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Research Paper

Climate Variability and Adaptation of Homegardens in South Asia: Case Studies from Sri Lanka, Bangladesh and India

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Abstract: This study assessed the climate variability, vulnerability of Homegardens (HGs), and elements that influence the adaptation decisions of homegardeners in selected regions in South Asia. Study sample comprised 148 HGs in three sites in Sri Lanka, 120 HGs in Bangladesh and 100 HGs in India. Variability in temperature and rainfall in the sites from 1961 to 2010, and changes in the onset of cultivating seasons during two decades (1991-2010) were analyzed. The socio-economic data of the homegardeners, agronomic data of HGs, diversity of trees and farm animals, and adaptation strategies used in HGs for perceived variability in climate during 1991-2010 were collected using a questionnaire survey. The annual rate of rise in night-time minimum temperature in the three Sri Lankan study sites (0.012 to 0.022 °C; R^2 = 0.251 to 0.589; $p<0.05$) and in the Indian study site (0.041 °C; R2 = 0.324; $p<0.05$) more pronounced than the increase in day-time maximum temperature. The average annual day-time minimum and maximum temperatures in Bangladesh study site did not show a significant variation ($p>0.05$). The annual cumulative rainfall did not reveal any discernible trend in all study sites ($p>0.05$). From 1991-2010, 85 % of *Maha* seasons in Sri Lanka (September to February) have not been set on time (p<0;05), whereas in Bangladesh and Indian study sites, the onset of the majority of cultivating seasons was not delayed. The HGs in Sri Lankan sites were mainly crop-based while those from India and Bangladesh had a rich blend of crops and farm animals. The homegardeners have made changes to planting dates of annual crops, agronomic practices, technology used (new annual crop varieties and irrigation equipment) and soil and water conservation measures to adapt to climate variability. Probit analysis showed that the type of employment, age, education level of the household head, experience in farming, HG size (extent), presence of farm animals and tree density of the HGs have significantly influenced the decision of homegardeners to adopt any adaptation strategy. Homegardeners who perceived climate variability were more adaptable and adaptation strategies were location specific.

Keywords: Climate variability, onset of rainfall, homegardens, determinants of adaptation strategies, Sri Lanka, Bangladesh, India

Introduction

Homegarden (HG) is an agroforestry system that combines multiple farming components such as annual and perennial crops, livestock and occasionally fish, and provides environmental services, household needs, and employment and income generation opportunities to the households (Weerahewa *et al*. 2012). An assessment of global distribution of HGs carried out by Nair and Kumar (2006) revealed that the HGs are more popular in humid and sub humid tropics and found between 40° N and 30° S latitudes. The largest concentrations of HGs are found in the South and Southeast Asian region with extents in Indonesia, Kerala (India), Sri Lanka and Bangladesh amounting to 5.1, 1.44, 1.05 and 0.45 million ha, respectively. The HGs are also well distributed in the Pacific islands, East and West Africa, Mesoamerica, tropical and subtropical China, Mediterranean region of Catalonia and Southern Africa (Agelet *et al*. 2000; High and Shackleton 2000; Wenhua 2001; Zhaohua *et al*. 1991).

Being a small-scale subsistence agricultural system, the main output of HGs is consumed directly and a minor proportion is marketed (Barnett 1997), and help supplementing the food requirements of the family (Galhena *et al*. 2013). In South Asia, HGs are a major form of land use that has evolved to suit the socio-economic, cultural and ecological needs for centuries (Kumar and Nair 2004; Pushpakumara *et al*. 2012). These subsistence or smallholder agriculture or agroforestry systems could reduce the vulnerability of food-insecure households, improve livelihoods, and adapt to fluctuating market conditions (Roshetko et al. 2007, Baiphethi and Jacobs 2009). The HGs also provide a number of ecosystem services such as habitats for animals and other beneficial organisms, nutrient recycling, reduced soil erosion, and enhanced pollination (Pushpakumara *et al*. 2010). Tropical HGs have a special role in carbon sequestration due to their ability to store carbon in the standing biomass, soil, and the wood products (Marambe and Silva 2012; Mattson *et al*. 2013).

Climatic variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events (IPCC 2007). Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). The ultimate significance of the climate change and variability is related to its global reach, with its complex and interactive affects in the global context (Rosenzweig and Tubiello 2007).

Most developing countries are particularly vulnerable to climatic change (especially climatic variability) because their economies are closely linked to climatic sensitive sectors such as agriculture (Mendelsohn et al. 2006). Literature provides clear evidence that countries in South Asia have continued to experience climate variability (Marambe et al. 2002, De Costa 2008, Marambe et al. 2013; Singh et al. 2014, Ahmed and Suphachalasai 2014). South Asia has been estimated to lose an equivalent to 1.8 % of its annual gross domestic product (GDP) by 2050 due to a variable and changing climate, which will progressively increase to 8.8% by 2100 (Ahmed and Suphachalasai 2014), where Bangladesh, India and Sri Lanka are projected to face 1.4%, 2.2%, and 1.2% loss of annual GDP, respectively, by 2050.

The changes in the wet and dry extremes during the monsoon season are relevant for managing climate-related risks, with particular relevance for water resources, agriculture, disaster preparedness and infrastructure planning (Singh *et al.*, 2014). Verchot *et al.* (2007) reported that the frequent extreme climate events would increase the production risk and uncertainty in crop revenue. In such situations, farm households have been reported to increasingly diversify their sources of income to include livestock, non-farm income and remittances from out-migration. An intensively managed livestock sector is hardly vulnerable to the short-term variability in climate compared to impacts on the food crops sector (Thornton 2009; Marambe *et al*. 2014).

Agroforestry systems, such as HGs, play an important role in adapting to a variable climate, particularly for smallholder farmers (Verchot *et al*. 2007; Linger 2014). Use of efficient and effective adaptation strategies in the HGs to minimize the damages caused by climatic variability is one of the reasons attributed to such resilience. Hence, a better understanding on the linkage between climate variability and the adaptation strategies at the HGs would help in policy interventions to develop best practices to be adopted under smallholder farming systems in the global context, to build their resilience.

There is a growing body of literature examining the types of adaptation strategies in agriculture systems that would vary according to the differing farm types and locations, and the economic, political and institutional circumstances in which the climatic stimuli are experienced and management decisions are made (Smit et al. 1999; Bryant *et al*. 2000; Smit and Skinner 2002; Nhemachena and Hassan 2007; Rao *et al*. 2007; Deressa *et al*. 2008; Ngigi 2009; Below *et al*. 2010; Deressa *et al*. 2010). The adaptation strategies for climate change and variability are also viewed as country or location specific (Bishaw *et al*. 2013). Smit and Skinner (2002) reported that the adaptation options in Canadian agriculture falls under four main categories namely, (i) technological developments, (ii) government programs and insurance, (iii) farm production practices, and (iv) farm financial management, and that most adaptation options are modifications to on-going farm practices and public policy decision-making processes. Ngigi (2009) reported that the use of shallow wells and hand-dug wells for dry-season irrigation and soil moisture improvement techniques such as mulching as adaptation strategies in northern Ghana, Burkina Faso and Mali, use of drip irrigation (new technology), choice of high yielding, high-value crops and drought-resistant crop varieties, and better water application technologies as the strategies adopted by the smallholder farmers in Nigeria, Senegal, Burkina Faso and Ghana, and preparation of bunds, agroforestry, crop rotation and rainwater harvesting as strategies used in Ghana. Deressa *et al*. (2008) reported that the use of different crop varieties, tree planting, soil conservation, change in planting date, and irrigation as adaptation strategies used in Ethiopian farmers.

