmers in the Barisal district usually raise seedlings of bottle gourd, pumpkin, wax gourd, papaya, beetroot, bitter gourd, brinjal, cabbage, cauliflower, chili and tomato in the floating beds.

Crops can be grown either individually or in combinations of three or four species. The following combinations were reported to grow in floating beds: potato, brinjal, bitter gourd and cucumber; potato, cabbage, brinjal, bitter gourd and cucumber; onion, brinjal, cucumber and bitter gourd; garlic, chili, white gourd and bitter gourd; tomato, water arum and sweet gourd; and sugar cane, tomato, brinjal and chili (Islam and Atkins, 2007). The farmers of Tungipara upazila in the Gopalganj district cultivate two rows of okra and one row of cucumber or ridged gourd alternately in the same bed during the monsoon season from June to August (Hossain, 2010). Because floating agriculture allows a diverse range of crops (Table 3) to be grown during flood and waterlogged conditions, this technique could be effectively utilized to protect and sustain crop diversity in the flood-prone regions of Bangladesh.

4. An assessment of the possibilities of floating agriculture as a technique for climate change adaptation and sustainable community development in Bangladesh

4.1. Economic feasibility of floating agriculture

Analyses of cost and income in a number of studies revealed that the income from floating agriculture is higher than its cost. In this study, we present (Table 4) a collation and analysis of the cost and income related to floating agriculture practices of different regions in Bangladesh. In the case of village Chandra in Jessore district, the total income from 10 floating beds was found to be US$ 280 (BDT 21,000) against a total cost of US$ 74.6 (BDT 5600), which resulted in a total profit of US$ 205.5 (BDT 15,400). The main associated cost occurred in the construction of the floating beds, and the main income resulted from the selling of vegetables and compost products. In this review, we also calculated the monetary profit per square meter of floating bed (Table 4). The highest profit of US$ 1.14 per m^2 bed was observed in the case of Nesarabad thana of the Pirojpur district, and the lowest profit (US**$** 0.38 per m^2 bed) was found in the floating agriculture practice of Muksudpur upazila in the Gopalganj district. In the case of the Pirojpur district, the main product of floating agriculture was seedlings, which contributed approximately two thirds of the total income (Table 4). This region of Bangladesh is renowned for the supply of seedlings throughout the country. An economic evaluation of the floating agriculture based on interviewing 30 farmers in Jamalganj upazila of the Sunamganj district in 2012 revealed that the monthly income of some farmers increased from approximately US$ 12 to US$ 48 after using this technique (Pavel et al., 2014).

The variation in profits from the floating agriculture practices of different regions could be a result of the differences in certain key factors such as the availability and cost of raw materials, labor cost, types of crops cultivated, quantity and quality of crops, size and number of beds owned by each farmer, scope for extension to winter cultivation, transportation facilities, and the local market price of the produced crops. Our analysis indicates that the main cost of floating agriculture is associated with the construction of the bed (cost of collecting the water hyacinths and other labor costs), which accounts for nearly 80–90% of the total cost, whereas the main income results from either selling the crop products and seedlings or the bed residues as compost (Table 4). The economic evaluation of the floating agriculture practice in Jamalganj upazila by Pavel et al. (2014) also indicates that more than 75% of the total expenditure is associated with bed construction. Therefore, this practice is more profitable in a region where there is high onsite

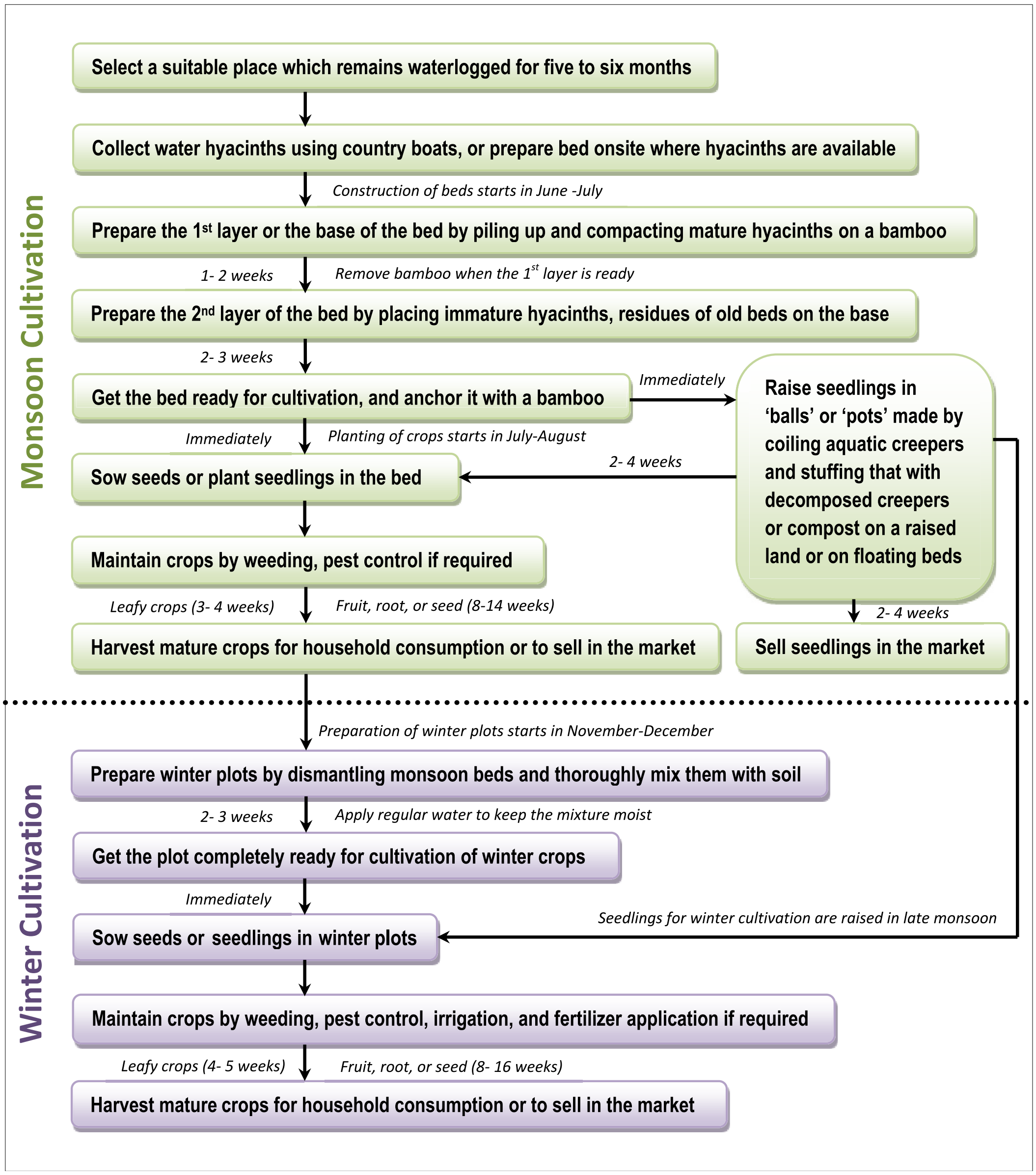

Fig. 3. A schematic view of the procedure of a typical floating agriculture practice in Bangladesh.

