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Agricultural innovation and adaptation to climate change: empirical evidence from diverse agro-ecologies in South Asia

Gopal Datt Bhatta[1,7] · **Hemant Raj Ojha**[2] · **Pramod Kumar Aggarwal**[1] · **V. Rasheed Sulaiman**[3] · **Parvin Sultana**[4] · **Dhanej Thapa**[5] · **Nimisha Mittal**[3] · **Khemraj Dahal**[6] · **Paul Thomson**[4] · **Laxman Ghimire**[5]

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Abstract While impacts of climate change on agricultural systems have been widely researched, there is still limited understanding of what agricultural innovations have evolved over time in response to both climatic and non-climatic drivers. Although there has been some progress in formulating national adaptation policies and strategic planning in different countries of South Asia, research to identify local-level adaptive strategies and practices is still limited. Through eight case studies and a survey of 300 households in 15

✉ Gopal Datt Bhatta
bhattagopal@gmail.com

Hemant Raj Ojha
ojhahemant1@googlemail.com

Pramod Kumar Aggarwal
p.k.aggawal@cgiar.org

V. Rasheed Sulaiman
rasheed.sulaiman@gmail.com

Parvin Sultana
parvin@agni.com

Dhanej Thapa
dhanejthapa@hotmail.com

Nimisha Mittal
nimisha61@gmail.com

Paul Thomson
d.khemraj@ymail.com

Laxman Ghimire
laxmanghi@gmail.com

1 CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), South Asia, International Water Management Institute (IWMI), New Delhi Office, NASC Complex, DPS Marg, Pusa, New Delhi 110012, India

2 School of Social Sciences, University of New South Wales, Sydney, Australia

3 Centre for Research on Innovation and Science Policy (CRISP), Hyderbad, India

locations in India, Nepal and Bangladesh, this paper generates empirical evidence on emerging agricultural innovations in contrasting socio-economic, geographical and agro-ecological contexts. The study demonstrates that several farm practices (innovations) have emerged in response to multiple drivers over time, with various forms of institutional and policy support, including incentives to reduce risks in the adoption of innovative practice. It further shows that there is still limited attempt to systematically mainstream adaptation innovations into local, regional and national government structures, policies and planning processes. The paper shows that the process of farm-level adaptation through innovation adoption forms an important avenue for agricultural adaptation in South Asia. A key implication of this finding is that there is a need for stronger collaborations between research institutions, extension systems, civil society and the private sector actors to enhance emerging adaptive innovations at the farm level.

Keywords Innovation · Climate change · South Asia · Socio-economic drivers · Adaptation

1 Introduction

Smallholder farmers in South Asia face several issues related to production and sustainability in agriculture and livelihoods. The situation is likely to get worse in the context of increasing climatic risks (Gitz and Meybeck 2012). With around one-fourth of global population (FAO 2013) and 40 % of the world's malnourished children and women (Aggarwal et al. 2013), South Asia is one of the most vulnerable regions to climate change (Sivakumar and Stefanski 2011). The climatic variability and the frequency of occurrence of extremes events such as heat waves, droughts, floods and timing of rainfall have increased in South Asia over the past few decades (De and Mukhopadhyay 1998) and these events are not only becoming more frequent but striking areas that never had a vulnerability record (Pai et al. 2004). The area-averaged annual mean surface temperature rise over South Asia by the end of twenty-first century is projected to range between 2.6 and 4.7 °C. The projected increase in area-averaged summer monsoon rainfall is within the currently observed range of interannual variability (IPCC 2007) which is sufficiently large to cause devastating floods or serious drought (Lal 2005). During winter, South Asia may experience between 5 and 15 % decline in rainfall (Lal et al. 2001). The conditions for food production in South Asia will substantially change in future, in particular due to climate change and market variations (Aase et al. 2013).

As countries in the region begin to respond to climatic risks in agriculture, such as through national action plans or strategies, there is still limited attention to local-level dynamics in agriculture systems. Smallholder farmers are among the ones who are most vulnerable to stresses and shocks such as rainfall variability, droughts, floods and cyclones

[4] Flood Hazard Research Centre, Dhaka, Bangladesh

[5] Southasia Institute of Advance Studies (SIAS), Kathmandu, Nepal

[6] Institute of Agriculture and Animal Science (IAAS), Tribhuwan University, Kathmandu, Nepal

[7] Present Address: Research and Strategy, Community and Neighborhood Services, The City of Calgary, AB, Canada

(Bhattacharyya and Werz 2012; World Bank 2009; Cruz et al. 2007), and are also the ones to suffer from longer-term stresses such as population increases and the degradation of natural resources among others (Sivakumar and Stefanski 2011). In such context, farmers in South Asia are constantly seeking ways and measures to adapt to multiple stressors including climate change (Ojha et al. 2013). By analyzing the case studies from Nepal, India and Bangladesh, this paper demonstrates how a variety of local-level agricultural practices (as a proxy of innovation) emerged over a period of time across specific agro-ecologies. Through this, it also highlights the need for transforming agricultural institutions for fostering adaptive capacity of farming communities in the face of growing climate risks.

Our approach to analysis does not specifically focus on assessing the effects of changing climate on agriculture, but on the ways in which the interplay between climate and social dynamics leads to change in agricultural practices. Taking a socio-ecological lens, we presume that at the local level, adaptation interventions are not exclusively in response to climatic stimuli alone (Jodha et al. 2012; Smit et al. 2001; Smithers and Blay-Palmer 2001) as adaptation is driven by a range of different pressures acting together that are difficult to isolate (Chhetri 2012; Chhetri et al. 2012). We still consider that spatial and temporal variations in climatic phenomena act as a source of technological and institutional innovations (Chhetri and Easterling 2010). Processes such as policies and governance, and how these enable the promotion of innovation and experimentation, are also equally important in understanding adaptive capacity of the farmers. Similarly, growth in market, knowledge, technology and trade, and consumption environments for agriculture and agricultural products substantially drive technological innovations and adaptation in agriculture sector (World Bank 2006). We also consider that adaptation to climate change occurs on a variety of scales, when actions are taken at the local or regional level in an attempt to make adjustments to changes (Klein et al. 2005), and that such actions can be undertaken by a range of stakeholders including farmers, public institutions, communities, civil society (NGOs) and the private sector. It is therefore important to look at how and to what extent these institutions promote the adaptive capacity of agricultural groups and whether agricultural institutions adapt to climate change and variability (Gupta et al. 2010).

The hypothesis of induced innovation focuses on qualitative changes in agricultural production, such as through the use of specialized inputs, improved varieties of crops, use of appropriate agronomic practices or change in resource organization. On the one hand, it indicates changes occurring through improvement in existing technologies and the other end shows new and more productive technologies that are developed with demand. Innovation system thinking represents a significant change from the conventional linear approach to research and development. It provides analytical framework that explores complex relationships among heterogeneous agents, social and economic institutions, and endogenously determined technological and institutional opportunities (Akon-Yamga et al. 2011). A sustained effort to adapt hence demands an active engagement of various stakeholders so that location-specific technology is innovated for effective adaptation.

Our choice of innovation as a key analytical lens to understand adaptation provides an important basis to understand human responses and social processes to adapt to the changing context (Amaru and Chhetri 2013). Innovations are analytically differentiated from the everyday practice and are defined by change in knowledge, practice, technology, institutions and policy. An understanding of dynamic linkage between adaptation and innovation processes should therefore draw attention to the broader set of stakeholders, including farm communities and their supporting institutions as well as wider policy actors and research groups. In particular, our results contribute toward understanding how innovations and adaptation policy can better support smallholder agricultural communities facing multiple stressors of climatic and social origin.

In this paper we aim to contribute to the debate in understanding local-level agricultural innovations that are emerging in response to both climatic and non-climatic stimuli, and also explore how agricultural actors mobilize the available resources and improve institutions and practices in response to climate change and variability (Mall et al. 2006). Specifically, this paper aims to (1) identify emerging agricultural innovations in relation to climatic and non-climatic drivers at different levels of a social system; (2) assess how various actors in the agricultural landscapes catalyze such innovative changes and to what extent these changes are adaptive; and (3) identify key issues and gaps in the dynamics of agricultural innovations so as to enhance the adaptability and resilience of agricultural systems to climate change in South Asia.