Despite the large empirical evidence on adaptation, there is a dearth of studies in the global context examining the extent to which homegardeners have adapted to a variable climate. Morton (2007) suggested the need for an interdisciplinary approach to apply the rapidly growing scientific knowledge of the effects of climate change and variability on farming systems in developing countries to build adaptive capacity at all levels. The objective of this study was to assess the climate variability of selected regions in South Asia, vulnerability of HGs and different elements that influence the decisions of homegardeners in adopting different adaptation strategies.

Materials and Methods

<u>Selection of study sites</u>

This multi-country study was carried out in three South Asian countries namely, Sri Lanka, Bangladesh and India (Table 1). A stratified sampling strategy was employed for selecting the study sites. The study sites (villages) were purposively selected based on the historical evidence of homegardening, to represent different climatic zones, and based on the availability of long term climate data (1961-2010). Within each study site, homegardens (HGs) that have been established and maintained for more than 20 years covering the entire period 1991-2010 were selected based on a common criteria namely, extent < 0.5 ha, having a composition of trees and annuals (preferably with farm animals), with at least a 3-tiered plant structure, and the surrounding area has not been subjected to significant man-made changes (*i.e.,* construction of roads, establishment of irrigation reservoirs, development of market places) that would mask the impacts of climate variability and the perception of farming community on the variable climate.

Based on the sampling strategy, three villages were selected from Sri Lanka, where two sites (i.e.

Keeriyagaswewa and Siwalakulama in the Anuradhapura district) were from the Low Country Dry Zone (altitude < 300 m amsl, rainfall <1750 mm/year).

Table 1. The characteristics of selected study sites in Sri Lanka, Bangladesh and India

Country and Villages	Agro-climatic/ Climatic zone	Number of Homegardens surveyed	GPS locations of the study sites
Sri Lanka (three villages)			
Keeriyagaswewa (Anuradhapura District)	Low Country Dry Zone	59	7.86° N, 80.65° E
Siwalakulama (Anuradhapura District)	Low Country Dry Zone	30	7.95° N, 80.75° E
Pethiyagoda (Kandy District)	Mid Country Wet Zone	59	7.27° N, 80.6° E
Bangladesh (five villages)			
Borjona, Nakasini, Koroli, Goshaigao, Tatulia, and Charbaria (Gazipur District)	Subtropical Monsoon Region	120	24.3° - 24.16° N 90.3° – 90.42° E
India (two villages)			
Ledagamar and Keshia (West Bengal)	Sub-humid	100	22.80° – 22.83° N 87.32° – 87.32° E

Considerable fluctuations in rainfall intensity and distribution pattern were reported from these two study sites due to the inherent characteristics of the North East Monsoon (NEM) that dominates the state of rainfall regime in the region. The remaining site from Sri Lanka (*i.e.* Pethiyagoda in the Kandy district) was from the Mid Country Wet Zone (altitude 300 – 900 m amsl, rainfall > 2500 mm/year) with a less variation in rainfall intensity and distribution pattern attributing to the strong influence of South West Monsoon (SWM) in the area. The three villages selected from Sri Lanka represented different temperature regimes. Five sites from Bangladesh (i.e. Borjona, Nakasini, Koroli, Goshaigao, Tatulia, and Charbaria villages from the Gazipur district) and two sites from India (i.e. Ledagamar and Keshia villages in the West Bengal) were selected with comparable climatic conditions to that of the Sri Lankan sites to facilitate direct comparison of information generated across partner countries. Both sites in Bangladesh and India received rainfall mainly from the SWM.

The study sites in Bangladesh were located in the central part/terrace zone (intermediate range of temperature, rainfall and humidity) while those in India were in the dry zone, high altitude, with a rich biodiversity and well established HGs. The production systems, particularly homesteads in this region, are well developed and are less prone to floods.

The total sample size of the study was 268 HGs. The species area curves (Cain 1938) were developed for each site to confirm that the number of samples (HGs) and area (extent of HG in hectare) selected were adequate to represent the diversity of crop and tree species of the study sites**.** The locations of selected sites and the number of HGs studied are given in Table 1.

<u>Data collection and analysis:</u>
Historical data on temperature and rainfall were collected from the Departments of Meteorology of the respective countries. Trend analysis for average annual minimum temperature, maximum temperature and annual rainfall were done for the entire data set from 1961 to 2010 (50 years). The varibaility in rainfall over the same period was also analyzed by using co-efficienct of variation (CV). All data were carefully examined for their accuracy and consistency prior to analysis and the missing values of the primary climate data (daily data) were estimated using the normal ratio method (De Silva *et al*. 2007). According to the guidelines of the World Meteorological Organization (WMO), as at

present, the base period for climate analysis is taken as the average of the period 1961-1990. In this study, our aim was to ascertain whether there was any rainfall variability during the recent 20-year period (1991-2010) compared to the base period, as the most recent variations of the climate is the factor that generally influences the perception of farmers.

Analysis of the onset of the cultivating season was carried out for the most recent two decades (1991-2010) using 1961-1990 period as the baseline, in accordance with the questions related to perception on climate variability as identified in the questionnaire survey described later, using the percentage cumulative mean rainfall method (Ilesanmi 1972; Adejuwon 1990). The analysis was based on daily rainfall data, and the study years were categorized as having early, normal and late onsets. In a given year, rainfall occurred one to three weeks prior to the expected commencement of the cultivation season was considered as an early onset, while rainfall occurred one to two weeks later than the expected commencement date was considered as late onset. The onset was analyzed for main cultivating seasons in each country. In sri Lanka, where there is a bi-model rainf fall pattern, onset was calculated for two cultivating seasons namely, *Yala* season (March to August) that receives rainfall mainly from the first inter monsoon (FIM) + SWM and *Maha* season (September to February) receiving rainfall from the second inter monsoon (SIM) + NEM.

Both Bangladesh and Indian study sites depicted a uni-modal rainfall distribution pattern attributing to the fact that only the SWM rains are effective over the locations as against to Sri Lankan sites where both the SWM and NEM rains are in force. However, farmers in Bangladesh have opted to make use of the non-monsoonal stormy rains received during mid-March to early or mid-July from the Western disturbances as *Kharif 1* growing season. Therefore, two onset occurrence times as *Kharif 1* (mid March to mid July) and *Kharif 2* (mid July to mid October) were considered for the Bangladesh site. For India, onset occurrence was considered for the major agriculture season *Kharif* (July to October).

A household survey was carried out through a structured questionnaire to obtain the information on general household characteristics and agronomic characteristics. The questionnaire was pre-tested in all partner countries and was administered from May to December 2010 in the selected sites. The general household characteristics and the descriptive Statistics of the variables used in the Probit model described later are shown in Table 2.