Fig. 4. Maintenance of growing crops in a floating bed (*Image Source: Dr. Tapan Kumar Ghosal, Environmental Specialist, SODEV Consult International Ltd.*).

availability of water hyacinths, low labor costs, and good market prices for the crops. The economic profits from floating agriculture might be even higher than what have been reported here, when considering the additional profits of farmers from reduced daily expenses for vegetable purchases to meet dietary requirements. For instance, in a scaling up project in 23 villages of the Kishoreganj and Sunamganj districts where 177 beds were prepared by 174 participants, floating agriculture was found to meet approximately 30–40% of the daily household vegetable requirements during the monsoon of 2007, while the winter cultivation met nearly 100% of the daily household vegetable demands (Irfanullah et al., 2011). In various floating agriculture projects from different regions, a number of farmers, including Mr. Sudhir Biswas from the Gopalganj project (IUCN Bangladesh, 2005), Mrs. Gulesha Begum and Mrs. Rupjan from the ORGANS project of the Kishoreganj and Sunamganj districts (IUCN Bangladesh, 2008), Mrs. Tara Begum and Mrs. Majeda Begum from the Gaibandha project (Practical Action, 2011; The Daily Star, 2013b), and Mr. Korban Ali, Mrs. Monwara Begum,

Table 3
Crops grown in floating agriculture practices of different regions in Bangladesh.

Monsoon crops (English name: *Scientific name*)	Winter crops (English name: *Scientific name*)
Amaranth: *Amaranthus* spp. [1, 4, 7]	Amaranth: *Amaranthus* spp. [4]
Bitter gourd: *Momordica charantia* [1, 6]	Arum: *Colocasia esculenta* [2]
Bottle gourd: *Lagenaria siceraria* [6, 7]	Bean: *Phaseolus vulgaris* [1]
Cauliflower: *Brassica oleracea var. botrytis* [5, 6]	Beet: *Brassica campestris* [5]
Ceylon spinach: *Basella alba* [7]	Bottle gourd: *Lagenaria siceraria* [1, 5]
Chilli: *Capsicum annum* [5, 6]	Broccoli: *Brassica oleracea* [4]
Cucumber: *Cucumis sativus* [1, 2, 3, 6]	Cabbage: *Brassica oleracea* [1, 5]
Chinese amaranth: *Amaranthus tricolor* [5, 7]	Carrot: *Daucus Carota* [1, 5]
Eggplant (brinjal): *Solanum melongena* [1, 5, 7]	Cauliflower: *Brassica oleracea var. botrytis* [1, 5]
Hyacinth bean: *Dolichos lablab* [4, 7]	Chilli: *Capsicum annum* [1, 6]
Indian spinach: *Basella alba* [1, 5]	Chinese amaranth: *Amaranthus tricolor* [5]
Jute: *Corchorus capsularis* [7]	Cowpea: *Vigna sinensis* [5]
Kang kong: *Ipomaea aquatica* [4]	Coriander: *Coriandrum sativum* [5]
Lady's finger: *Abelmoschus esculentus* [1, 2, 3, 7]	Garlic: *Allium sativum* [1]
Musk melon: *Cucumis melo* [6]	Ginger: *Zingiber officinale* [1, 5]
Pumpkin: *Cucurbita maxima* [1, 4, 5, 7]	Kang kong: *Ipomaea aquatica* [4]
Red amaranth: *Amaranthus cruentus* L. [1, 4]	Kohlrabi: *Brassica oleracea var gongylodes* [1, 5]
Ridged gourd: *Luffa acutangula* [1, 3]	Lady's finger (Okra): *Abelmoschus esculentus* [4, 5]
Snake gourd: *Trichdsanthes cucumerina* [1, 2, 7]	Potato: *Solanum tuberosum* [1]
Spinach: *Spinacea oleracea* [5]	Radish: *Raphanus sativus* [1, 5]
Sweet gourd: *Cucurbita maxima* [6]	Red amaranth: *Amaranthus cruentus* L. [4]
Taro: *Colocasia esculenta* [1, 5, 7]	Spinach: *Spinacea oleracea* [1]
Turmeric: *Curcuma longa* [1, 5, 7]	Tomato: *Solanum lycopersicum* [1, 5]
Water spinach: *Ipomoea aquatica* [7]	Turnip: *Brassica rapa* [1,6]
Water melon: *Citrullus lanatus* [6]	Yard long bean: *Vigna unguiculata* [1]
Wax gourd: *Benincasa hispida* [1, 5]	

Sources: [1]Haq et al., 2004 (Village Chandra of Jessore district); [2]Asaduzzaman, 2004 (Pirojpur and Gopalgonj districts); [3]Hossain, 2010 (Tungipara upazila of Gopalgonj district); [4]Irfanullah et al., 2011 (Villages of Kishoreganj and Sunamganj districts); [5]IUCN Bangladesh, 2005 (Chanda beel of Gopalganj district); [6]Islam and Atkins, 2007 (Nesarabad thana of Pirojpur district); [7]Irfanullah et al., 2008 (Baniachang upazila of Habiganj district).

and Mrs. Rahima from the Lamonirhat project (The Daily Star, 2012; Practical Action, 2014a) opined that after meeting their daily dietary requirements of vegetables, floating agriculture also helped them to earn income from selling vegetable products. Floating agriculture practices may also provide the farmers with an opportunity to earn additional income as labor in the construction of floating beds for others.

4.2. Multisectoral advantages of floating agriculture

Floating agriculture is advantageous not only from an economic perspective but also from an agricultural, environmental, and social and cultural perspective. The unique quality of providing multisectoral benefits ultimately makes it a viable technique for adaptation to flood and waterlogging conditions (Fig. 5). As outlined in Fig. 5, some of the key multisectoral benefits are that it relies on locally available materials, requires a low economic investment, and provides better crop production compared to land agriculture. In addition, this technique is completely organic in nature, requires no or less fertilizer and pesticides, and generates environment friendly residues that can be utilized as compost. Moreover, it supplies fresh vegetables to help meeting the dietary and nutritional demands of farming communities, helps to sustain their lives and livelihoods during floods, provides opportunities to earn income, increases land-holding capacity and reduces migration to urban areas. This technique also helps farming communities to sustain traditional knowledge and cultural practices, supports them in overcoming poverty, ensures women's empowerment, motivates the communities to work together and increases their capacity to adapt to the impacts of climate change. For instance, in the ORGANS project of the Kishoreganj and Sunamganj districts, approximately 75% of the 174 participants were women, a majority of whom successfully performed floating agriculture, and were able to contribute to the family income and food supply (IUCN Bangladesh, 2008). Approximately 60% of the participants of the Habiganj district project were also women, where it was observed that the participants who learned of floating agriculture through training and capacity building programs were keen to share their skills and products with their neighbors and relatives, which eventually improved social bonds (Irfanullah et al., 2008). The leading role and successful participations of women in floating agriculture were also reported in many other instances (Practical Action, 2011; The Daily Star, 2012; The Daily Star, 2013b; Practical Action, 2014a; Practical Action, 2014b; Anglican Alliance, 2015).

4.3. Suitability of floating agriculture as a technique for climate change adaptation

By nature, floating agriculture is only suitable to practice in the waterlogged condition. This unique quality allows farmers to transform the adverse impacts of climate change (such as floods and waterlogging) into an opportunity for agricultural production, which eventually makes it a perfect technique for climate change adaptation. According to the IPCC (2001: 880), climate change adaptation is an ‘adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It also refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with climate change.’ From our analysis of the available published information as presented in Fig. 5, it is evident that the indigenous floating agriculture practice of Bangladesh has almost all of the qualities to potentially make it a suitable adaptation technique according to the IPCC definition. Such qualities of floating agriculture include supporting farming communities to adjust their ecological, social, or economic systems during floods and waterlogged conditions; helping these communities to offset damages by continuing agricultural practices during floods; and

Table 4
Analysis of cost, income and profit of floating agriculture practice in different regions of Bangladesh.