2 Conceptual framework

Current approaches to understanding agricultural adaptation are mainly dominated by technical models which focus on assessing the adoption of innovations (Niles et al. 2015) and the impacts of climatic parameters on biological potential of crops. These models rarely consider smallholder farmers' innovativeness and agriculture actors at different levels (Oreskes et al. 2010). What farmers do is affected by what happens at market, policy, and research and at a whole set of social networks with which farmers are affiliated. The innovation system requires the scientific knowledge along with the totality and interaction of all stakeholders involved in innovation (World Bank 2006). Accordingly, adaptation responses are substantially shaped and mediated by their relationships with markets, research and extension and other institutions, all of which together constitute what we name 'innovation interface' spanning multiple levels (Fig. 1). Farmers also respond to political and socioeconomic and environmental factors other than climates (Wood et al. 2014). The

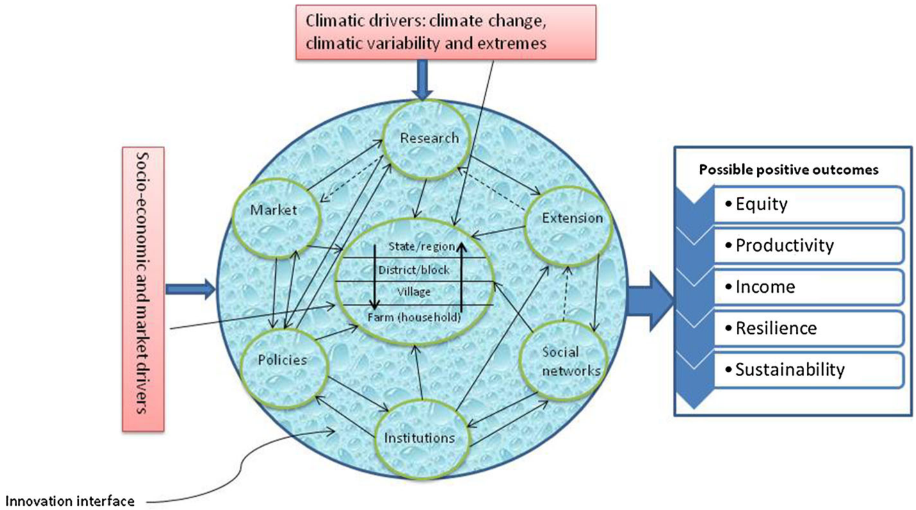

Fig. 1 Conceptual framework

adoption of adaptation practices by specific households and communities depend on their social and economic profiles, networks of relationships, and access to resources and power (Agrawal and Perrin 2008). The policy and governance environment, and how innovation and experimentation is being promoted by private and/or public sector actors, and the institutional arrangements supporting food system actors all influence farmers' decisions as to whether and how to change their agricultural practices. In fact, farmers' organizations and their institutions are viewed as the core to the innovation process in facilitating social learning (Spielman et al. 2009), enhancing adaptive capacity in communities (Rodima-Taylor 2012; Sterrett 2011; Pelling et al. 2008) and implementing or strengthening the adaptive strategies (Eriksen and Selboe 2012).

In this research we aim to explore how different farm interventions have emerged over the past decade, including the responses of the agricultural stakeholders at different levels under varied agro-ecologies in South Asia. We use the term innovation as a proxy of farm interventions in response to both climatic and non-climatic drivers. The term innovation in this study is defined as the agricultural practices that are new to the farm households, irrespective of whether they are new to their neighboring farm communities, their region, country or elsewhere (World Bank 2006; Spielman 2005; Mytelka 2000). Innovation in subsistence agricultural system also comprises many small improvements and a continuous process of upgrading of already existing practices (World Bank 2006). For instance, when poor rural families start producing a new crop or following new cropping sequence that provides them better yield, this new livelihood option becomes an innovation to them (World Bank 2006), as it features the novel use of existing knowledge about food production (Aase et al. 2013).

We thus presume that innovation expresses the capacity to adapt to change (Aase et al. 2013). Current innovation studies agree that innovation is not a result of independent decision making on the part of the production unit (Aase et al. 2013). Rather, innovation must be seen as the joint outcome of interaction among individual decision-makers, sociocultural context, institutional framework, regulatory systems and so on (Mytelka and Smith 2001). The concept of innovation system has become an important framework for understanding technology development and diffusion in recent times (Mytelka 2000; World Bank 2007). The framework stresses that innovation is neither research nor science and technology, but rather the application of knowledge in production to achieve desired social or economic outcomes. This knowledge might be acquired through learning, research or experience, but until applied it cannot be considered innovation (Akon-Yamga et al. 2011). In the context of agriculture, innovation could be physical innovation (such as crop varieties/animal breeds), institutional innovation (producers' networks, evolution of new policy regime) and innovation in terms of practices (crop production practices) (Akon-Yamga et al. 2011).

A wide range of innovations in agriculture that have been shown to increase agricultural productivity and adaptation to climatic variability at the farm level include resource-conserving technologies (Gupta and Seth 2007; Harrington and Hobbs 2009; Ladha et al. 2009), various approaches for enhancing water use efficiency, switching to more drought tolerant crops (Mongi et al. 2010), improved pasture and livestock management strategies, introduction of crop cover or mulching, planting trees on-farm (agroforestry), and the adoption of new crop varieties that are flood tolerant, disease and pest resistant, or shorter cycle, among others (Kristjanson et al. 2012). New crops and/or varieties (Aase et al. 2013), and crop husbandry (such as late or early planting, crop rotation and space management) (Smithers and Blay-Palmer 2001) serve as an indicator of innovativeness at a farm level. Innovations emerge both at the micro- and at the macro-levels: Farmers introduce practices at the local level and local institutions such as farmers' groups/clubs/self-help groups are formed, and the government, NGOs or private institutions introduce practices nationally and formulate climate adaptation strategies (Nhemachena and Hassan 2007). While macro-level institutions may be able to create enabling environment for adaptation at a broader scale (Amaru and Chhetri 2013), they may ignore important actors at micro-level and hence a gap exists in understanding the relationship between climate trends and adaptation outcomes at micro-level. This disconnect between actors operating at different scales can be problematic in designing robust adaptation strategies at the local level (Fresque-Baxter and Armitage 2012). Current studies on the importance of the social aspects of climate change have thus particularly highlighted the interaction between institutions (Agrawal 2010; Nielson and Reenberg 2010; Ribot 2010) and actors across multiple levels.

We assume that climate change and variable markets imply substantial transformations of the conditions for agricultural production. As a result, farmers have to change their practices to maintain or preferably increase productivity by introducing new crop varieties, trying out new farming techniques and marketing their products in new ways. The farmers who are best able to adopt such novelties are those who will most successfully cope with changing production conditions (Bhatta and Aggarwal 2015). In other words, a farmer's adaptation to change will largely be conditioned by the farming household's innovative capacity (Aase et al. 2013). We emphasize linking emerging changes in agriculture in response to different stimuli and in the interface between climate, socio-economic, market drivers, and institutional and policy framework (Fig. 1). It is a challenge to make a compelling case for technological innovation as being driven solely by climatic factors because agricultural production is framed within the context of other changes that are part of its agricultural development. Yet, this study recognizes that climate is one of the most important factors to which farmers have to adjust their production system (Chhetri and Easterling 2010). We see that adaptive practices could exist, but not all of them could be climate adaptive or necessarily innovative. But there is definitely willingness or pressure for adaptive practices at different levels, and it would be worthwhile for the enabling policy system to keep track of these as part of the goal of enhancing agricultural adaptation to changing circumstances including climate change.