The agronomic characteristics included the structure and composition of the HG systems. The total extent cultivated and managed by each household was recorded in terms of their type (HG, lowland, *chena*, other), proportion and ownership (owned, tenant, other). The land distribution pattern was further elaborated by the proportion devoted for each crop, farm animals and other elements present in the HG. The nature of management (*i.e.* cultivated by self or not) was also recorded. The Shannon-Wiener Index (SWI) was used to estimate the species richness and abundance of trees in all five locations (Margurran 1988). The proportion of species (i) relative to the total number of species (p_i) was calculated and then multiplied by the natural logarithm of the same proportion [$\ln(p_i)$]. The resulting product was summed across species, and multiplied by -1 (Equation 1). The SWI of individual households across the five locations was used as an explanatory variable in probit analysis.

$$SWI = -p_i\left[\ln\left(p_i\right)\right] \qquad \text{(Equation 1)}$$

Responses were collected on the changes made in HGs during the past 20 years with regard to crops, woody trees, and domestic animals. Specific adaptation strategies were identified and the binary variables were used to capture whether a certain practice was adopted or not across sites. The three villages in Sri Lanka were considered separately for the analysis, while five villages in Bangladesh and two in India were pooled separately due to being located in the same agro-climatic/climatic zones in the respective countries.

Table 2. Descriptive Statistics of the variables used in the Probit Model

Explanatory Variable	Description	Units	Mean		
			Sri Lanka	Bangladesh	India
Socio-economic and demographic characters	Age of the homegardener (household head)	Years[a]	55.41 (13.84)[b]	50.64 (13.08)	72.93 (19.76)
	Level of education of the homegardener (A dummy variable)	Low	3.4%	14.2%	56.0%
		High	96.6%	85.8%	44.0%
	The number of family members in farming	Number	1.66 (1.33)	1.5 (1.17)	1.77 (1.34)
	The number of family members employed off-farm	Number	1.033 (1.15)	3.48 (1.54)	2.11 (1.35)
Exposure of the homegardener to climate variability (household head)	Experience in farming	Years	34.56 (13.91)	31.58 (12.38)	27.56 (14.29)
	Number of years of residence in site	Years	42.09 (20.45)	57.76 (29.95)	42.5 (12.86)
	Perceived change in temperature (A dummy variable)	Yes	70.9%	10.8%	100.0%
		No	29.1%	89.2%	0.0%
	Perceived change in rainfall (A dummy variable)	Yes	78.2%	10.8%	0.0%
		No	21.8%	89.2%	100.0%
Intrinsic features of the homegarden (HG)	HG size	ha	0.28 (0.17)	0.11 (0.07)	0.07 (0.06)
	Presence of farm animals	Number of species	0.027 (0.20)	2.38 (0.88)	2.03 (1.15)
	Tree density per HG	SWI[c]	2.0 (0.4)	1.09 (0.38)	1.44 (0.32)
Degree of dependence on the HG	Income from HG as a proportion of the Total Household income	Proportion	0.051 (0.09)	0.20 (0.15)	0.05 (0.05)

[a] average ages of the household head were reported for Bangladesh and Sri Lanka and the average age of the household members between 15-60 years was reported for India; [b] Values within parenthesis are standard deviation of the mean; [c] Shannon-Wiener Index

In the case of binary data, Chi Square (χ^2) and Fisher Exact tests (p=0.05) were carried out as appropriate as the test statistics to identify the relationship between variables. Econometric diagnostics of the probit models was done using Chi Square test at p=0.1, 0.05 and 0.01.

The modelling approach:

The probability of adopting a strategy was hypothesized to be influenced by the intrinsic characteristics of the HG (extent, tree density and presence of farm animals), the socio-economic and demographic characteristics of the homegardeners (employment, education, sex and age of the head of the household and size of the household), exposure to climate variability (experience in farming, years spent in the village, and perception on changes in climatic conditions such as rainfall and temperature), and the degree of dependence on the HG. Accordingly, a binary probit model was used to analyze the factors that influence the decision to adapt to climatic changes following Deressa *et al*. (2010). The algebraic specification of the model is given in Equation 2.

$$P(Y = 1 \mid X) = F(BX) + \varepsilon, \varepsilon \sim N(0, \sigma 2) \qquad \text{(Equation 2)}$$

where, P(.) is the probability function, Y is the dependent variable, X is a vector of independent variables and B is the vector of co-efficient estimates. In the empirical specification, the dependent variable was treated as 1 if a homegardener adopted a strategy and 0 otherwise. A variety of models was specified and estimated treating different subsets of independent variables. The best model was selected based on the statistical criteria of estimations such as pseudo R^2 and statistical significance of the coefficients, following Burnham and Anderson (2002). The global model hypothesized consisted of many parameters including all potentially relevant effects, and reflects the causal mechanisms thought likely, based on the review of literature and judgments of the research team. The vectors showing intrinsic characteristics of the HG, the socio-economic and demographic characteristics of the homegardeners, exposure to climate variability, and the degree of dependence on the HG were designed. Models with fewer parameters were then derived as special cases of the global model for each location and for each strategy. As shown in the results section, the alternative models involved differing numbers of parameters corresponding to different sets of independent variables chosen.

Results

Socioeconomic characteristics of homegardeners and tree and animal compositions in HGs

The analysis of survey data indicated that the average age of the homegardeners in the study sites of Sri Lanka and India was approximately 55 years and that in Bangladesh was 51 years. An average family consisted of four members in each site in Sri Lanka whereas in Bangladesh and Indian sites it was higher at 5 (ranging from 2 to 10) and 6 (ranging from 2 to 15), respectively. Among the HGs surveyed, 13% of the head of the households in the Sri Lankan study sites were educated up to secondary or above and 3% were in the "no schooling" category. About 48% and 37% in the Bangladesh site have had education up to primary and secondary levels, respectively, and 14% have not attended school education, while 49% of the heads of households in the Indian site were educated up to the secondary level or above and 29% have not followed school education.

The HGs surveyed in Sri Lanka consisted of comparatively higher diversity of trees recording 116 species from 85 genera belonging to 37 families compared to those of study sites in India (75 species, 71 genera and 37 families) and Bangladesh (47 species, 47 genera and 28 families). Sixteen tree species were common to all three countries. The most common tree species to the three study sites in Sri Lanka were (in the descending order the dominance) *Cocos nucifera* L., *Azadirechta indica* A. Juss., *Mangifera indica* L., *Areca catechu* L. and *Berrya cordifolia* (Wild.) Burret. The HGs in the Bangladesh site were dominated by *Artocarpus heterophyllus* Lam., *Mangifera indica* L., *Cocos nucifera* L. *Litchi* *chinensis* Sonn. and *Swietenia mahagoni* L. Jacq., while those in the Indian sites, *Azadirachta indica* A. Juss., *Mangifera indica* L., *Artocarpus heterophyllus* Lam., *Cocos nucifera* L., and *Psidium guajava* L. were the dominant tree species. The species richness of trees in the HGs estimated using Shannon-Winner Index (SWI) showed that the majority of HGs in Sri Lanka and India are with high density of trees. The mean SWI (±standard deviation) of HGs at Pethiyagoda was 1.99±0.4, Keeriyagaswewa 2.13±0.43 and Siwalakulama 1.77±0.38. The SWI in HGs of the Bangladesh site was 1.09±0.38 and for India 1.44±0.32. The tree density in some HGs in the Sri Lankan sites was considerably high with 76 HGs having 2<SWI<3, while in the Bangladesh site, 55 out of 120 HGs showed a SWI<1.