Studies	Location	Size of the bed L = length W = width H = height (meter)	No. of bed	Cost			Income			Profit	
				Nature of cost Values in BDT[a] (BDT 75 = US$ 1)	Total cost BDT (US$)	Cost per m^2 bed BDT (US$)	Nature of income (from selling) Values in BDT	Total income BDT (US$)	Income per m^2 bed BDT (US$)	Total profit BDT (US$)	Profit per m^2 bed BDT (US$)
Haq et al., 2004	Village Chandra of Jessore district	L: 15 W: 2 H: 1	10	⇒ Construction of floating beds: 3000 ⇒ Collection of raw material (weeds): 1000 ⇒ Seed and seedling purchase: 600 ⇒ Bamboo and rope purchase, crop harvesting and maintenance: 1000	5600 (74.6)	18.67 (0.25)	⇒ Lady's finger (1800 Kg): 9000 ⇒ Ridged gourd (400 Kg): 2400 ⇒ Red amaranth (600 Kg): 3000 ⇒ Taro, Indian spinach (150 Kg): 600 ⇒ Compost (30000 Kg): 6000	21,000 (280)	70 (0.93)	**15,400 (205.5)**	**51.33 (0.69)**
IUCN Bangladesh, 2005	Muksudpur upazila of Gopalganj district	L: 9 W: 3 H: 1.5	3	⇒ Labor cost for constructing bed: 1080 ⇒ Buying Chinese amaranth seeds (50 g): 10 ⇒ Buying seeds of spinach, pumpkin, bottle gourd, cauliflower and wax gourd: 190 ⇒ Cost of pesticides: 100	1380 (18.4)	17.04 (0.23)	⇒ Red amaranth: 400 ⇒ Wax gourd: 300 ⇒ Bottle gourd, cauliflower and spinach: 2500 ⇒ Pumpkin: 500	3700 (49.3)	45.68 (0.61)	**2320 (31)**	**28.64 (0.38)**
Islam and Atkins, 2007	Nesarabad thana of Pirojpur district	L: 60 W: 1.5 H: 0.5	7	⇒ Collection of hyacinth (5250 Kg): 2100 ⇒ Collection of topapana (3500 Kg): 1400 ⇒ Collection of seeds: 700 ⇒ Collection of aquatic weeds: l700 ⇒ Collection of tall grass: 1400 ⇒ Labor cost and other: 4200	11,500 (153)	18.25 (0.24)	⇒ Different types of vegetables: 22000 ⇒ Seedlings: 43500	65,500 (873.5)	103.97 (1.39)	**54,000 (720)**	**85.72 (1.14)**

[a] Values of different products and services in BDT as stated in this Table are according to the corresponding year of study. Currently, the values of different products and services are higher than what have been presented (as reported by earlier studies) in this Table, and in some cases, the current values could be even three to five times higher. The conversion of BDT into US$ is according to the conversion rate of June, 2012 as BDT 75 = US$ 1.

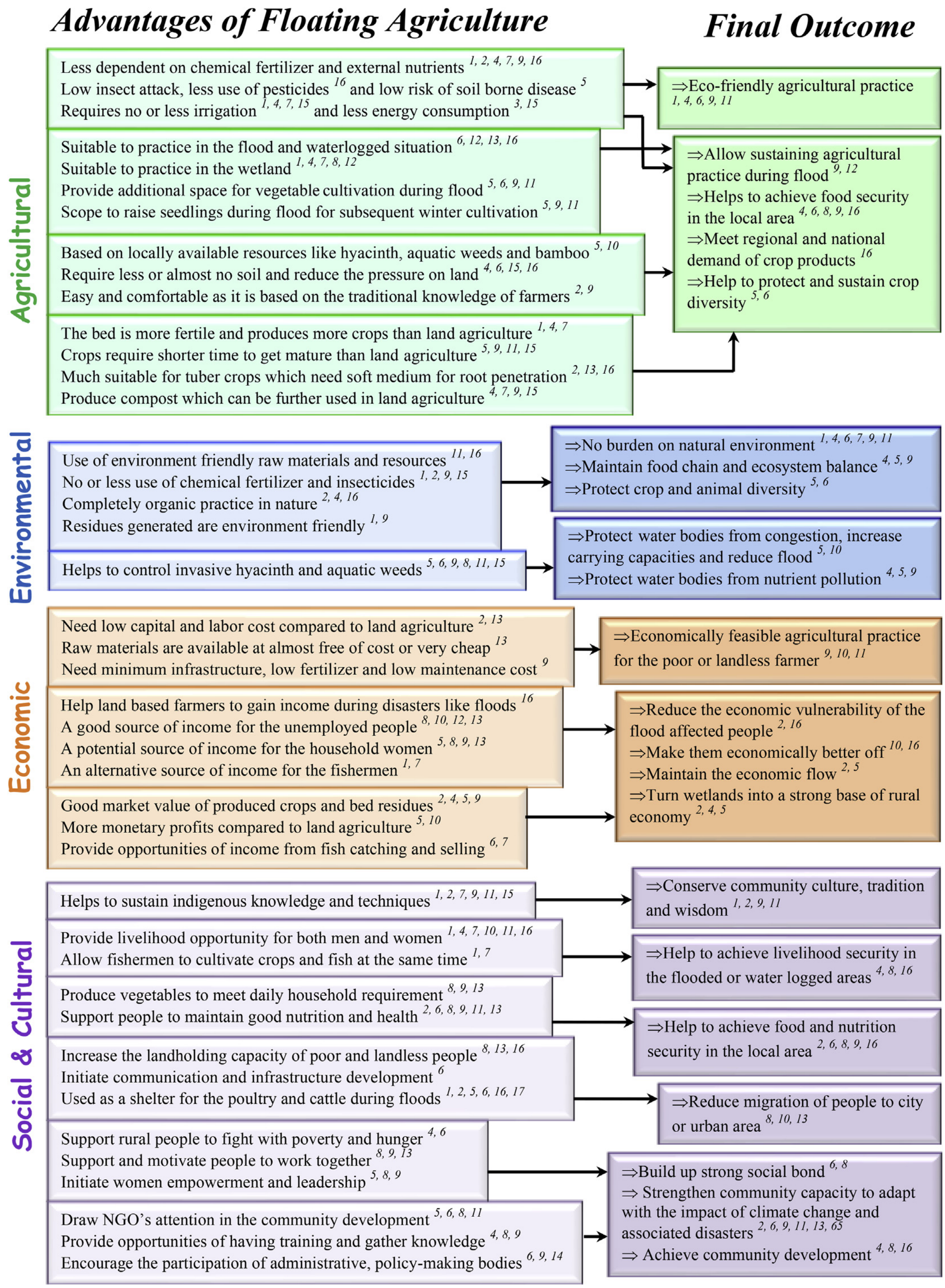

Fig. 5. Multisectoral advantages of floating agriculture, and their contribution to climate change adaptation and sustainable community development.
Sources: [1]Asaduzzaman, 2004; [2]BARCIK, 2010; [3]Dev, 2013; [4]Haq et al., 2004; [5]Haq et al., 2005; [6]Haq and Nawaz, 2009; [7]Hossain, 2010; [8]Irfanullah et al., 2008; [9]Irfanullah et al., 2011; [10]Islam and Atkins, 2007; [11]IUCN Bangladesh, 2005; [12]Mallorie, 2010; [13]MoEF Bangladesh, 2005; [14]Saha, 2010; [15]SATNET Asia, 2014; [16]Sen and Zaid, 2010; [17]UNEP, 2009.

allowing them to convert the adverse impact of climate change into an opportunity for crop production. In a working paper of the Tyndal Centre for Climate Change Research, Schipper (2007:6) attempted to explore the relationship between climate change adaptation and development and mentioned that 'an effective adaptation process would hinge on the ability of livelihoods, which includes social networks, cultural traditions, and activities that provide food and income, to be sufficiently flexible so that no adverse impacts of climate change are discernable on the social system.' The assessment of the diverse benefits of floating agriculture to the agricultural, environmental, economic, and social and cultural sectors (Fig. 5) indicates that this practice strongly matches the qualities of an effective adaptation process, as indicated by Schipper (2007:6). In addition, any technique like floating agriculture that is based on the indigenous knowledge of the community and utilizes locally available materials and resources is suitable for adaptation to climate change. Moreover, an agricultural practice that is sustainable over a hundred year period is likely to be effective in climate change adaptation. With all these considerations, indigenous floating agriculture holds great promise as a climate adaptation technique for Bangladesh.