3 Study sites and methodology

3.1 Site characteristics

We conducted the case studies in the eight sites and a survey of 300 households in 15 locations in three countries of South Asia (India, Nepal and Bangladesh). The study sites represent diverse climate stresses (flood and salinity prone areas of coastal Bangladesh to landslide prone area of Nepal's mountain and over-exploited groundwater resources of Punjab, India), agro-ecological systems (from humid Terai, Nepal to semi-arid Udaipur, India), socio-economic and institutional settings (from high-poverty region of Bihar to well-off location in Punjab, relatively weak and poorly accountable local institutions in the studied sites of coastal Bangladesh and Nepal to more responsive local public agencies in Punjab) and the innovation dynamics (technology focused in Punjab to more institutional innovations in Nepal and Rajasthan). All sites are depicted in Fig. 2 and an overview of key characteristics of the case study sites is presented in the Table 1.

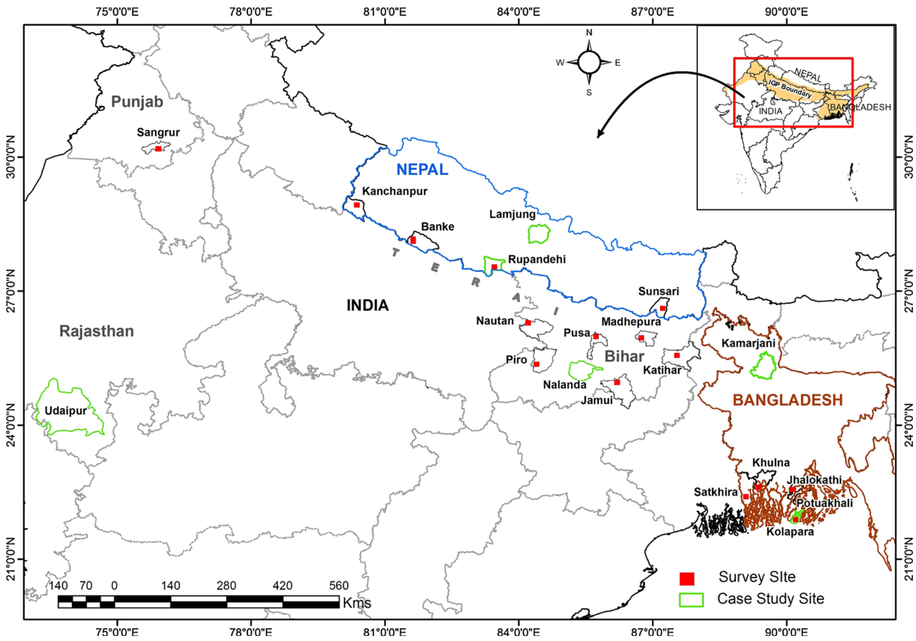

Fig. 2 Case studies and household survey sites

3.2 Sampling and data collection

A scoping exercise comprising key informants at the sub-national and district levels was done to prepare a refined list of possible sites in respective countries and locations. Considering both diversity and climatic risks, we selected eight case study sites (Table 1). While the case studies thus selected capture important agro-ecological diversity in South Asia, they may not necessarily be representative as countries in this study are extremely diverse in terms of socio-economic, biophysical and institutional settings. Once the study sites were selected, a discussion with key informants (local leaders, teachers and development workers) in each site was conducted to generate information on innovation dynamics and adaptation. We further used household interviews to explore household-level behavior in relation to emerging agricultural practices in different case study sites. This included five households in each site—each representing extremely poor, upper class, lower class, women headed and well-off households. Community-level participatory exercises in each site were used to find the community-level actions in the context of climatic and non-climatic drivers. Three focus groups of women, disadvantaged groups (such as Dalits) and poor farmers were held in each case study site to identify and capture different perspectives. Focus groups were defined for each location by undertaking community heterogeneity analysis with key informants—using locally defined criteria based on key informant findings. A generic checklist that included climatic variability observed over the last two decades, key agricultural practices changed, institutional processes, climate change adaptation policies at local level and innovation outcomes was prepared for focused group discussion.

We further selected 15 additional sites (7 sites from India, 4 from Nepal and 4 from coastal Bangladesh; each 10 km × 10 km block designed by CGIAR Program on Climate Change, Agriculture and Food Security (CCAFS) for participatory action research on

Table 1 Overview of case study sites

Sites	Agro-climatic features	Agricultural systems	Climatic risks
Lamjung, Nepal	Mid-hills, altitude 1800 m, humid temperate area, annual rainfall around 3200 mm	Subsistence agriculture, maize–millet cropping pattern, decline in transhumance and slash and burn systems	Variable rainfall, frequent hailstones, landslides and erosion, foggy days and cold spells
Rupandehi, Nepal	Fertile lands, altitude 83 m, humid sub-tropical climate, annual rainfall 1455 mm	Rice–wheat pattern, market-oriented vegetable production, average landholding 0.9 ha	Uncertain monsoon, rainfall variability, foggy days and prolonged cold spell, terminal heat stresses
Sangrur, Punjab, India	Low lying plain, altitude 236 m, tropical climate, semi-arid region, annual rainfall around 700 mm	Rice–wheat pattern, groundwater irrigated, highest cropping intensity in India, highly mechanized farming, high agro-chemical use, average land holding is 4.32 ha	Erratic rainfall, declining groundwater table, increased wind velocity, terminal heat stresses, declining soil fertility
Udaipur, Rajasthan, India	Aravali mountain range and valleys, altitude 600 m, semi-arid region, annual rainfall around 640 mm	Livestock-based livelihoods, rainfed and ground water irrigated, very sparse vegetation	Highly drought prone, land degradation, declining ground water resources, heat stresses—affecting dairy performance and fodder production
Nalanda, Bihar, India	Alluvial plains, altitude 63 m, tropical climate, average rainfall 1000 mm	Rice–wheat pattern, rainfed and ground water irrigated, share cropping and lease farming, average land holding <0.5 ha	Erratic rainfall, rise in winter temperature, increased incidence of drought
Madhepura, Bihar, India	Alluvial plains of Koshi, altitude 41 m, tropical climate, average rainfall 1300 mm	Rice–wheat cropping pattern, maize is also an important crop, rainfed and sub-surface irrigation, average land holding <0.5 ha	Flood and drought prone, decline in annual rainfall, increased temperature and humidity
Kamarjani, Gaibandha, North west Bangladesh	Active floodplains and attached char (submerged during monsoon)	Monsoon rainfed rice, cash crops in charlands, three cropping seasons (two rainy and one dry), landless and poor farmers seek access to charland	Flood and drought risks, river bank erosion, cold spells, high rainfall variability
Kolapara, Potuakhali, coastal Bangladesh	Tropical floodplain of Ganges, altitude up to 3 m	Rainfed rice, limited winter crops, around 65 % depend on farming and rest on fishing and labors, lease farming	Rising tide levels, lack of fresh water in dry/winter season, floods, cyclone and salinity, foggy days and cold spells

climate-smart agricultural interventions and subsequently to monitor agricultural adaptation dynamics to climate change over time) for household survey (Bhatta et al. 2015a, b; Kristjanson et al. 2010). The objective of laying out 100 km^2 block was to develop simple, comparable cross-site household-level indicators, for which changes can be evaluated over time, of food security, livelihood diversity and adaptive innovations (Kristjanson et al. 2012) and to link those indicators with the land health and soil carbon (Kristjanson et al. 2010).

These sites comprise diverse agro-ecologies and risk profiles. We first selected four villages in each site (one closest to the center of the block, one toward southwest, one toward northwest and one toward southeast of the block). The purposeful selection of the villages, which is standard practice in most research of this type, means that results may not be applicable beyond the selected sites. However, they were chosen to be representative of the major farming types available in the area. With the help of key informants, a list of relatively large land owners (land holding >1 ha) and small/marginal farmers (land holding <1 ha) was prepared. We randomly selected 2 and 3 large and smallholder/marginal farmers, respectively, from each village. Therefore, the total sample size in each site was 20. A structured questionnaire was developed and administered to the selected households to collect the relevant information (such as socio-demographic information, membership in the group, on- and off-farm livelihood sources, changes made in agriculture in the last decade, training/meeting attended, government policies/programs helping farmers to adapt to climatic risks, outcomes of innovations and women's workload, etc.). The study blended qualitative and quantitative methods—combining case studies with survey research methods. The qualitative method was used for data collection and analysis, spanning the household, community and district levels through focus group discussions at community level and expert interactions at district level.