The number of animal species per household was found highest in Bangladesh (Average 2.38) followed by India (average 2.03). In Sri Lanka it was less than one. The majority of the HGs in the Sri Lankan study site were crop-based with only 20 out of 59 HGs in Keeriyagaswewa and 7 out of 30 HGs in Siwalakulama having farm animals (at least one breed of neat cattle), while no farm animals were found in the HGs at Pethiyagoda. Neat cattle (*Bos taurus*), water buffaloes (*Bubalus bubalis*), indigenous chicken (*Gallus gallus domesticus*) and indigenous goats (*Capra aegagrus hircus*) were the farm animal species found in the HGs in the two Sri Lankan sites. In contrast, 102 out of 120 HGs in the Bangladesh site and 63 out of 100 HGs in the Indian site comprised of at least two species of farm animals. In the HGs in Bangladesh and India, the common farm animal species found were neat cattle, chicken, goat, sheep (*Ovis aries*), ducks (*Anas platyrhynchos*), pigs (*Sus scrofa domesticus*) or a mix of those species. In fact only 24 % of the total households in the study sites reared farm animals in their HGs.

<u>Analysis of meteorological data:</u>

Vulnerability, which is a function of exposure and sensitivity (IPCC 2001), is defined by the existing environment and not by the future stress, and by analogy, the vulnerability of HGs could be determined primarily by their existing state and environment, rather than by what may or may not happen in the future. In the study sites of Sri Lanka, a significant rise in the average annual minimum temeprature were observed (p<0.05, Table 3) compared to the day-time maximum temperature. Both Pethiyagoda and Siwalakulama study sites in Sri Lanka dod not show discernible trend in the day-time maximum temperature during the period 1961-2010.

The variability of the maximum temperature at the Siwalakulama site has markedly decreased during recent times (data not shown). The average annual minimum and maximum temperature regimes in the Bangladesh study site did not show a significant change during the study period (p<0.05). The Indian site did not have a good coverage of meteorological data ranging from 1961-2010 to carry-out a complete analysis unlike in the case of Sri Lanka and Bangladesh. However, available data from 1969 to 2006 for the minimum temperature data showed a significantly increasing trend (p<0.05) as in the case of neighboring Sri Lanka. The average annual maximum temperature for both the Bangladesh and Indian sites did not show a significant increase (p>0.05; Table 3) during the study period.

The annual cumulative rainfall did not reveal any discernible trend in the case of study sites in Sri Lanka (p>0.05; Table 3), but a high variability (data not shown). A similar pattern was observed from Bangladesh and Indian sites, too. In the Bangladesh study site, the variability of annual rainfall during the last decade has been high compared to 1960s. At the Keeriyagaswewa (Sri Lanka) site, the onset of the *Maha* season has become highly variable during the past two decades (Fig. 1). Out of the 20 *Maha* seasons during the last two decades, the season has not been set on time in 85% of the occasions (p<0;05).

During this period, onset of the season has been delayed in most of the years. In contrast, the onset of *Yala* season has not been subjected to much variation during the period concerned. During the most recent decade of 2001-2010, the rains of *Yala* season has arrived on time in 70% of the years. The same is true for the preceding decade, too. However, the trends observed in Pethiyagoda (Sri Lanka) was in contrary to those of the Keeriyagaswewa site, where in 65% of instances, the rains during *Maha* season has arrived early compared to the expected time (Fig. 1), which was more pronounced during the most recent decade 2001–2010.

Table 3. Changes in the average minimum (night time) and maximum (day time) temperatures of study sites (1961-2010)

Location	Trend	R^2
Sri Lanka (Keeriyagaswewa)		
Minimum temperature	Y = 0.022X - 21.85	0.589*
Maximum temperature	Y = 0.024X - 16.7	0.395*
Sri Lanka (Pethiyagoda)		
Minimum temperature	Y = 0.013X - 7.114	0.329*
Maximum temperature	Y = 0.012X + 4.428	0.147
Sri Lanka (Siwalakulama)		
Minimum temperature	Y = 0.012X - 2.571	0.251*
Maximum temperature	Y = 0.005X + 21.49	0.031
Bangladesh Site		
Minimum temperature	Y = 0.001X + 16.92	0.003
Maximum temperature	Y = -0.009X + 49.48	0.089
India Site[a]		
Minimum temperature	Y = 0.041X – 60.65	0.324*
Maximum temperature	Y = -0.015X + 61.57	0.113

[a]Data used were for the period 1969-2006. *statisfically significant at p=0.05

The onset of the *Yala* season at Pethiyagoda during 1991-2010 has been either on the correct time or early. Occurrence of delayed onset of *Yala* season has occurred in only about 10% of the years in the 20-year study period. However, during the most recent decade of 2001-2010, the onset of *Yala* season has never been delayed at the Pethiyagoda site. At Siwalakulama (Sri Lanka), the onset of *Maha* season has become highly variable during the two decades. However, similar to the Keeriyagaswewa site, the *Yala* season at Siwalakumalam has never got delayed over the study period and has not been subject to much variation during the 1991-2010. During 2001–2010, the rains of *Yala* season has arrived on time in 60% of the years at the Siwalakulama site in Sri Lanka.

Unlike in Sri Lanka, the onset of the growing seasons in the study site at Bangladesh in the major rainy seasons has been varible over the two decades (Fig 1). The *Kharif I* season has started on time in 70% of the years during the most recent decade ($p<0.05$), whereas the *Kharif II* season has never failed in its onset during the past two decades. In the Indian study site, the onset of major growing season (*Kharif*) during the last 16 years has either been on correct time or early in the season (Fig. 1). Occurrence of delayed onset during the 16-year time period in the Indian study site accounted only for 20% ($p>0.05$).

The result of the CV analysis of rainfall over the years has showed that the the varaibility of the First Inter Monsoon (FIM) in the Pethiyagoda site has increased during the recent two decades (1991-2010) compared to the standard 30-year period of 1961-90 (Table 4). The same is true for the rainfall during *Maha* season. While at Keeriyagaswewa and Siwalakulama sites, the variability of SWM has increased during recent two decades compared to the standard 30-year period of 1961-90, and same is true for the NEM season. In the Bangladesh site, the variability of rainfall during the period 1991-2010 through SWM has decreased when compared to the 1961-1990 period. The variability of rainfall in the *Kharif* season (SWM) in the Indian site has increased during the 16-year period (1991-2006) compared to the standard 30-year period (1961-1990), while the variability of annual rainfall has shown an increase during the period 1991-2006.