In response to the decision of the seventh session of the Conference of Parties (COP7) of the UNFCCC, the Ministry of Environment and Forest (MoEF) of Bangladesh prepared the National Adaptation Program of Action (NAPA) and submitted it to the UNFCCC in November 2005. Based on the existing coping mechanisms and practices, NAPA suggested 15 future strategies for Bangladesh that would address the adverse impacts of climate change, including variable and extreme events. The 12th strategy was the 'adaptation to agriculture systems in areas prone to enhanced flash flooding in the northeast and central regions,' which considered the implementation of floating agriculture as an adaptation strategy to flood and waterlogged conditions (MoEF Bangladesh, 2005). Although a significant time period has been passed since NAPA was formed, sufficient initiatives have not been taken by the government for the promotion and practical implementation of floating agriculture as an adaptation strategy to climate change. Only recently in early 2013 has a remarkable US$ 1.6 million grant been approved by the government under the Bangladesh Climate Change Trust Fund to promote floating agriculture as an adaptation technique in a 3-year project in 8 districts of Bangladesh (Irfanullah, 2013b). If properly implemented and managed, this initiative could make a significant contribution to promoting the practice of floating agriculture as a climate change adaptation strategy in different flood-prone regions of Bangladesh.

Over the last decade, however, some local non-government and international organizations have made substantial efforts to strengthen the capacity of farmers and CBOs (Community Based Organizations) to sustain this indigenous technique of Bangladesh, particularly in regions where it has already been in practice for a significant period of time. Some other similar organizations have also attempted to introduce and promote this practice as an adaptation strategy in regions where it has not previously existed. It is a good sign that in the recent years, the use of indigenous floating agriculture as an adaptation to climate change in Bangladesh has received explicit mention in official documents of renowned international organizations involved in combating global climate change. For instance, one official document of the UNFCCC (United Nations Framework Convention on Climate Change) titled 'Technologies for adaptation to climate change' addressed the possibilities of utilizing floating agriculture as a climate change adaptation technique for Bangladesh (UNFCCC, 2006). In addition, a UNEP (United Nations Environment Program) guidebook included floating agriculture as a suitable technology for climate change adaptation in the agriculture sector (Clements et al., 2011). A recent Asian Development Bank report also highlighted floating agriculture as one of the potential technologies for climate change adaptation in developing Asia (ADB, 2014). The potentials of floating agriculture as a community based adaptation strategy in Bangladesh have also been addressed in a recent books series on disaster risk reductions (Habiba et al., 2013; Alam et al., 2013; Abedin and Habiba, 2015). In an interview with 'Nature News', Dr. Saleemul Huq, a pioneer and internationally renowned expert of climate change adaptation in Bangladesh mentioned that floating agriculture is one of the key climate change adaptation techniques in Bangladesh (Nature News, 2009). Irfanullah (2013c) also highlighted the growing interest of international scientific community in this fascinating adaptation technique. Moreover, in April 2014, a case study on floating agriculture technique of Bangladesh was presented in a workshop organized jointly by UNEP, the International Institute for Environment and Development (IIED), and the International Centre for Climate Change and Development (ICCCAD) for raising awareness, sharing experiences, and providing capacity building training to Asian partner countries on climate change adaptation technologies and their application (UNEP, 2014). Therefore, it is evident that the practice of indigenous floating agriculture practice in Bangladesh is receiving growing international attention as a technique for climate change adaptation.

A review on different organizational involvements in supporting and promoting floating agriculture practice in different regions of Bangladesh has been presented in Table 5. Most of these organizations achieved remarkable success in introducing and promoting this practice as an adaptation strategy for flooded and waterlogged conditions. An experimental floating agriculture plot used in the 'Baira' project of the Gopalganj district has been presented in Fig. 6. To demonstrate the possibilities of floating agriculture as a suitable technique for climate change adaptation in Bangladesh, here, we present evidence of the success of projects that attempted to introduce and promote floating agriculture in the flood-prone regions of Bangladesh. For instance, when floating agriculture was first proposed in the village Chandra of the Jessore district by the Wetland Resource Development Society (WRDS) under the 'Reducing Vulnerability to Climate Change' project (2003–2005), villagers did not initially believe that it is possible to cultivate on water. However, after receiving training and technical supports, more than 150 villagers began to practice floating agriculture, and they eventually realized that this practice is more beneficial and produces more crops compared to terrestrial agriculture (Haq et al., 2004). The success of that project encouraged the WRDS to continue these promotional activities with a second phase (2007–2008) supported by Action Aid (an international voluntary organization) under the project titled 'Adapting to waterlogging situation through the promotion of floating gardens' in four new unions (rural administrative unit) of the same district. Although it was a comparatively short-term project, the outcome of this project in terms of farmer's profitability was quite significant (Haq and Nawaz, 2009).

A satisfactory outcome was also observed in another pilot project (2005–2006) of the IUCN and CARE Bangladesh that introduced and promoted floating agriculture to 21 vulnerable families in three villages of the Baniachang upazila in the Habiganj district. After the introduction of floating agriculture, a number of positive changes such as an increase in villagers' knowledge of floating agriculture, vegetable production for household consumption, income generation (through selling vegetables), community mobilization and increased land-holding capacity were observed in those villages (Irfanullah et al., 2008). Because of the success of the floating agriculture practice in this project, these two organizations jointly developed another follow-up project (2007–2009) titled 'Organizing Resource Generation and Nutritional Support (ORGANS)' for another four districts of haor regions in Bangladesh. Despite some challenges, in the first year of the project with 174 participants in 23 villages of the Kishoreganj and Sunamganj districts that coincided with the repeated and devastating floods of 2007, floating agriculture provided tremendous support towards improved household income, nutritional security, and land-use capacity of the poor and landless people during the post disaster period (IUCN Bangladesh, 2008). Even people who were initially doubtful of the success of floating agriculture were highly satisfied and praised the practice at the end of the project (IUCN Bangladesh, 2009). A second phase (2012–2014) of the ORGANS project that is primarily aimed at organizing and establishing 1000 community-based floating gardens was ongoing (IUCN Bangladesh, 2012b). Moreover, in a 5-year (2004–2009) project

Table 5
Projects and organizational involvements relating to floating agriculture practices in different regions of Bangladesh.