Table 2 Variable description

Variables	Description
Innovations (dependent variable)	Number of farm interventions introduced in the last 5 years (practices in land, soil and livestock management; crop and/or variety; livestock species and/or breed; time, method and techniques of sowing/transplanting; changes in irrigation, fertilizer, pesticides and manures; method of harvesting and post-harvest operations; and new mode of marketing)
Site	Six sites from Bihar and one from Punjab states of India, four sites from Terai of Nepal and four sites from coastal Bangladesh
Land owned	Total land (ha) owned by the farm household
Nature of farming	Type of farming operation (either subsistence or market-oriented farming)
Family size	Number of family members in the households
Membership	Whether a household is a member of any group (farmers group, community-based organizations, cooperatives etc.)
Participation	Whether a farm household has participated in any kind of farm experiment/demonstration such as varietal selection, resource conservation and management, farmers field schools, etc., over the past 5 years
Visit	Whether a farm household has visited any demonstration sites or improved agricultural farms to get ideas on agricultural technology over the past 5 years
Climate change training/meetings	Number of training/meetings related to climate change and agriculture over the past 5 year
Government program	Whether a farm household is aware of any government programs or rules that help better adapt to climate change
Number of livelihood sources	Number of on-farm and off-farm livelihood sources (agriculture, job, remittances, livestock, pension, wage, etc.)
Access to finance	Whether a farm household has access to financial services to undertake new improvements in agriculture
Government policy	Whether government policies/rules affected the choice of farm household on agricultural practices over the last five year

Regression analysis was done to estimate the variance of different factors (Table 2) on number of farm practices changed in the last decade. We ran both a general linear model (GLM) and log-linear model using the same set of explanatory variables. Based on residual analysis, both modeling approaches showed a satisfactory fit to the data. We only used the results of the GLM in this paper. The model was evaluated with a Wald test (RWALD). The advantage of RWALD is that the model does not have to be refitted (excluding each variable) to calculate F statistics and probability (Kristjanson et al. 2012). It thus provides a much more efficient method of assessing the model. Variables with a Wald statistic below 10 % level of significance were excluded from the model if their inclusion resulted in a change in the percentage variance accounted for (R^2), to prevent overfitting of the model. Other variables that were above the 10 % significance level, but without an effect on the overall R^2 of the model, were kept in the model for reasons of comparison. The percentile analysis of the key quantitative variables showing significant variation on overall model was done to find out the relative contribution of these variables on innovativeness.

4 Results

4.1 Socio-demographic attributes of the farm households

Table 3 depicts the socio-demographic attributes of the farm households. The respondents were asked to provide the highest level of education of the household head. A large number of household head in the region except in Punjab are either illiterate or just had primary level of education. This clearly demonstrates that level of education of the farmers in the studied areas is very low. As expected, households across the regions are male dominated. Terai, in general, demonstrates a slightly different picture when compared to other areas. It may be because most of the family farms are run by women due to out-migration of men (Bhatta and Aggarwal 2015). The Maoist conflict period that occurred from 1996 to 2006, a key driver of out-migration, and subsequent exodus of men from villages put additional burden on women to take the sole responsibility of agricultural production (Gartaula et al. 2010). The agricultural production in the region is predominantly subsistence based except in Punjab where farming is largely mechanized and commercialized.

The average landholding per household is significantly higher in Punjab (6.44 ha) compared to Bihar (3.16 ha), coastal Bangladesh (2.59 ha) and Terai (1.93 ha). A majority of the households are either marginal or smallholder farmers in Bihar, Terai and coastal Bangladesh, while a large number of farmers are either medium holder or large holders in Punjab (Table 3). The household size is more or less similar in all areas, while significantly higher working age family members are available in Bihar compared to Punjab. Respondents were also asked to list the number of livelihood sources (agriculture, wage, salary, pension, remittances and business). Farmers in the region derive their livelihoods through a variety of on- and off-farm sources; all of which vary across the sites. At all sites, the majority of the farm-families predominantly pursue agriculture-based livelihood strategies through intensification and diversification (Bhatta et al. 2015a, b). The number of sources is slightly higher in Bihar compared to other areas. Small farmers that manage diversified and small-scale farms and that produce both subsistence and commercial goods are a predominant mode of production in many regions of the world (Astier et al. 2012). It is interesting to see that the number of farm practices changed (a proxy of innovativeness) in Punjab is significantly lower than in other areas. This is mainly because farming in Punjab is mostly commercial

Table 3 Socio-demographic attributes of the farm household

Attributes	Bihar, India ($n = 120$)	Punjab, India ($n = 20$)	Terai, Nepal ($n = 80$)	Coastal Bangladesh ($n = 80$)
Level of education of the household head (%)				
Illiterate	26	5	30	15
Primary	43	25	56	66
Intermediate	18	55	9	18
University	13	15	5	1
Household type (%)				
Male headed	93	95	68	95
Female headed	7	5	32	5
Nature of farming (%)				
Subsistence	34	10	66	50
Commercial	28	15	10	15
Mixed	38	75	24	35
Average land (ha)	3.16^{b} (0.32)	6.44^{a} (1.64)	1.93^{b} (0.25)	2.59^{b} (0.56)
Type of farm households (%)				
Marginal (<1 ha)	36	10	39	43
Smallholder (1–2 ha)	25	15	29	35
Medium holder (2–5 ha)	22	35	26	15
Large holder (>5 ha)	18	40	6	8
Household size	5.40 (0.30)	4.40 (0.47)	4.53 (0.31)	4.44 (0.27)
Number of adults	3.28^{a} (0.21)	1.80^{b} (0.31)	2.59^{ab} (0.23)	1.95^{b} (0.16)
Number of livelihood sources	2.31^{a} (0.08)	1.75^{b} (0.14)	2.05^{ab} (0.12)	2.07^{ab} (0.08)
Number of farm practices changed (innovativeness)	6.13^{a} (0.30)	1.60^{b} (0.41)	6.94^{a} (0.33)	6.50^{a} (0.24)

Values in parentheses indicate standard error of mean. Letters in the superscript show significant difference between the areas at 5 % level of significance according to Kruskal–Wallis test

and government has assured minimum support price (MSP) for rice and wheat. As a result, technological innovation in Punjab happens within a predominant cropping pattern—the rice–wheat system. Furthermore, farmers in Punjab have assured irrigation system in place and they have access to other improved production practices. The level of innovativeness of the farmers is also governed by biophysical situation of the farm. For instance, farmers in climate vulnerable areas (coastal Bangladesh) responded more to the climatic stressors than those living in relatively less vulnerable areas (Punjab) (Bhatta et al. 2015a, b). Our data reflect a number of changes made during specified period of time (2007–2012) which conferred some benefit to the farmers who made such changes. Therefore, number of changes is a proxy measure of potential innovativeness (Wood et al. 2014).

4.2 Responses of farmers to climatic variability and socio-economic drivers

Households were queried about what changes they had made in the last decade with respect to a wide range of practices in agriculture. The total number of changes made gives an indication of experimental actions and exploration of adaptive practices and is thus used as a proxy of innovativeness.

Farm-level changes are categorized into seven groups: land preparation, crop and varietal change, sowing and planting, agro-input use, mechanization, harvest and market operations. Land-related changes encompass new time and method of land preparation, and soil management and method of pond preparation. Crop and varietal changes refer to the introduction of new crops and/or new varieties, and new farm animals and/or breeds. Sowing innovation covers new time and method of sowing/transplanting of the crops. Changes in agro-inputs include new time and method of irrigation, farm manure preparation and application of improved agro-inputs. Mechanization refers an introduction of farm implements in agriculture. Innovations related to harvest include new time and method of harvesting of the crops and post-harvest technology. Market-related changes cover the method of marketing farm surplus and structural arrangement for marketing and/or alteration of existing value chain.