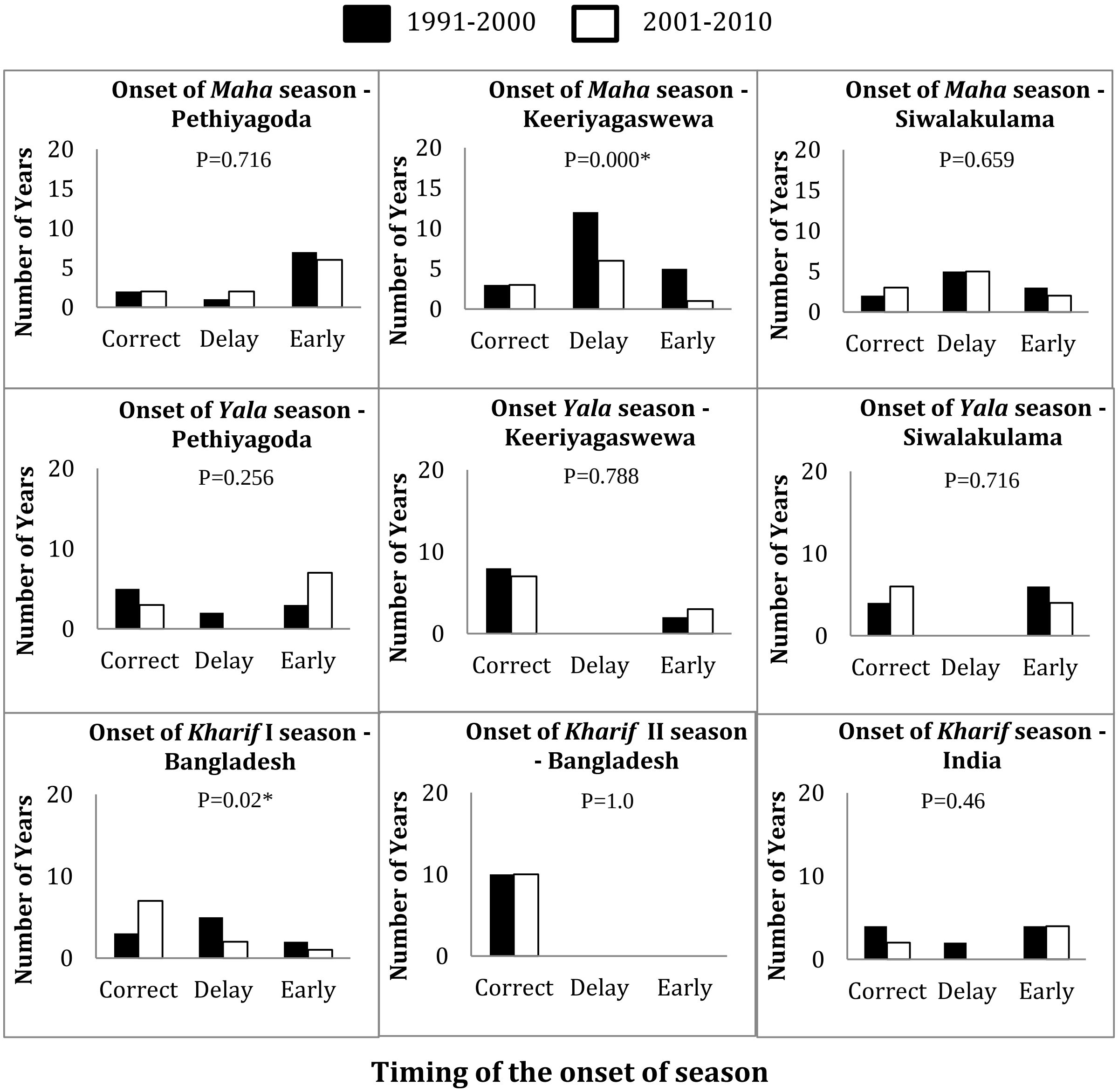

Figure 1. Status of onset of rain in the study sites. P=probability values calculated using the chi squatre test at p=0.05. *Cultivating seasons: Yala* season = March to August, *Maha* season = September to February; *Kharif 1* season = mid-March to mid-July, *Kharif* 2 season = mid-July to mid-October, *Kharif* season = July to October. *significant association (p<0.05).
Notes: In the Indian study site, data were available only up to 2006. Fisher Exact Test was used for Yala cultivating seasons in Keeriyagaswewa and Siwalakuma in Sri Lanka and Khraif II cultivating season in Bangladesh

Adaptation to climate variability:

The specific adaptation strategies used by the homegardeners in five study sites were (a) changing planting date of annual crops, (b) changing agronomic practices for annual crops, (c) changing technology such as use of new varieties of annual crops and irrigation equipment, and (d) use of soil and water conservation measures. The degree of adoption of these strategies across the study sites varied significantly (p<0.01; Figure 2). Change in technology was the most common adaptation strategy in the HGs in Sri Lanka and Bangladesh, while soil and water conservation methods were much popular in the Indian sites. In Bangladesh, all the farmers in the sample have adopted a new technology.

Table 4. Variability of rainfall during the period 1991-2010

Country and Study Site	Monsoon/Season	1961-1990	1991-2010
		Mean ± standard deviation and CV %[a]	
Sri Lanka			
Pethiyagoda			
	FIM[b]	257.5±92.7 (0.36)	308.7±163.6 (0.53)
	SWM	666.6±199.9 (0.30)	588.0±158.7 (0.27)
	SIM	569.5±182.2 (0.32)	569.7±182.3 (0.32)
	NEM	338.7±203.8 (0.60)	361.7±253.2 (0.70)
	Yala season	772.1±200.7 (0.26)	770.1±207.9 (0.27)
	Maha season	1062.2±297.1 (0.28)	1042.7±312.8 (0.30)
	Annual	1832.5±384.8 (0.21)	1839.3±331.1 (0.18)
Keeriyagaswewa			
	FIM	256.2±125.5 (0.49)	246.3.1±113.3 (0.46)
	SWM	264.9±87.4 (0.33)	235.7±98.9 (0.42)
	SIM	498.5±164.5 (0.33)	548.3.1±186.4 (0.34)
	NEM	329.4±197.6 (0.60)	366.0±212.3 (0.58)
	Yala season	433.6±134.4 (0.31)	393.8±114.2 (0.29)
	Maha season	1005.3±341.8 (0.25)	167.1±58.60 (0.34)
	Annual	1354.7±282.5 (0.21)	1404.4±252.8 (0.18)
Siwalakulama			
	FIM	216.3±77.5 (0.36)	238.8±93.1 (0.39)
	SWM	233.1±83.9 (0.36)	194.5±114.7 (0.59)
	SIM	470.7±115.3 (0.33)	501.0±130.3 (0.26)
	NEM	316.1±230.7 (0.73)	327.8±213.1 (0.65)
	Yala season[c]	375.2±86.3 (0.23)	372.3±122.9 (0.33)
	Maha season	860.9±258.3 (0.30)	878.6±298.7 (0.34)
	Annual	1244.4±286.2 (0.23)	1265.8±202.5 (0.16)
Bangladesh			
	Kharif 1 season	431.2±206.9 (0.48)	488.2±175.8 (0.36)
	Kharif 2 season	1221.0±439.6 (0.36)	1326.1±397.8 (0.30)
	Annual	2090.1±606.1 (0.29)	2286.3±548.7 (0.24)
India			
	Kharif season	1173.9±422.6 (0.36)	1964.8±468.5 (0.44)[d]
	Annual	1574.1±503.7 (0.32)	1423.4±583.6 (0.41)

[a]Values within parenthesis are co-efficient of variation; [b]FIM – First Inter Monsoon (March-April); SWM – South West Monsoon (May-August); SIM – Second Inter Monsoon (September – October), NEM – North East Monsoon (November – February); [c] Cultivating Seasons - *Yala* season = March to August, *Maha* season = September to February; *Kharif 1* season = mid-March to mid-July, *Kharif* 2 season = mid-July to mid-October, *Kharif* season = July to October, [d]Data available from 1991-2006

No significant trends were identified to ascertain a relationship between rate of adaptation with tree and farm animal composition in the HGs studied, when these factors were considered one at a time. However, the results of the probit models evaluated the effect of tree density and number of farm animals in HGs along with the socio-economic criteria of the homegardners on the likelihood of adoption of an adaption strategy. Tables 5, 6, 7 and 8 presents only the statistically significant descriptive variables from among those listed in Table 2 under each adaptation strategy.