Project title	Organization	Location	Key objectives	Duration
"Baira: the floating gardens for sustainable livelihood" under the Sustainable Environment Management Program (SEMP) [1]	IUCN Bangladesh, and Bangladesh Centre for Advanced Studies (BCAS)	Madhumati floodplain areas in Gopalganj and Madaripur districts (South-west region)	⇒ Utilize local knowledge, and participatory planning and interventions to promote Baira farming as an alternative livelihood option, ⇒ Illustrate the Baira extension initiative taken under SEMP.	Late 1998 to December, 2005
"Soil-less agriculture in waterlogged areas" under Reducing Vulnerability of Climate Change (RVCC) project [2, 3]	WRDS (Wetland Resource Development Society) and CARE, Bangladesh (funded by Canadian International Development Agency)	Village Chandra of Jessore district (South-west region of Bangladesh)	⇒ Improve the livelihood and food security, ⇒ Familiarise all villagers with soilless farming, analyse its potential, and actively involve farmers in producing crops	2003 to 2005
"Introduce and promote environment-friendly, natural resource-based floating gardening and associated winter gardening" under the SHOUHARDO Program [4, 5]	IUCN Bangladesh and CARE Bangladesh (funded by USAID under SHOUHARDO program)	Baniachang upazila of Habiganj district (North-east region)	⇒ Contribute to the food security of targeted marginalized communities, ⇒ Test the feasibility of floating gardening as an option for alternative livelihoods in the vulnerable communities.	2005 to 2006
Disappearing lands: supporting communities affected by river erosion [6]	Practical Action (an international voluntary organization)	Gaibandha district (North-west region)	⇒ To reduce vulnerability of men, women and children to the physical, social, economic and political effects of river erosion, flooding and other natural disasters in the Gaibandha district, ⇒ Motivating and engaging farmers in floating agriculture practice.	2004 to 2009
"Organizing Resource Generation and Nutritional Support (ORGANS)" under the SHOUHARDO program [5, 7]	IUCN Bangladesh and CARE Bangladesh (funded by USAID under SHOUHARDO program)	Villages of Kishoreganj, Sunamganj, Habiganj and Netrokona districts (North-east region)	⇒ Organize and establish a community based 1000 floating gardens and 1000 winter gardens by utilizing locally available natural resources, ⇒ Support nutritional deficiencies of poor household members and enhance their family income through increasing vegetable production, consumption and selling, ⇒ Enhance their capacity through the involvement of Village Development Committee (VDCs) members in the year round vegetable gardening initiatives, ⇒ Encourage conveniently selling of vegetable produces of community gardeners to neighbors and in local markets, ⇒ Raise awareness and capacity.	April, 2007 to June, 2009

Sources: [1]IUCN Bangladesh, 2005; [2]Haq et al., 2004; [3]Haq and Nawaz, 2009; [4]Irfanullah et al., 2008; [5]IUCN Bangladesh, 2012a; [6]Practical Action, 2010; [7]IUCN Bangladesh, 2009.

in the Gaibandha district by Practical Action (an international voluntary organization), only 10 farmers were initially engaged with 15 floating beds on a trial basis in 2005. Over the course of the project, the number of farmers increased to 423, and they produced nearly 50,000 kg of vegetables from floating agriculture (Practical Action, 2010). Through a UK-aid funded project between 2010 and 2012, Practical Action trained and involved approximately 700 poor families in four northern districts of Bangladesh in the practice of floating agriculture. These families produced approximately 131,600 kg of vegetables (worth approximately US$ 20,500) on nearly 1500 floating beds during the monsoon months, and the supply was sufficient to meet their average household demand of vegetables (Irfanullah, 2013b). Apart from these, positive outcomes were also observed in a number of other experimental and promotional floating agriculture projects (IUCN Bangladesh, 2005; The Daily Star, 2012; HSI BD, 2013). A household survey (involving 120 participants) in the low lying areas of north-eastern Bangladesh also identified floating agriculture as one of the popular climate change adaptation strategies (Anik and Khan, 2012).

Fig. 6. Experimental floating agriculture plot in the 'Baira' project of BCAS in the Gopalganj district (*Image Source: Md. Golam Rabbani, Research Fellow, BCAS*).

Despite the success, some challenges were reported regarding the promotion of floating agriculture. For instance, in the second phase (2007–2008) of the WRDS project in the Jessore district, organizing poor farmers at the grass-roots level and developing their capacity as small-scale entrepreneurs was found to be challenging (Haq and Nawaz, 2009). In the pilot project of the Habiganj district, challenges were related to convincing the community to accept floating agriculture, identifying the availability of water hyacinth and other raw materials, protecting the floating bed from wave actions during heavy flood, and selecting the appropriate crop types for floating cultivation (Irfanullah et al., 2008). Irfanullah (2013b) highlighted a number of limitations of the development agencies involved in promoting floating agriculture in Bangladesh. These limitations include a failure to develop entrepreneurs; inability to recognize the potential of this technique to thrive in new locations; putting more emphasis on the seasonal benefits such as household nutrition security, rather than on the key facts such as seasonal variability in the availability of mature water hyacinths and marketing opportunities for the produced crops; and a lack of follow-up project or long-term engagement to assess the sustainability of this practice in a new location.

4.4. Possibility of floating agriculture as a tool for sustainable community development

The development in farming communities that results from floating agriculture practice is somewhat comparable to the concept of 'sustainable development.' According to the renowned definition of by the Brundtland Commission (1987), 'sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' Our review indicates that floating agriculture has the potential to support farmers by meeting their current demands for food and nutrition together with building their capacity to sustain agricultural practices that safeguard food and nutritional security for future generations. Economic growth, environmental protection, and social progress are widely regarded as the three main pillars of sustainable development (Adams, 2006). According to the Johannesburg Declaration on Sustainable Development (2002), "to achieve sustainable development, a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development viz. economic development, social development and environmental protection is required at the local, national, regional and global levels". The multisectoral benefits of floating agriculture as presented in Fig. 5 indicate that apart from supporting the farming communities to adapt to flood and waterlogged conditions, floating agriculture helps them to achieve economic growth and social progress while also protecting the environment, which is a clear indication of sustainable development. Moreover, farmers of certain regions in Bangladesh have been successfully performing this practice for more than 100 years (IUCN Bangladesh, 2005; Islam and Atkins, 2007; Irfanullah, 2009; Haq and Nawaz, 2009), which is a long enough time period to claim it as a sustainable practice. Lichtfouse et al. (2009:3) stated that 'agricultural systems are considered to be sustainable if they sustain themselves over a long period of time, that is, if they are economically viable, environmentally safe and socially fair'. Our review confirmed that the indigenous floating agriculture practice of Bangladesh has almost all of the characteristics of sustainable agriculture as stated by Lichtfouse et al. (2009:3). The potential of floating agriculture as a sustainable agricultural practice was also highlighted by Padmavathy and Poyyamoli (2011). We believe that a sustainable practice like floating agriculture could enormously support a farming community in achieving sustainable development.

Based on our understanding of the multisectoral benefits of floating agriculture as well as its suitability for climate change adaptation as discussed in this review, we have attempted to conceptualize the mechanism through which floating agriculture could be rendered as an effective tool for sustainable community development in Bangladesh (Fig. 7). We believe, If properly planned and managed, floating agriculture could simultaneously contribute to the development of a number of key sectors viz. agricultural, environmental, economic, social and cultural sectors, and once improvements are achieved in one sector, this success might contribute to the development of other sectors because all of these sectors are interlinked and influenced by the changes in the others. For instance, floating agriculture could primarily support the farmers to meet their dietary demands and earn money by selling vegetables. Once the economic conditions of the farmers have improved, they might be capable of investing more capital (increased capacity of purchasing raw materials and labor) in the construction of additional floating beds, which in turn would support the sustainability of the floating agriculture practice. A sustainable floating agriculture practice might allow farmers to produce additional crops and earn more income from selling the crop products. Consequently, this condition could provide them with an improved social and cultural life by alleviating poverty, providing food and nutrition, reducing migration to urban areas and providing a venue to exercise their traditional and cultural practices, which eventually could add to the sustainability of their social and cultural lives. Once social and cultural sustainability has been achieved, the farmers may be inspired to work together and promote a participatory approach for environmental protection, which in turn could help achieve the sustainability of the environment. A sustainable environment, on the other hand, could support the economic sector by providing more natural resources for economic activities and reducing pollution abatement costs. Therefore, it is reasonable that the sustainability of one sector achieved through the floating agriculture practice, could contribute to the sustainability of other sectors, which may eventually support a farming community in achieving holistic development. For the better demonstration of this concept, a number of similar explanations could be provided from Fig. 7. Although our conceptualization is only based on the positive aspects of floating agriculture, in order to obtain a better and more realistic understanding of the possibilities of floating agriculture as a tool for holistic community development, the uncertainties and challenges relating to the sustainability of this technique (discussed in the following section) should also be considered. However, we believe that the conceptual representation of the interactions of various sectors in terms of achieving holistic development through floating agriculture practice (Fig. 7) could provide a new perspective on how different vital sectors interact and contribute to each other in a process of holistic and sustainable development that resulting from a particular type of adaptation technique.