Survey results show that a large number of farmers in coastal Bangladesh (around 90 %) introduced new method and timing of land preparation, while only approximately 12 % of the farmers did so in Sangrur, Punjab. Around 50 % of the households have introduced new crops/animals and/or varieties/breeds across all areas. Mechanization is more prevalent in Sangrur (as >50 % farmers reported) compared to other areas. Changes in agro-inputs (irrigation, fertilizers, pesticides and manure) are very high in Terai, Bihar and coastal Bangladesh as reported by around 90 % of the farmers in each region. Shifting from local to early maturing and less water requiring crop varieties, changing cropping calendar and planting methods to adjust to climatic risks are notably frequent in many areas (Kristjanson et al. 2012; Manadhar et al. 2011). However, these changes are not only in response to a changing environment but also in response to the demands of a growing population as well as to the availability of new technology.

The results of modeling the set of factors explaining variation on innovations across households showed that the data are better in explaining differences in innovativeness, with 65 % of the variance accounted for. The site explained 43 % of the variation in innovativeness between households, land size explained 21 %, membership explained 31 %, climate change and agriculture training/meetings attended explained 196 %, number of livelihood sources explained 22 % and access to finance explained 21 % (Table 4). The

Table 4 Results of GLM (innovation: dependent variable, adjusted $R^2 = 65$ %)

Variables	Mean square	F value	Significance
Sites	43	12.8	<0.001
Land owned	21	6.15	0.014
Nature of farming	10	3.00	0.085
Family size	0.43	0.13	0.721
Membership	31	9.29	0.003
Participation	10	2.97	0.086
Visit	2	0.46	0.500
Climate change training/meetings	196	58.4	<0.001
Government program	3.52	1.05	0.307
Sources of livelihoods	21.76	6.48	0.011
Access to finance	21.26	6.33	0.012
Government policy	10.07	3.00	0.084

results infer that climate change and agriculture-related training brings higher level of variability in terms of farm-level innovation.

We also pooled information on farm innovations from the case study sites and we found that there are five key motivations behind farm-level changes: transformative learning, adapting to climatic variability, risk reduction through farm experiments, market orientation and social learning (Table 5). An important result from our analysis is that the various ways in which adaptive innovations emerge are not confined to any one level of organization. Hence, Table 5 presents responses at three levels: the household, the community and the district. The first category of responses implies the learning to live with change and uncertainly learning from extreme events, building portfolio of livelihood options and developing coping strategies. The second category of responses covers the processes of learning and adapting including institutional diversity and farm experimentation (Dietz et al. 2003). The third category of responses encompasses creating opportunity for wider resilience.

The results from focus group discussion demonstra, nonte that certain weather-related events provide farm communities with an opportunity for transformative learning. For instance, farmers started shifting cropping patterns and the timing of shearing sheep wool following repeated and unexpected hailstones in Lamjung, Nepal. Farmers who experienced hailstones only once or twice in summer/rainy season are now exposed to frequent and intense hailstones after 2000. In Udaipur, recurrent droughts in 1990s and early 2000 and increasing resource degradation brought the communities together to form collaborative action groups for common pool resources (pasture land, for instance) regeneration. Building a portfolio of livelihood options is seen in many areas, particularly in Madhepura and Lamjung. In the context of increasing rainfall risks, farmers in Madhepura replaced rice–wheat by maize–wheat which is a safer cropping pattern in terms of water and labor requirements (Gathalaa et al. 2013). This crop rotation is considered an innovative as progressive farmers themselves tried and tested it on the farm and has now disseminated to a wider scale.

In everyday explorations of options to adapt to multiple drivers, farmers have developed ways and methods to experiment innovative solutions, which largely operate at the farm and community levels, but is often supported and informed by social networks. Local networks provide multiple functions in reducing vulnerability and enhancing adaptive capacity (Below et al. 2010). New adaptive strategies such as floating agriculture (waterlogged areas in coastal Bangladesh), zero tillage of wheat and direct seeded rice (DSR) (Punjab and Rupandehi), system of rice intensification (SRI) (Bihar and to some extent in Rupandehi) and community-based weather stations (Udaipur) are part of such learning, and farmers have experimented these innovations in the field to learn and adapt. Community weather stations are managed by school clubs and in some cases by farmers' club to record hydro-meteorological data and to help educate the community for informed decision making in farming activities. The benefit of experience-based adaptation is that it is directly responsive to local conditions and may be developed and managed by those implementing the adaptation measures.

The third category of responses helps create opportunity for self-organization and promote adaptation at a wider scale. For instance, restoration of embankment and measures to reduce inflow of saline water following 2007 Cyclone Sidr (Kolapara), Farmers Field Schools (FFS) (Rupandehi), soil and moisture conservation machines (Punjab), community management of forest resources (Lamjung), community group regulating fisheries (Kolapara) and community pasture land management (Udaipur) are some of the notable examples in this category. Collective action provides ample scope for social learning and

Table 5 Observed agricultural practices in relation to several drivers in the case study sites

Key motivations	Key variability/opportunities	Observed changes in different sites	Scale		
			HH†	Village	District
Transformative learning from extreme events	A severe hailstone in 2000 damaged one but not other varieties of wheat	Varietal and crop diversification (Rupandehi)	**	*	*
	Recurrent droughts in 1990s and early 2000	Collaborative action for common pool resource regeneration (Udaipur)	–	**	**
	Koshi flood in 2000	Off-farm livelihood diversification, mainly out-migration (Madhepura)	**	**	**
	Cyclone Sidr 2007	Restoration of embankment and measures to reduce inflow of saline water (Kolapara)	–	**	**
	Repeated and unexpected hailstones	Shifting time of shearing sheep wool and declining wheat cultivation (Lamjung)	**	*	*
	Heavy flood in 2007	Focus more on dry season crops (Kamarjani)	**	*	*
Adjusting farming with the uncertain cycle of weather events	Uncertain incidence of floods	Grow multiple varieties of rice in the seedbeds in charlands (Kamarjani)	**	*	–
	Uncertain cyclones	Cultivation of dry season crops (Kolapara)	**	*	*
	Rainfall risks	Introduction of legumes in the rainfed fields (Lamjung)	**	**	**
		Replacement of rice–wheat by maize–wheat (Madhepura)	**	*	–
		Use of less water requiring varieties (local cultivars) of crops (Udaipur)	**	*	–
	Salinity issue	Re-excavation of silted up canals and embankments to prevent intrusion of saline water (Kolapara)	–	**	–
Experimental actions to reduce the risks	Flood risks	Prepare seedbeds in the higher ground and use late varieties to cope with the post-flood cultivation, fodder storage for flood season and avoid planting the same crop in the same plot in consecutive seasons (Kamarjani)	**	*	*

Table 5 continued

Key motivations	Key variability/opportunities	Observed changes in different sites	Scale		
			HH†	Village	District
	Unfavorable field environment during planting (mainly due to temporary flooding)	Zero tillage of wheat (Rupandehi); zero tillage garlic, women farmers floating beds in waterlogged area, leave paddy residue in the field, seed storage in plastic containers instead of bamboo bags, replace goat by sheep which can withstand wet environment (Kamarjani)	*	–	–
	Declining groundwater table	Soil and moisture conserving machines (zero till, happy seeder, rotavator), underground pipelines and laser land leveling (Sangrur)	**	**	**
	Rainfall and drought risks	Water storage tanks, and install pipelines to reduce water wastage and shift to sturdier breed of goats (Udaipur)	**	*	–
		SRI (Nalanda and Rupandehi)	*	*	–
		Direct seeded rice (Rupandehi, Punjab)	*	*	–
Market opportunities	Ecotourism	Moving away from transhumance and replace cereals with cash crops (Lamjung)	**	**	*
	Better prices of milk and vegetables	Commercial dairy and vegetables (Udaipur), replace traditional with improved breeds of cows (Madhepura)	**	**	*
	Comparative advantage	Replace rice with jute and women produce vegetables in monsoon (Kamarjani); smallholder farmers replace rice–wheat with vegetables and relatively larger sized farmers with banana (Rupandehi)	**	*	–
	Mechanization	Replace bull (used in the past for plowing) by cows or buffaloes and introduce mechanical tillage system (Nalanda and Madhepura), mechanization is introduced entirely (Punjab) and partly (Udaipur)	**	**	**