<u>Determinants of changing technology as a strategy to adapt to a variable climate:</u>
The results revealed that the households in the Sri Lankan sites with positive perceptions on variability and changes in both temperature and rainfall have significantly ($p<0.1$) and positively affected the likelihood of adoption of new technologies in HGs (Table 5).

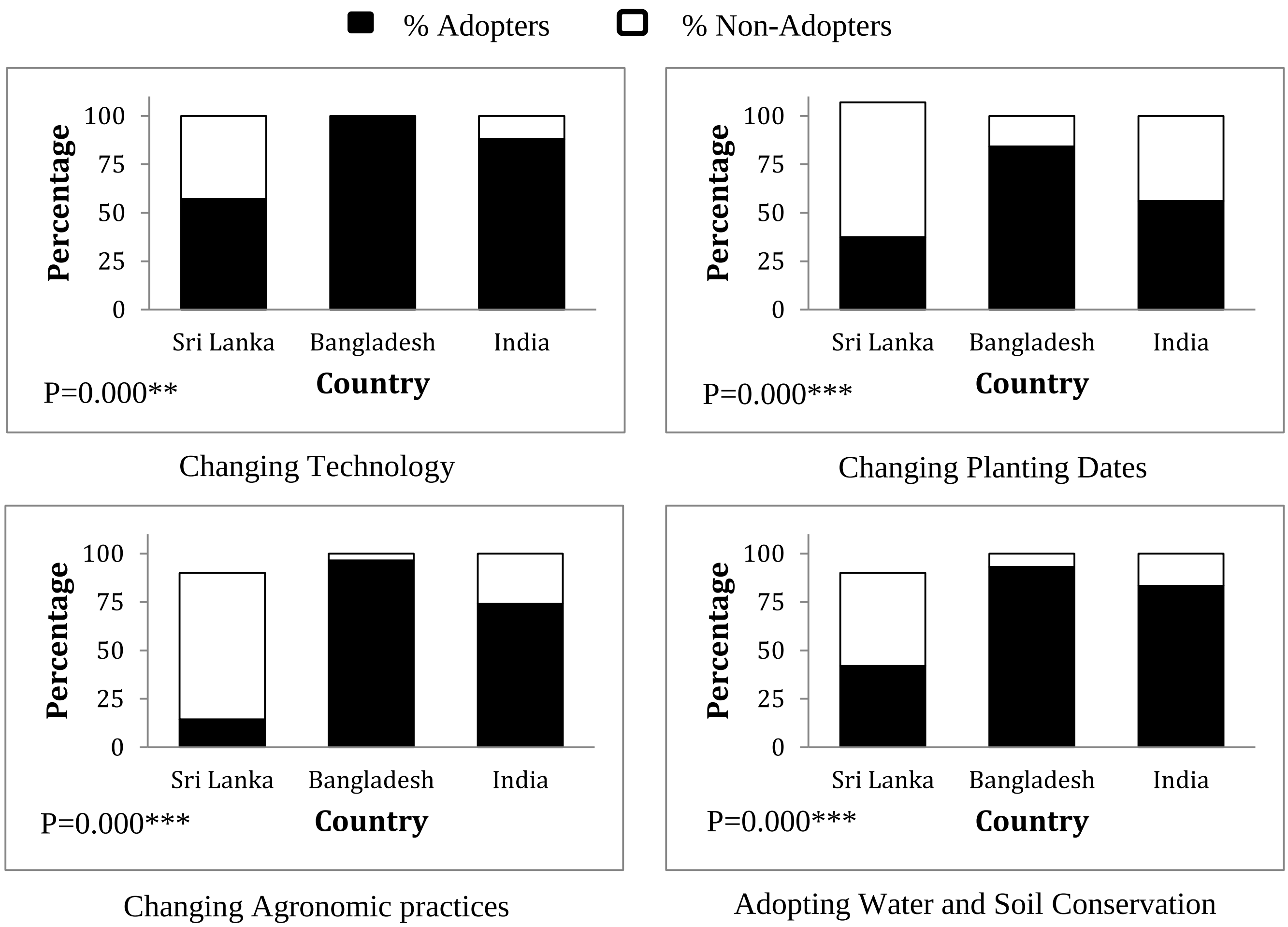

Fig 2. Degree of adoption of adaptation strategies across different countries. P=probability values calculated using the Chi Square test, ***significant association (p<0.01)

The marginal probabilities of adopting technologies for those who perceived a change in temperature and rainfall are higher by 42% and 17%, respectively. In the Indian sites, the results showed that the experienced homegardeners are more likely to adopt, where one year of experience increases the probability of adoption by 0.6%. All the homegardeners in the Bangladesh have adopted new technology and hence a model to explain the determinants of adoption could not be estimated.

<u>Determinants of changing planting date of annual crops as a strategy to adapt to climate variability:</u>
In the three study sites in Sri Lanka, HGs with high tree diversity and families with higher number of members engaged in farming were more likely to change planting dates of the annual crops (Table 6). Interestingly, the families with individuals who are engaged in non-farming activities were less likely to adopt this adaptation strategy to climate variability. Furthermore, the results showed that elderly farmers are less likely to change planting dates of the annual crops as an adaptation strategy to perceived variability in the climate. In the Bangladesh study site, the homegardeners having higher tree densities in their HGs are less likely concentrate on change the planting dates of annual crops as an adaptation strategy. Experienced farmers were also less likely to adopt this technology however, those who have spent longer time in the village were more likely to adapt. The results also showed that those who extract relatively more from the HG are more likely to change panting dates as a resilience measure.