4.5. The sustainability challenges of floating agriculture

Although floating agriculture is highly beneficial as an adaptation technique in flooded and long-term waterlogged conditions, it is not free from limitations. A number of challenges to the sustainability of this practice have been assessed in this review and are discussed below.

4.5.1. Challenges related to the availability of raw materials, and storage and transportation of produced crops

Sometimes, there is a paucity of raw materials such as water hyacinth, aquatic weeds, and stubble in some regions, which can make it difficult to practice floating agriculture (Asaduzzaman, 2004; Irfanullah et al., 2008). The availability of water hyacinths usually becomes low after a heavy flood. In the ORGANS project, after the devastating flood in 2007, the availability of water hyacinths became very low in 7 villages of the Sunamganj district and 3 villages of the Kishoreganj district. Two additional villages in Kishoreganj became completely devoid of water hyacinth after the flood (IUCN Bangladesh, 2008). Moreover, the use of water hyacinth as cattle feed or for protecting homestead plinths from flood waves can also lower its availability (Irfanullah et al., 2011). If hyacinths are available but at a distance from the optimal location to build a bed, transporting the hyacinths to that location is difficult and

Fig. 7. Conceptualizing the interrelationship among vital sectors and their contribution to each other in a sustainable development process that results from floating agriculture practice.

increases the cost (IUCN Bangladesh, 2005; Irfanullah et al., 2008), which ultimately reduces the economic efficiency of this practice. Another problem with using water hyacinth is that it cannot survive in saline water (FAO, 1996). In some regions of Bangladesh where there is an absence of paddy (Aman) straw, water hyacinth and other aquatic plants are used as the main elements for constructing floating beds. In such places, a shortage of water hyacinth because of saline water intrusion can make the implementation of floating agriculture practice impractical. Sen and Zaid (2010) reported that because of the increased intrusion of saline water into the Chandar beel in Gopalganj district by the rivers from southern side, the production of water hyacinth was significantly reduced. Due to the shortage of water hyacinth resulting from the increased salinity of water, the floating beds of some farmers in the Gopalganj district have been recently decreased by approximately 30–35% compared to the previous years (Alauddin, 2014). Shortages and high costs of good quality seeds and seedlings of preferred crops could also lower the productivity of floating agriculture (Haq, 2009; Irfanullah et al., 2011).

A lack of storage and transportation facilities for produced crops is another significant challenge to the economic sustainability of floating agriculture. Because of the low availability of land space in waterlogged areas, storage of harvested crops becomes difficult. In addition, waterlogged conditions in the areas surrounding the floating beds, remote production locations, and high transportation cost could make it problematic to transport crop products to the market (Asaduzzaman, 2004; Irfanullah et al., 2008; MoA Bangladesh, 2015). In the current practice in Bangladesh, there is also lack of organized marketing systems and agro-processing facilities for the produce from floating agriculture (MoA Bangladesh, 2015). Because of inadequate logistics, a considerable amount of crops could remain unharvested and spoil before reaching the market.

4.5.2. Challenges induced by natural calamities and climate variability

Floating agriculture is not suitable for all types of water bodies, particularly those with frequent tidal interruptions. The physical structure of the bed cannot endure heavy floods or strong waves and such waves can cause the bed to drift and increase the probability of damage to seeds, seedlings and the raft (IUCN Bangladesh, 2008; MoA Bangladesh, 2015). In the experimental project of the Kishoreganj and Sunamganj districts in 2007, a total of 200 floating platforms were prepared in July, and 23 were damaged by recurring floods in August–September (Irfanullah et al., 2011). Heavy rainfall sometimes results in excessive stagnant water on the bed that can cause rotted seedling shoots and roots (Irfanullah, 2009; Rahman, 2014). The problem of stagnant water could result from a lack of proper drainage systems in the bed. Therefore, future designs of floating beds should incorporate proper system to drain out excessive water.

By its nature, floating agriculture is highly dependent on climatic conditions. Long-term waterlogged conditions are a requirement for this practice, and this condition may vary with the variability of climatic events, such as heavy rainfall, floods, and drought. The productivity of crops in floating beds could also vary with changes in weather patterns. Some studies already indicated that climate variability could prove challenging to the sustainability of floating agriculture. For instance, because of the shortage in rainfall during the pilot project of the Habiganj district in 2006, the farmers in the haor area who had prepared their beds in early July in shallow water, experienced difficulty in cultivating their floating beds. In the same project, the majority of the pumpkin and bottle gourd seedlings did not survive because of the unusual monsoon (Irfanullah et al., 2008). A 2008 questionnaire survey of farmers (of ages ranging from 25 to 80 years) of the Gopalganj district who had been practising floating agriculture for many years (ranging from 7 to 60 years) revealed that climate variability caused a reduction in floating agriculture productivity by increasing pest attacks, increasing requirements for chemical fertilizer, and decreasing availability of raw materials (mainly water hyacinths). The respondents also opined that despite doubling the number of floating beds, the productivity and income from floating agriculture reduced compared to that of previous years, and as a result, farmers were gradually losing interest in floating agriculture (Irfanullah, 2009). Irfanullah (2013c) stressed that it is questionable to view floating agriculture, a practice which is too dependable on climatic events, as the most feasible strategy for climate change adaptation when the climatic events (for instance, rainfall) are becoming increasingly uncertain.

4.5.3. Challenges related to plant diseases and pest attacks

Because the bed remains moist most of the time, the likelihood of fungal attacks on seeds and seedlings is high (Asaduzzaman, 2004). Diseases caused by viruses, bacteria and fungi, such as die-back, damping off, wilt and mosaic, are sometimes found in the plants of the floating beds (IUCN Bangladesh, 2005; The Daily Observer, 2015). Protecting plants from fungal attack may require the application of fungicides, which may eventually increase the maintenance cost and cause unforeseen environmental consequences. Floating beds can also become infested by rodents (rats) and insects (ants, aphids, cutworms, fruit-borers, etc.) that cause damage to seeds, seedlings and growing plants (Asaduzzaman, 2004; IUCN Bangladesh, 2005). In addition, ducks and other animals such as cows, monitor lizards, etc. can cause damage to growing plants in the floating beds (IUCN Bangladesh, 2008; Haq, 2009; Choudhury and Bepary, 2014). Several bird species were reported as causing damage to the fruits of the pumpkin group (IUCN Bangladesh, 2005). Pest infestation increases the difficulty of maintenance activities and lowers the crop productivity.