Table 5 continued

Key motivations	Key variability/opportunities	Observed changes in different sites	Scale		
			HH†	Village	District
		Char areas (traditionally left fallow and under grass production) are being intensively cultivated using power tillers (Kamarjani)	**	**	*
	Involvement of market actors	Shift to cash crops (resilient to drought and salinity)—promoted by wholesalers of Dhaka, local dealers introduce high yielding varieties, farmers cultivate maize on fallow, barren and sandy charland (as maize demand increased due to poultry business) (Kolapara)	**	*	–
Collaborative actions for social learning and adaptation	Cooperative-based production, marketing and resource conservation	Banana and Dairy Cooperatives (Rupandehi)	–	**	*
		Leasehold farming (Rupandehi, Kamarjani, Nalanda, Kolapara)	**	**	*
		Coordinated individual business such as home stay tourist services (Lamjung)	**	**	–
		Community-based weather stations, community infrastructure (communal water tank) and pasture land management (Udaipur)	–	**	*
		Formation of self-help groups (SHGs) to collectively decide about technological adoption (Udaipur, Bihar and Rupandehi)	–	**	*
		Community regulation of fisheries (Kolapara)	–	**	–
		Saving credit groups to collectively decide the fund mobilization (Rupandehi and Udaipur)	–	*	–
		Community forestry group to conserve resources (Lamjung)	–	**	**
		Farmers field school (Rupandehi)	–	*	*

† HH: Household level, **: Highly observed, *: Observed moderately, –: Not observed/not applicable

enhances adaptive capacity at a wider scale (Thomas et al. 2007). However, it should not be understood that all community actions have evolved through the action of the community members only. Most of these innovations have been promoted by nongovernmental organizations (NGOs) and government institutions. For instance, the local government formulated new rules of resource allocations which led to the abolition of slash and burn (locally called *khoria*) and evolution of community forest groups to manage forest resources sustainably in Lamjung, FFS has been promoted by the Government of Nepal as an effective mode of extension, State Government of Rajasthan promoted community management of pasture lands and NGOs promoted cultivation in charlands in Kamarjani.

Like other places in the world, marketing opportunity remains a highly visible driver of change in agriculture in South Asia. It is not just the market of agricultural inputs or outputs but also the opportunity costs or the relative value of substitutes for producing agricultural commodities. Accordingly, changes can be observed in the crop varieties, cropping pattern, agro-techniques and marketing arrangement. Although external drivers such as marketing opportunity may enhance income-generating ability of a household, they may not promote adaptation. For instance, off-season vegetable production (Rupandehi), mechanical plowing in charlands (Kamarjani) and input subsidy (Punjab) are some of the interventions which may be less adaptive.

4.3 Responses of agricultural institutions and actors supporting farmers

Key agricultural stakeholders involved in extension, research, market, technology and policy have also undertaken diverse responses to help farmers to adapt to the changing circumstances that include both climatic and non-climatic drivers of changes. The actual response is mixed and conditioned by prevailing institutional, policy and economic contexts. Here we focus on key actors: research, extension, policy-related institutions and local-level actors.

The results from key informant interview and district-level participatory exercises highlight that research system in agriculture has shifted its focus from on-station experiment to participatory action research, but this has remained less attentive to issues related to adaptation. Farmer participation in many cases has remained limited to providing feedback. However, several innovations in the region have climatic considerations too. Examples of climatic considerations in agricultural research include: zero tillage machine development by Punjab Agricultural University, on-farm testing of laser land leveling (LLL) equipment in Punjab, exploring water harvesting structures and identification of fodder grasses resistant to drought in Rajasthan, development of drought tolerant varieties in almost all sites and participatory research on zero tillage in Rupandehi and Bihar. Scientists in Bangladesh Rice Research Institute and Bangladesh Institute of Nuclear Agriculture developed the low-yielding varieties (BR-33 and BINA-7) to adjust timing of the crop harvest with critical food scarce periods (locally known as *Monga*) in the north including Kamarjani (MoEF 2011). Their choice of research goal seems to be quite different from those of others—focus on year round productivity rather than maximizing productivity of a single crop. The improved crop varieties have considerable potential for strengthening adaptive capacity (Lybbert and Sumner 2010; Boko et al. 2007).

There have been little structural changes in agricultural extension system in the region, but a number of functional changes have emerged, some of which have the potential to contribute to climate resilience of agricultural system. Six most notable climate change-related extension innovations found in the case study areas include—(a) weather advisory services offered by Sangrur and Bihar Krishi Vigyan Kendra (KVKs) to the registered farmers through SMS; (b) assistance provided by Sahayog Sansthan (an NGO) to set up community-based weather monitoring stations in Udaipur; (c) NGOs providing advice and inputs to cultivate floodplains during winter in Kamarjani; (d) introduction of dry season crops and a rice variety that can be harvested before salinity becomes severe in Kolapara; (e) NGOs, community-based organizations and government institutions providing training and extension services through FFS in Rupandehi; and (f) community management of forest resources introduced by the government in Lamjung.

There are also less obvious and perhaps not so overtly climate-conscious ways in which farmers are receiving innovative advice from the extension system—stopping straw burning and avoiding overuse of fertilizer in Sangrur, training of farmers by NGOs on compost preparation in the context of declining soil quality resulting from excessive use of chemical fertilizer in Kamarjani and Madhepura, floating gardens (beds) and cage fish culture to turn the flooding from a threat to opportunity in Kamarjani. However, the linkage between research–extension–farmers has not been strong (Ojha et al. 2013), and thus, the dissemination of successful innovations is limited. It is more usual to have NGOs and government not to coordinate, and in the prevailing context of donor funding strategies (short-term support and frequent shift in priority), NGO-led activities have remained short-lived, as seen in the context of dysfunctional farmer groups in Rupandehi. The extension system in the study areas lacks enough scientific research backing mainly because of cultural hierarchy that prevails in many countries of South Asia and the lack of convergence and alignment between research, extension and farmers efforts. Some of the innovations promoted by extension organizations could be enhanced if research system offers additional back up.

The effectiveness of the cooperatives, NGOs and local government institutions such as village committee/Panchayat is instrumental in bringing more awareness and technological information to the farmers as compared to District Agriculture Offices and national agriculture research system (NARS) in case study and survey sites. For instance, farmers in the surveyed sites accord first rank to the cooperatives followed in order by NGOs, local government, District Agriculture Office and research centers in terms of their importance in providing technological information related to agriculture and climate change. Technical training on initiation of floating beds in flooded areas of Kamarjani by Practical Action is one of the best examples of NGO supported activity (DAE 2013).

With increasing climatic risks, governments in India, Nepal and Bangladesh have started formulating policies and strategic planning for enhancing adaptive capacity of the farmers. Policy responses in the case study sites have remained mixed, but largely ignorant of the current and future effects of climate change on agriculture. Punjab's ground water regulation seems to be at the forefront, though the agricultural development plan of Sangrur district does not see this as a climate problem. Rajasthan State Water Policy 2010 intends to function from the new perspective of Integrated Water Resources Management, which is holistic and includes a bottom-up approach. There is also an active process to implement country-specific National Adaptation Plan of Action (NAPA) in all countries, Local Adaptation plan of Action (LAPA) in Nepal and State Level Action Plan on Climate Change in Bihar and Rajasthan, to combat climate change and increase resilience of farming communities. These policies have strong components of climate change adaptation. Since these action plans are recently implemented in the local level, their visible impact on the ground has not been observed.