Table 5. Statistically significant estimations of the explanatory variables in the probit models to assess the determinants of changing technology as an adaptation strategy to climate variability

Explanatory Variable	Description	Model 1: Sri Lanka		Model 2: Bangladesh[a]		Model 3: India	
		Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities
Constant		-0.93 (0.74)[b]		NE		0.30 (1.07)	
Exposure to climate variability	Years spent in the village	-	-			0.04** (0.02)	0.01**(0.01)
	Perception on changes in temperature	0.43* (0.26)	0.17*(0.10)			-	-
	Perception on changes in rainfall	1.13***(0.288)	0.42*** (0.09)	NE		-	-
Total No. of Observations		143		NE		100	

***significant at p=0.01, **significant at p=0.05, *significant at p=0.1. [a] all the homegardeners in the Bangladesh study site did adopt new technology and hence a model to explain the determinants of adoption could not be estimated. [b]Values within parenthesis are standard error, [c]Shannon-Weiner Index

Table 6. Statistically significant estimations of the explanatory variables in the probit models used to assess the determinants of changing the planting date in annual crops as an adaptation strategy to climate variability

Explanatory Variable	Description	Model 1: Sri Lanka		Model 2: Bangladesh		Model 3: India	
		Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities
Constant		-1.57 (1.04)[a]		1.21 (1.22)		-0.66 (0.72)	
Intrinsic feature of the HG[b]	Tree density in the HG (SWI)[c]	0.87*** (0.29)	0.31*** (0.11)	0.89* (0.47)	-0.17* (0.09)	0.74*(0.42)	0.29*(0.17)
Socio-economic and demographic characters of homegardeners	Employment: the No. of members in HH[d] whose occupation is farming	0.40*** (0.11)	0.15*** (0.04)	0.57 (0.68)	0.11 (0.13)	0.15 (0.16)	0.06 (0.06)
	Employment: the No. of members in HH employed (other than farming)	-0.34** (0.14)	-0.12** (0.05)	0.65 (0.67)	0.13 (0.13)	-0.21 (0.19)	-0.08 (0.07)
	Age of the HHH[e]	-0.02*** (0.01)	-0.01***(0.01)	0.02 (0.02)	0.01 (0.01)	-	-
Exposure to climate variability	Experience in farming	-	-	-0.34 (0.02)	-0.01* (0.01)	0.01 (0.01)	0.01 (0.01)
	Years spent in the village	-	-	0.01* (0.01)	0.01** (0.01)	-	-
	Perception on changes temperature	-	-	0.83 (0.64)	0.11** (0.05)	-	-
Degree of dependence on the HG	Proportion of income from HG	-	-	1.95* (1.17)	0.38* (0.23)	-1.26(0.45)	-0.49 (0.96)
Total No. of Observations		145		120		100	

***significant at p=0.01, **significant at p=0.05, *significant at p=0.1; [a]Values within parenthesis are standard error, [b] Homegardens, [c]Shannon-Weiner Index, [d] Household, [e] Head of the household

Table 7. Statistically significant estimations of the explanatory variables in the probit models used to assess the determinants of adopting soil and water conservation methods as an adaptation strategy to climate variability

Explanatory Variable	Description	Model 1: Sri Lanka		Model 2: Bangladesh		Model 3: India	
		Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities
Constant		-1.89** (0.77)[a]		1.74 (1.17)		0.57 (0.17)	
Intrinsic features of the HG[b]	Presence of farm animals	0.15 (0.63)	0.06 (0.24)	-0.14 (0.18)	-0.03 (0.03)	0.46* (0.24)	0.03* (0.02)
Socio-economic and demographic characters of homegardeners	Education	-	-	-1.02 (0.68)	-0.13***(0.05)	-	-
	Age of the HHH[c]	-0.01 (0.01)	-0.01 (0.01)	0.06***(0.02)	0.01*** (0.01)	-	-
Exposure to climate variability	Experience in farming	0.02 (0.01)	0.01 (0.01)	-0.05** (0.02)	-0.01***(0.01)	0.04**(0.02)	0.01* (0.01)
	Perception on changes in temperature	0.85***(0.30)	0.29***(0.09)	-	-	-	-
Total No. of Observations		121		120		100	

***significant at p=0.01, **significant at p=0.05, *significant at p=0.1; [a] Values within parenthesis are standard error, [b] Homegardens, [c] Head of the household,

Table 8. Statistically significant estimations of the explanatory variables in the probit models used to assess the determinants of changing agronomic practices as an adaptation strategy to climate variability

Explanatory Variable	Description	Model 1: Sri Lanka		Model 2: Bangladesh		Model 3: India	
		Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities	Coefficient	Marginal Probabilities
Constant		-2.89**(1.17)[a]		2.42 (2.86)		2.39***(0.85)	
Intrinsic features of the HG[b]	Tree density in the HG (SWI)[c]	0.07 (0.29)	0.02 (0.09)	-2.72* (1.42)	-0.01 (0.01)	-1.02**(0.48)	-0.32** (0.15)
	Presence of farm animals	-	-	0.88* (0.49)	0.01 (0.01)	0.10 (0.13)	0.03 (0.04)
Socio-economic and demographic characters of the homegardeners	Age of the HHH[d]	0.02* (0.01)	0.01*(0.01)	-0.04** (0.05)	- 0.00***(0.00)	-	-
Total No. of Observations		126		112		100	

***significant at p=0.01, **significant at p=0.05, *significant at p=0.1; [a] Values within parenthesis are standard error, , [b] Homegardens, [c]Shannon-Weiner Index, [d] Head of the household

The probability of adopting this strategy is higher by 11% ($p<0.05$) for those who perceived a change in the temperature than those who did not. In the Indian site, the homegardeners who possessed HGs with higher plant diversity are more likely to change planting dates of annual crops. Other factors that were hypothesized to affect changing planting date, and the presence of farm animal, were not statistically significant ($p>0.1$).

Determinants of using soil and water conservation methods as a strategy to adapt to a variable climate:
Perception on changing day temperature significantly contributed to the likelihood of adoption of soil and water conservation methods in the Sri Lankan sites. The probability of adoption of this strategy of those who perceived a change in day temperature was 30% higher ($p<0.05$) than those who did not (Table 7). In the Bangladesh site, soil and water conservation is less likely to be practiced by experienced farmers even though the elderly farmers tend to adopt more. In the Indian site, the livestock farmers and experienced farmers showed a high likelihood of practicing soil and water conservation.

Determinants of changing agronomic practices as a strategy to adapt to a variable climate:
Willingness to change agronomic practices in the Sri Lankan sites could only be explained using the age of the household head (Table 8). The elderly household heads in Sri Lanka tend to change the agronomic practices more where as in India, the opposite was true. In the Bangladesh and Indian sites, the HGs with high tree densities were less likely to change the agronomic practices as an adaptation strategy

Discussion

Analysis of meteorological data:
The increasing trend of the average annual minimum and maximum temepratures observed in the study sites follows the general global trend (IPCC 2014). The rate of rise in nighttime minimum temperature in the study sites was more pronounced than that of the daytime maximum temperature, a phenomenon that is evident in most parts of the world (Prasad *et al*. 2008). However, the negative trends in daily maximum temperature over the past 40 years as experienced in the study sites in Bangladesh (with a very low R^2 value) and India, though in contrary with the commmon global phenomenon, could be a result of region-specific variability in the climate as observed in the past (Pielke, 2002). Robinson *et al*. (2002) and IPCC (2007) have also reported overall cooling trends in the southeastern United States over the 20th century, in contrast to the widespread global warming.

The change of the trend in annual rainfall as seen in this study is the most common phenomenon of the rainfall climatology in Sri Lanka (Punyawardena 2002, Marambe *et al*. 2014). Variability of rainfall pattern was the highest in the NEM during the *Maha* season, affecting the production of rice and other field crops affecting food security in Sri Lanka (ME 2011). A wide disparity in the magnitude of changes has also taken place in different rainfall seasons at different spatial locations in Sri Lanka (Punyawardena 2011). Temporal and spatial variation of rainfall over smaller spatial scales has also being observed in India (Gohatakurta and Saji 2012) and other South Asian countries (Singh et al. 2014) as observed in the present study. The climate data analysis of the study sites clearly indicates that the HGs are highly exposed to and variability thus, increasing its vulnerability if proper adaptation measures are not adopted.