4.5.4. Social and political challenges

As the majority of farmers in Bangladesh are economically poor and low-literate, it gets quite challenging to introduce and promote new adaptation techniques. At the beginning of most projects, the farmers were skeptical about floating agriculture and not likely to be convinced to accept it (Haq et al., 2004; Irfanullah et al., 2008, 2011; IPS, 2012; Alam, 2012). A lack of sufficient financial means to purchase the necessary materials and facilities for floating agriculture practices can also result in an unwillingness of farmers to pursue this technique. Generally, farmers do not obtain any type of financial support or incentive from the government to practice floating agriculture.

Another major challenge to the sustainability of floating agriculture in Bangladesh is the problem of encroachment into wetlands suitable for this practice, and the subsequent misuse of political power in this regard. In Bangladesh, floating agriculture is usually practiced in Khas or common property wetlands and these areas are often claimed by politically or financially powerful residents, and poor farmers are prevented from using these areas for agricultural practice (Islam and Atkins, 2007; Bertram, 2015). Although they sometimes allow the farmers to use their claimed space, it requires a significant financial bribe. In the Habiganj project (2005–2006) by the IUCN and CARE, only one-third of the total participants prepared winter gardens using the residues of monsoon floating beds because of a shortage of suitable land (Irfanullah et al., 2008).

5. Policy implications and future research requirements to render floating agriculture as a sustainable climate change adaptation technique for Bangladesh

The sustainability challenges of floating agriculture practice that we highlighted in this review should be considered as the prime areas for interventions to transform this technique as a sustainable climate change adaptation strategy for Bangladesh. Enhanced and adequate supports from the governmental, non-governmental and international organizations are needed to strengthen the capacity of poor farming communities involved in this practice and increase their resilience in the face of climate change. For instance, facilities such as the provision of necessary knowledge and training as well as sufficient logistics and financial supports that are required from the initial stage of bed preparation to the final stage of storage, transport, and marketing of crop products could greatly motivate farmers to sustain this practice. Training should focus primarily on developing the skills of constructing floating beds, cultivating suitable crops, maintaining crops growth, encouraging and sharing the knowledge within communities and passing down through generations over time (Linham and Nicholls, 2010). It is a good sign that some NGOs viz. Wetland Resource Development Society (WRDS), IUCN, CARE, Practical Action have already put substantial efforts to provide training on this technique to a large number of farmers around the country (IUCN Bangladesh, 2005; Irfanullah et al., 2008; IUCN Bangladesh, 2009; IRIN, 2010; Practical Action, 2010), and these efforts need to be continued with enhanced coverage. Recently, Bangladesh government through its Department of Agricultural Extension (DAE) has initiated a project in 42 upazilas of the south-central districts to strengthen current farm level activities to improve the production system and transfer this technique in similar wetland ecosystems (MoA Bangladesh, 2015). However, the government needs to take urgent action to provide security of tenure to waterlogged areas for farmers to grow and harvest the raw materials required to construct the beds before local corrupt practices become entrenched. Necessary mechanisms should also be developed by the government to provide adequate assistance to private, community-based, non-governmental, and international organizations that involved in introducing and promoting floating agriculture in the flood-prone regions of Bangladesh. In the Habiganj project, a good relationship with the local government office proved to be a great support in introducing this technique to the local people (Irfanullah et al., 2008).

Moreover, the government needs to ensure the proper implementation of NAPA strategies that aim to promote indigenous floating agriculture as well as the appropriate and corruption-free utilization of the Climate Change Trust Fund invested for such promotion. Mahmud and Prowse (2012) highlighted that corruption is a potential barrier to successful climate change adaptation in Bangladesh and without increasing honesty, hard-won funding is not likely to enhance the resilience of poor communities to the level it should. Mainstreaming floating agriculture practice in the ongoing development planning of Bangladesh could also help to strengthen the sustainability of this indigenous technique. Haq (2009) stressed that the success of the floating agriculture as a sustainable farming practice depends on motivating and organizing poor farmers at grass-root level, strengthening their capacity as micro and small entrepreneurs, and its integration with government's mainstream agricultural planning process. The overview of Ayers et al. (2014) on the case of mainstreaming climate change adaptation into development in Bangladesh could provide some useful insights in this regard. A systematic evaluation of the floating agriculture practice of Bangladesh using a Modified Sustainable Livelihood Framework (MSLF) towards the conceptual development of the Globally Important Agricultural Heritage Systems (GIAHS), pointed out a number of shortcomings of the existing management system and provided some directions for improvement (Hutton et al., 2015). Some of the recommendations include need for baseline assessment and detailed database, governmental involvement in promoting this technique, coordination among government and other stakeholders for the field level implementation, and the recognition of this technique both nationally and internationally. The Ministry of Agriculture of Bangladesh government has recently developed a GIAHS site proposal on indigenous floating agriculture practices (MoA Bangladesh, 2015). This proposal includes a dynamic conservation plan that outlines a number of essential activities (such as preparing scientifically recommended crop production packages; developing road communications, marketing and value addition facilities; and providing training to farmers on the modern techniques of crop production) obtained through participatory and community-driven approaches. Proper implementation of this plan could contribute towards the sustainability of this indigenous practice in the south-central districts of Bangladesh. Policy interventions towards sustainable floating agriculture should also incorporate necessary mechanism to enhance its potential as an ecosystem-based adaptation (EbA) strategy that ensures restoration, enhancement, conservation and effective use of natural resources with the active participation of local communities so that the natural ecosystems function properly and provide services for the benefits of nature and local livelihoods (Rahman, 2014). Jones et al. (2012) stressed that EbA provides flexible, economically effective and widely applicable alternatives for minimizing the impacts of climate change, while curbing several shortcomings of hard infrastructure. However, we argue that before widely disseminating this practice in different regions of Bangladesh, adequate high quality research should be done to understand its scientific basis as well as long term social, economic, and environmental implications. Hiwasaki et al. (2014) stressed that local and indigenous knowledge should be integrated with science prior to its utilization in policies, education and actions relating to disaster rick reduction and climate change. Above all, we suggest for a comprehensive fieldwork based assessment covering the entire country (staring from local to national level) to identify the current conditions as well as the probable future challenges relating to the floating agriculture practice of Bangladesh. Finally, based on the outcomes of that assessment, adequate long-term and effective policy and management initiatives should be formulated and properly implemented at the national, regional, and local levels to manage this practice as a sustainable adaptation strategy for Bangladesh. In the following sections, we highlight a number of future research requirements that can form the basis of such assessment.

5.1. *Assessing the current situation*

The current situation must be assessed based on the identification of key facts such as the total amount of flooded or waterlogged areas that are currently used for floating agriculture practice in Bangladesh; total quantity of various crops produced through this practice and their current market value; and total number of people involved in this practice, their average annual income, diverse benefits they obtain from such practice and the influence of those benefits in achieving sustainable community development and avoiding migration to urban areas. In addition, field based investigations are required to rigorously assess floating agriculture's current role in strengthening social bonds, initiating participatory approaches for community development, empowering women, sustaining cultural practices and developing infrastructure in the flood-prone regions of Bangladesh. A comprehensive assessment of the existing social, economic, and political challenges relating to this practice is also required, and this assessment should include the impacts of these challenges on the life and economic productivity of farmers, and the current efforts made by farmers to overcome these challenges. Moreover, it is necessary to identify the regions where farmers have been sustainably practising this technique for many years and the factors that made it sustainable in those regions. There is also need for collecting adequate information on the role of various local NGOs and international organizations in introducing and promoting the practice to new regions, the challenges and successes that they experienced, and their ability to use the lessons from successes in other regions. Apart from these, the available government policies and initiatives that either support this practice or hinder it must be identified.