5 Discussions

The result section shows that some of the changes in agriculture occurred at the farm and community levels are innovative in terms of technical and social outcomes. Farmers in the region have responded to climatic and socioeconomic drivers to agriculture, which involved a wide range of social, technological, environmental adjustments (Levine et al. 2011), often in association with a wide range of agricultural stakeholders. But all of these changes may not be climate adaptive. Crop varietal change remains a key change in studied areas. Changes have also happened in land preparation, crop husbandry, agro-input use, harvesting and post-harvest operations. Bhatta and Aggarwal (2015) found that farmers in South Asia made several changes in crop varieties and introduced new method of sowing and land preparation and crop management practices; some of them are a unique response to climatic risks. Factors such as location, land size, membership, livelihood sources, access to finance and participation in climate change and agriculture-related training explain large amount of variations in innovativeness of the farmers. The percentile data analysis shows that one-fourth of the farm households are either landless or marginal (own a very small land) in coastal Bangladesh (0.36 ha), Terai (0.64 ha) and Bihar (0.66 ha) (Table 6). Punjab is a specific case example where farmers possess relatively large land size compared to other regions in South Asia. Three forth of the farm households in Bihar possess less than 5.11 ha, while the same proportion of households possess less than 3.73 and 2.36 ha of land in coastal Bangladesh and Terai, respectively. Since land size showed a

Table 6 Percentile distribution of key variables included in regression analysis

Percentile	Total land (ha)	Number of adults	Number of training attended	Number of livelihood sources	Number of changes made in farming
Bihar					
25 %	0.66	1	0	1	4
50 %	1.55	3	1	2	5
75 %	5.11	5	2	3	11
SD	3.50	3.28	1.76	2.05	6.13
Terai					
25 %	0.64	1	0.5	1	5
50 %	1.21	2	2.5	3	8
75 %	2.36	3	3.0	4	10
SD	1.95	2.59	1.85	3.05	7.15
Punjab					
25 %	2.00	1	0	1	0
50 %	4.00	2	0	2	1
75 %	7.85	3	0	2	3
SD	6.44	1.80	0.52	0.64	1.85
Coastal Bangladesh					
25 %	0.36	1	1	1	5
50 %	1.82	2	1.5	2	7
75 %	3.73	3	2	4	8
SD	3.01	1.95	1.35	2.15	6.50

SD standard deviation

significant variation on innovativeness (Table 4), higher variation on innovativeness could be observed in Punjab followed by Bihar compared to other areas. It would also be interesting to investigate whether smallholders' or those with relatively large land owners make more changes in farming practices to adapt to changing circumstances.

One half of the surveyed households in Terai have attended two trainings related to climate change and improved agriculture production, while only one by the households in Bihar and coastal Bangladesh. The variation on innovativeness in Terai as imparted by farmers' participation on climate change-related trainings has been higher compared to other areas. Below et al. (2010) also reported that all sorts of practical trainings for farmers and agricultural extension officers affect adaptive capacity of the farmers. The variation on innovativeness due to the number of livelihood sources is slightly higher in Terai compared to other areas. Bhatta et al. (2015a, b) also reported higher number of livelihood sources in Terai compared to Bihar and coastal Bangladesh. One half of the surveyed households made almost 5, 8 and 7 changes in farming during last five years in Bihar, Terai and coastal Bangladesh, respectively. Smallholder farmers have developed innovative farming strategies for withstanding challenging climatic conditions (Altieri and Nicholls 2013). The recovery of traditional management practices from creative and motivated local stakeholders in fact represents adaptive innovations to prepare for climate change (Astier et al. 2011). Most of the innovations observed in the case studies and survey sites are novel to the users rather than to the entire region. For instance, cultivation of floodplains may not be novel for the farmers in India and Nepal, but certainly it constitutes an innovation in the production activity of coastal Bangladesh.

Like other places in the world, marketing opportunity still remains a visible driver of change in agriculture in South Asia (Ojha et al. 2013). Most actors have considered private risks in the short run and they fail to capture wider resilience of the production systems. For instance, mechanization in Udaipur has reduced the traditional shallow plowing. The mechanized and deep plowing adversely affects soil structure and promotes wind erosion (Narain and Kar 2005). Growing dairy farming in Udaipur has enhanced livelihoods of the farmers, but unsatisfactory nutritional status and lack of knowledge of balanced feeding and the scarcity of fodder make livestock-based livelihood unsustainable (Rohilla et al. 2004) and contribute to higher emissions compared to traditional system (Chhabra et al. 2009). The agriculture policy (such as minimum support price for rice and wheat and subsidy in fertilizers in Punjab) focuses on higher productivity. The political economy of paddy and wheat cultivation in Punjab hence favors continued growing of these crops and unless similar incentives (MSP, full procurement and high profits) are given to other crops, strategies to promote diversification will not yield results. New technology also risks increasing costs and requires more careful thinking and applied research before introducing it to the farmers. This is evidenced in Kamarjani where intensification of cropping in charland (traditionally fallow lands) has promoted the use of inorganic inputs and created scarcity of fodder/grasses for livestock species. In order to enhance productivity, adaptability and reduce emission, investments on scientific breeding, feeding and management are therefore required (Staal et al. 2008; Nin et al. 2007).

Some innovative techniques such as SRI in Bihar have emerged. Similarly, DSR has the potential to provide several benefits (mainly saving water and labor) to the farmers and environment (Balasubramanian et al. 2013; Kumar and Ladha 2011). Zero tillage and LLL can be other adaptive agriculture options in water scarce areas. Community-based activities helped farmers make collective decisions on resource management and hence are more adaptive strategies. Community forestry, communal pasture land management and farmers-managed irrigation systems in parts of South Asia have initially evolved as a response to environmental problems as opposed to climate change (Reid 2015). Over the last decades strong local institutional processes have been established to institutionalize community-based efforts for sustainable adaptation under changing environmental circumstances including climate change and variability. An existing knowledge of innovative practices is an important asset for designing and implementing them in the future (Mbilinyi et al. 2007). Collective action has emerged as an important way to enhance resilience to climatic risks (Thomas et al. 2007) by empowering local people and improving institutional governance (Reid 2015). The knowledge and experience gained on these innovative practices can be replicated to other feasible agro-ecologies through on-farm experimentation with a strong institutional and policy support.

Climate adaptation does not occur in institutional vacuum (Amaru and Chhetri 2013; Agrawal and Perrin 2008). Institutions help society to interpret scientific knowledge and devise adaptive strategies. Participatory technology development focussed by NARS in Nepal, India and Bangladesh provides a clearer strategy for coordination of new players (e.g., private enterprises, farm communities and NGOs) involved in innovation of agricultural technologies (Gauchan et al. 2003) and also provides the participants an innovative way to manage their livelihoods (Amaru and Chhetri 2013). This new institutional approach has not only improved the relationship between farmers and researchers but has created a dialogue that has benefited both partners (Chhetri and Easterling 2010). Local ownership in decision making was a central component in a number of institutional and policy innovations in the past. In Nepal for instance, the LAPA pilot in the Rupa watershed was driven by three villages and two co-operatives. Using local institutions, farmers were able to plan together and make decisions that benefited the whole watershed (Sterrett 2011). In Bangladesh, local communities in the Hari River Basin own the Tidal River Management technology (raise waterlogged areas using sediments brought in by tidal flows for agriculture). Working together with Uttaran (an NGO) and technical partners, they implemented a traditional technology that has long-term benefits and is owned by the community (Kibria 2011).

Progress has been made in streamlining policies and strategies to address climatic risks at national and local levels in South Asia. In terms of climate-specific planning, Bangladesh was one of the first countries to develop its NAPA in 2005 (Ayers et al. 2014). Following the NAPA, the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) is widely regarded as a comprehensive and integrated example of adaptation planning (MOEF 2009). Bangladesh has also introduced community-based adaptation (CBA) action research through a consortium of international and national research institutions (Sterrett 2011). However, mainstreaming CBA needs to move beyond identifying and promoting best practices, toward tackling drivers of vulnerability and institutionalizing an enabling environment for CBA to occur as a process (Wright et al. 2014). Climate is also being integrated into the research priorities of the Bangladesh Agricultural Research Council (Hussain and Iqbal 2011) and Nepal Agriculture Research Council (Chhetri and Easterling 2010). Nepal's NAPA (2010) has given specific focus to conducive governance mechanism for facilitating local-level adaptive responses. Alongside the NAPA, the LAPA and Community Adaptation Plan of Action (CAPA) have been developed with an aim to providing action at a more localized level (Sterrett 2011). A lot of community forest users groups have been a major part of CAPA and these local-level plans are considered an innovative approach to foster local adaptation. The LAPA was an important innovation in terms of the effort involved in downscaling the science and improving representation in adaptation processes. Despite the intention to anchor LAPA with local governments, LAPA projects failed to understand the political questions surrounding institutional ownership (Ojha et al. 2015). The National Action Plan on Climate Change in India is another policy initiative to address mitigation and adaptation issues (Wiseman and Chhetri 2011). The Mahatma Gandhi National Rural Employment Guarantee Act has contributed to rebuilding India's natural resource base by engaging unemployed youths in resource management (Reynolds and Nierenbirg 2012).