The onset of the *Maha* season at Keeriyagaswewa and Sivalakulama has occurred early in almost all *El Nino* years during the study period (www.bom.gov.au/climate/current/soi2.shtml). However, this trend was not evident in any of the other locations used in the study. Moreover, any other tele-connections with onset of growing seasons were not evident either with *El Nino* or *La Nina* events. A similar trend for the region was earlier reported by Punyawardena *et al*. (2004).

Adapting to a variable climate:

Tree dominated agroforestry systems including HG offer compelling synergies between adaptation and mitigation especially in smallholder situation because tree component of these systems are less vulnerable to extreme events (Lasco et al. 2014; Nguyel et al. 2010). The multiple benefits of high agro-biodiversity, more efficient water utilization, improved microclimate, enhanced soil productivity and nutrient cycling, control of pests and diseases, improved farm productivity, and diversified and increased farm income while at the same time sequestering carbon in the agroforestry landuse system have mainly enhanced smallholders' capacity to adapt climate risks and improved the resilience of smallholder farmers (Aguilar-Støen et al. 2009, Kumar, 2006; Lasco et al. 2014; Nguyel et al. 2010; Rao et al. 2007; Verchot et al. 2007).

Adaptation and mitigation functions of HGs and agroforestry systems and how these systems enhance resilience particularly at small scale level are discussed in detail by Verchot et al. (2007). Though it is not explicitly clear in all sites of the present study, the positive role of the farm animal component in improving the food stock of HGs has been well documented (FAO 2001, Musoti et al. 2008) and the contribution of livestock in building up resilience of the system has also been highlighted (Ickowicz *et al*. 2012). As reported by Morton (2007), in South Asia, strategies such as increasing livestock production relative to crops, and selection of crop varieties, are responses to both drought and floods in the agriculture systems. Marambe *et al*. (2011) reported that 44% of the homegardeners did strategic changes to the HG agro-ecosystem without due consideration to a variable and changing climate while about 19% did not adapt strategies in HGs to cope up with the changes. Accordingly, the results indicate that the homegardeners are ready to change the strategies to their activities though determinants of change could be diverse.

Determinants of adaptation strategies:

The results of the probit model clearly indicated that there is a country-specific response in changing technology adopted in HGs as an adaptation strategy to a variable climate. The change of technology considered in the present study included the use of new varieties of annual crops and irrigation equipment and hence justifies the country or site/locations specificity as explained by Morton (2007). Farmers have to depend on the outside sources and actors, especially those in the macro environment, on these technological inputs. Hence, the site-specificity or country-specificity cannot be avoided in decision making on change of technology as an adaptation strategy. Location specificity in adaptation strategies for climate variability and change is evident from the reports by Smit and Skinner (2002) for Canada, Deressa et al. (2008) for Ethiopia, and Ngigi (2009) and Bishaw et al. (2013) for the African continent.

Change of planting date is a direct response of farmers in relation to annual crops found in the HG. Inclusion of trees or perennial plant composition in the HG tends to increase the level of resilience in the long run (Howden *et al*. 2007) and influence the decision whether to further adapt to any changes in the surrounding environment. As highlighted in the results, we argue that the presence of high diversity and density of trees in Sri Lanka and farm animal component in India and Bangladesh has made the HGs more resilient to external shocks. In addition, other most highlighted determinant of the change of planting date of annuals is the age or experience of the homegardener. However, the age and experience acted on two different ways in some locations where experience was positively related to the change while the age was negatively related due to the conservative attitudes of elderly farmers.

The number of members in the family unit and the non-farming activities of the household are the other factors identified in this study across countries that have determined the strategies to respond under variable climatic conditions. Non-farming activities have made homegardeners less likely to adopt strategies to cope up with climate variability as those members are less sensitive to weather aberrations. The results revealed that the homegardeners tend to change the planting date of annual crops as an adaptation strategy depending on the labor or time availability for the additional the workload deviating from the usual practice, as the HGs have already developed higher resilience to climate varibaility by being an agroforestry system (Roshetko *et al*. 2007, Verchot *et al*. 2007, Baiphethi and Jacobs 2009, Linger 2014).

Perception of people on climate variability in the tropical environments is always linked with the amount and distribution of rainfall. Therefore, the homegardeners who have always relied on the rainfed cropping systems tend to practice water and soil conservation methods as adaptation strategies as revealed by the country-specific responses to climate variability. Generally, Bangladesh is relatively less vulnerable to soil erosion compared to other study sites due to prevailing on-site terrain characteristics. Country specificity could also be due to the heterogenic nature of the sample in three countries where addition of farm animals in the HGs could be an extra reason to adopt water and soil conservation methods in those sites where farm animals form a considerable component in HGs. The positive trend of number of farm animal units and water and soil conservation strategies observed in the present study is due to the known behavior of farmers for ensuring adequate supplies of water, which is among the globally practiced adaptation strategies in livestock systems (Howden *et al*. 2007). The country-specific nature of adaptation strategies and their determinants as observed in this study revealed that the perception of the homegardeners, which are governed by traditions, practices and culture, is playing a critical role in determining the practice of water and soil conservation methods similar to that reported by Bishaw *et al*. (2013) in smallholder system.

Change of agronomic practices showed a lower response according to many of the determinants evaluated but for age and the tree density. Following a routine pattern of practices is an intrinsic character of smallholder system everywhere in the world (Altieri *et al*. 2011), which is less likely to change by the practitioners. However, the observation of the present study that the HGs with limited land extent and high tree densities are less likely to change agronomic practices is valid as the agronomic practices are not a necessity when the ratio between trees:annual crops is high.

We argue that when the tree density is high in HGs, the farmers tend to be less dependent on the non-tree components in the HG thus paying less attention on the change of agronomic practices, which highly influence the production of non-tree components irrespective of the variability observed in the climate. As the present study did not take into account the economic yield of the tree crops, we recommend to have an improved assessments of yield responses of the tree species to future climate to help in selecting and prioritizing adaptation strategies. The bio-physical conditions and socioeconomic factors of homegardeners must also be assessed and considered along with the effectiveness of adaptation strategies in order to make recommendation to the HG production systems in relation to a changing and variable climate.

Conclusion

The increased variability of seasonal rainfall, onset of rains and the increasing annual average minimum and maximum temperatures would affect the productivity of annual crops and trees, and farm animals in the HGs thus affecting the livelihood of the households. The type of employment, age, sex, education level of household experience in farming and the size of HG have influenced the decision of homegardeners to adopt a given strategy to cope up with the variable climate. Development programs to promote adaptation should be designed taking above determinants into consideration. Emphasis should also be given to the systematic changes in the resource allocation and utilization in the system. Adaptation to a variable climate largely depends on the socio-economic and cultural factors of the homegardeners, which shape up the household management capacity, hence the system resilience.

Even though most of the determinants identified in the present study are country- or location-specific, those who perceived variability in climate were more adaptable in all locations. Enabling mechanisms should focus more on people's perception on climate variability at local scale and help communities make informed decisions based on climate information such as seasonal climate forecasting, to reduce their vulnerability and achieve climate adaptation at global scale.

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