5.2. *Assessing future challenges and opportunities*

Along with assessing the current conditions, there is a requirement for evaluating the future opportunities and challenges relating to floating agriculture practices in Bangladesh under various scenarios of flood and waterlogging induced by global climate change. Such scenario analyses should identify the total amount of land area of Bangladesh that could be flooded and waterlogged in the future, the proportion of such areas that could be utilized for floating agriculture practice, and the number of unemployed and landless farmers that could be employed with that and prevented from migrating to urban areas. It is also necessary to assess the possible amount of the various types of crops that could be produced through floating agriculture in Bangladesh in the future, their monetary value, the dietary demand of the number of people could be met with that amount of crops, and the total damage (in monetary value) to the agricultural sectors that could be avoided through floating agriculture. In addition, an extensive economic analysis should be conducted to determine the costs and benefits of this practice under different climate change scenarios as well as modified environmental, social, economic and political conditions of Bangladesh. Moreover, the productivity of this practice must be verified against different scenarios relating to the intrusion of saline water from rises in sea level, particularly in the southern part of Bangladesh. Based on the outcome of these assessments, sufficient measures should be taken to enhance the future opportunities and minimize the challenges.

5.3. *Assessing key facts related to agricultural productivity*

Sustainability of floating agriculture to a great extent depends on the availability of raw materials and other logistics. Thus, future research should focus on addressing challenges related to the availability of raw materials and logistics as well as determining methods of minimizing those challenges. Emphasis should be given to assessing the current availability of raw materials in different regions of Bangladesh, limitations that exclude farmers from accessing raw materials and other logistics, and support required to overcome these shortcomings. In addition, the trend of availability of raw materials (water hyacinth, aquatic weeds) with time must be identified along with the reasons behind the trend, their future availability in different regions, their relation with climate variability, and the possible measures that could be taken to increase their availability through effective management. Irfanullah (2013b) also stressed the need for assessing the regeneration rate of water hyacinths under different temperature and hydrological conditions. Moreover, additional research is required to determine the possible alternatives of the raw materials so that this practice might be sustained even when their availability is low.

Field experiments are also required to identify certain key information such as the types and combinations of raw materials that make the bed more fertile, nutrient quality of the bed at different stages of its life, nutrient quality of residues generated from the bed, benefits of utilizing these residues for land-based or winter cultivation, the amount of different chemical fertilizers that could be avoided by using these residues, and the market value of such residue. Moreover field trials should be performed to determine the crops that are more suitable for floating agriculture, crops that are suitable for monsoon or winter cultivation, combinations of different crops that give better production, common diseases of crops in floating beds, and possible methods of protecting plants from diseases and pest attacks. In addition, experiments are necessary to identify the scope and ways of safeguarding the adequate availability of quality seeds and seedlings as well as providing proper storage, transport and marketing facilities for the produced crops.

5.4. Assessing key facts related to environmental productivity

Assessment of the environmental productivity of floating agriculture may require identification of a number of key facts, such as the amount (weight) of harmful chemical fertilizers and pesticides that could be avoided through this practice, the type and amount of vital nutrients (nitrogen, phosphorus) that are possible to recover and recycle from water bodies by utilizing water hyacinths for bed construction, and the role of such construction in avoiding water pollution and eutrophication. In addition, the possibilities of using floating agriculture for recreational and ecotourism purposes and what such a contribution would make to the local economy and infrastructural development should be assessed. Moreover, the role of floating agriculture in biodiversity (particularly birds and reptiles) conservation should be examined. Apart from these, the probability of nutrient runoff or leakage from the beds to the water and the potential of floating beds to cause nutrient pollution must be assessed. Testing the quality of water surrounding the beds could provide useful information in this regard. Irfanullah (2013a) also raised some environmental and health related concerns of floating agriculture for instance, decomposition of beds in stagnant water, and risk of heavy metal and pathogen borne contamination of crop products. Therefore, experiments are necessary for verifying whether there are any health issues among the farmers that might be associated with this practice. Given the associated environmental benefits such as minimizing energy use and GHG emission from avoiding the use of fertilizer, pesticides and irrigation, conserving wetlands that sink large amount of carbon, and avoiding massive dewatering cost of using the land for conventional agriculture; the possibilities of floating agriculture as a Clean Development Mechanism (CDM) should also be examined (Haq, 2009).

5.5. Assessing the scope of technological and scientific interventions

The technological and scientific interventions that could make floating agriculture more productive, profitable and sustainable as a climate change adaptation strategy must be identified. Provided that floating agriculture is completely organic practice in nature, biotechnological approaches could be used to increase the crop productivity, and future research should focus on this area. In addition, experiments are required to assess the strength of floating beds when presented with sudden heavy rainfall (Irfanullah, 2013b) and identify the appropriate bed design to overcome problems of bed damage from heavy rainfall and crop damage from stagnant water. Research is also required to explore how the bed performs in terms of crop productivity if artificial materials such as plastic tubes, PET bottles, or other buoyant materials are used as the base of the bed. Moreover, the possibilities of improvising this technique (according to local conditions) to perform it in combination with fish cultivation and duck rearing should be investigated, however, farmers of some regions in Bangladesh have already attempted such improvisation (Dhaka Tribune, 2013; The New York Times, 2014; ANEP, 2014).

6. Conclusions

In this review, we have examined the potentials of indigenous floating agriculture as a technique for climate change adaptation and sustainable community development in Bangladesh. Our review indicates that the floating agriculture practice can significantly support the farmers to sustain lives and livelihoods during floods and long-term waterlogged conditions. We observed, this technique is not only suitable as an agricultural practice but is also environmentally sound, economically feasible, and socially viable. The most important feature of floating agriculture is that it is based on the traditional knowledge of farmers and locally available materials. Our review of a number of case studies on the experimental and promotional floating agriculture projects in the flood prone regions of Bangladesh indicates that this technique can potentially support farming communities to adapt to the flooding and long-term waterlogged conditions by providing a means for producing vegetables for households consumption, generating incomes through selling vegetables, and mobilizing community activities. Moreover, this technique has the potential to build community capacity for sustaining agriculture practices to adapt to future disastrous conditions. Therefore, the proper utilization of this technique could substantially reduce the vulnerability of the agriculture, environment, economic, and social sectors in the flood-prone regions of Bangladesh. Although this practice has several sustainability challenges, mostly associated with the inadequacy of logistics; these can be overcome through improved policy and management initiatives at the national, regional and local levels as suggested in this review. We believe, through proper planning and the appropriate execution of planned activities by the government, this traditional practice can be rendered as a sustainable technique for climate change adaptation in Bangladesh. Once floating agriculture becomes widely successful and sustainable in Bangladesh, the knowledge and techniques of this practice could be utilized in a technology transfer to other countries that are in need of similar adaptations to climate change induced floods and long-term waterlogging, and have similar conditions such as high onsite availability of water hyacinths, availability of marginalized communities that are interested in such agricultural practice, low labor costs, favorable weather and climatic conditions for growing vegetables, and good market price for the floating agriculture products. However, before widespread transfer of this technology, some small scale pilot projects should be undertaken to investigate the feasibility of floating agriculture practice for such countries.

The baseline information on the floating agriculture practice of Bangladesh that we generated through the current review could be utilized to produce effective guidelines for any future research relating to this indigenous adaptation technique. Our current assessment of the potency of indigenous floating agriculture as a technique for climate change adaptation is primarily based on an evaluation of the information from available published literature. Therefore, additional field-based research and scientific experiments are required to validate the potential of floating agriculture as a suitable technique for climate change adaptation and sustainable community development in Bangladesh. The future research needs as identified through this review could be effectively utilized in this regard.

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