Despite widespread consultations that went into the production of the NAPAs and other adaptation strategies, it appears that anticipated role of local-level institutions in adaptation was limited (Agrawal and Perrin 2008). At the local level additional ways are needed for strengthening institutional mechanisms through which farmers and vulnerable communities can access resources and increase their involvement in decision making (Amaru and Chhetri 2013). One possible modality is to form local, regional and national committees on adaptation to ensure farmers participation. Other means include strengthening and promoting farmer-to-farmer learning networks by prioritising them in policy and in climate change adaptation mechanism in the NAPAs and supporting ways of sharing community-level local knowledge and good practices in agriculture.

Adaptability of agricultural practices also depends on their ability to deliver equity and fairness. Although there are diverse groups making decisions on innovation and adaptation—including farmers' groups, institutions and governments—all such decisions 'privilege one set of interests over another and create winners and losers' (Adger 2003). Farmers in the case study areas reported that new farm practices helped them increase their marketable surplus of major cereals, vegetables and fruits. However, it is the large landholders who benefitted as they are the ones introducing the majority of farm interventions in relation to socioeconomic drivers. For instance, equipment such as laser land leveler, zero till, happy seeder and rotavator are generally expensive and it is difficult for the small and marginal farmers to purchase without any financial support from the government. Though the Government of Punjab provides 50 % subsidy to the farmers and co-operative societies to purchase these equipments, their usage is limited. Lack of awareness and training, high cost of these equipments and lack of high-power tractors have all constrained wider adoption of these equipments. Many technological innovations have not adequately addressed the workload of women. New technology on farming has resulted into an increased workload of the women farmers in all survey sites. Although a large number of the households (58 %) reported that there has been either no change (36 %) or decrease (22 %) in the workload of women due to an adoption of new technologies, yet approximately 42 % of the households reported an increased workload for women (Table 7).

Table 7 Women's workload as a result of changes in agricultural practices over the last 5 years

Agricultural activities	Percentage of household reporting		
	Increased	Decreased	No change
Agro-inputs ($n = 164$)	34	19	47
Field preparation ($n = 180$)	39	23	38
Sowing/transplanting ($n = 186$)	49	6	45
Intercultural operations ($n = 145$)	38	8	54
Harvesting ($n = 173$)	46	18	36
Post-harvest operations ($n = 155$)	37	25	38
Marketing ($n = 140$)	11	24	66
Overall workload ($n = 300$)	42	22	36

The agricultural policy approach in South Asia continues to be top-down and linear, while there is an increasing need for 'a comprehensive and dynamic policy approach, covering a range of scales and issues' (Howden et al. 2007) in the context of climate change. Strong gaps exist between perceptions of climate change and the adaptive actions among both the farmers and local stakeholders, suggesting the deficit of processes and institutions to translate information into adaptive actions. In some cases, especially when farmers have access to services and information, they have resorted to adaptive and innovative practices—such as changing cropping patterns and technological changes (such as SRI in Bihar and Rupandehi). Ecological rethinking (for instance in Punjab) has begun in terms of reducing straw burning and sustainable exploitation of groundwater resources. But this has not been translated into a bold new strategy of 'ecologizing' agriculture while maintaining farmers' benefits. Such innovations also lack backing by adaptation thinking.

Farmers' ability to engage in innovative practice is substantially shaped and mediated by the stakeholders operating at micro (community groups, clubs, cooperatives, self-help groups, local government, etc.) and meso (NGOs, political institutions, research institutions, extension system, etc.) levels. The capacity of a household to cope with climate risks depends to some degree on the enabling environment of the community (Smit and Wandel 2006). Although farmers and extension organizations at different levels have been able to identify, experiment and develop innovative actions, there is still a lack of framework to understand and catalyze adaptive responses in such a way that it is informed by long-term trends in climate change, as well as recognize the local socio-cultural contexts. In order to facilitate learning and innovation, science must adapt, too, by continuing to review research needs and providing effective tools for decision making (Howden et al. 2007). By fostering conditions that are conducive to learning, especially the transformative learning, farmers would likely be more open to new ideas and practices that promote adaptation in the face of environmental change. In the long term, there are some innovations that need capital investments to deploy. In this case, there is need for stronger collaborations to be established between research institutions, extension system, civil society and the private sector actors to bring these technologies to farmers. As demonstrated in the LAPA pilot in Nepal, it is not enough simply to work with local communities; local and district government is an essential component, for financial, technical and policy support. Therefore, building adaptive capacity for the most vulnerable requires a dual approach: first, a 'bottom-up,' locally inclusive approach to adaptation planning that is sensitive to the disaggregated nature of climate change vulnerability, and second, this local-level adaptation must be supported by meso- and higher-level institutions that enable them build adaptive capacity and act as the means of delivery for external resources to facilitate adaptation and up-scaling of innovations.

6 Conclusion

This study demonstrates that farmers and stakeholders have engaged in a great deal of experimentation and exploration of adaptive practices in agriculture in South Asia over the past decade. These have resulted from dynamic learning and innovation processes that have taken place within and around the agricultural sector. Such experimentation and innovation processes, which are largely informal, may be useful for local communities in adapting to the risks of climate. The value of such innovation which community groups have been fostering is particularly high, in view of the fact that communities are often overlooked by government and donor agencies in South Asia. In all the study areas, farmers' and stakeholders' responses to the changing circumstances including climate change and variability tend to be both proactive and reactive. For instance, pastureland management, zero tillage, system of rice intensification, laser land levelling and community rules for fisheries management represent some of the proactive actions, while on-farm diversification and restoration of embankment represent some of the reactive actions. While many of the farm-level innovations are not fully informed by longer-term trends and projected scenarios of climate change, some of these adaptive practices appear highly promising in the context of growing climatic risks. There is also a scope for wider dissemination of promising practices through on-farm experimentation, especially when there is enabling policy and institutional support. Given such rich local-level adaptive innovations in South Asian agriculture, the focus of policy and institutional support should be more on strengthening location-specific innovations and adaptation strategies and disseminating low-cost technologies for smallholder farmers. This study also reinforces the research that creating necessary agricultural technologies and harnessing them to enable farmers to adapt their agricultural systems to changing climate will require innovations in policy and institutions (Howden et al. 2007; Ojha et al. 2013). The success of local institutions and how well they coordinate with both public and private sector actors to streamline the agriculture production will play a key role in whether or not smallholder farmers are able to take up innovative practices that will allow them to adapt to their changing circumstances including climate change. The evidence has also demonstrated that a community-based approach to develop and manage commons, for instance, common pasture lands in Udaipur and forest resources in Lamjung, is viable and can be sustainable only when there is a concurrent change in policy and institutions to enable adaptive innovations at local level. All these community-based approaches have emerged over long periods of handholding support and promoting these types of adaptation would require public investments.

Although there has been some progress in formulating national adaptation strategies (such as NAPAs) in different countries of South Asia, policy, research and extension systems lack adequate attention to wider resilience of the system. As a result, productivity-focused interventions have got higher merit for wider dissemination at the expense of resilience-enhancing innovations. Further research on technologies which recognize changing economic, social and ecological contexts and which consider longer-term trends and projected scenarios of climate change are required before upscaling them in a larger scale. In any further efforts to develop or refine national adaptation plans, the potential role of local institutions and institutional partnerships both at the local level and across multiple scales should be paid greater attention. We recommend that adaptation policies should enhance and strengthen emerging farm and landscape-level innovations, while also promoting informed research and extension systems and pro-poor government policies that improve local adaptation and coordinate activities of different actors.

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