Article

Farmers' Net Income Distribution and Regional Vulnerability to Climate Change: An Empirical Study of Bangladesh

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Abstract: Widespread poverty is the most serious threat and social problem that Bangladesh faces. Regional vulnerability to climate change threatens to escalate the magnitude of this poverty. It is essential that projections of poverty be made while bearing in mind the effects of climate change. The main purpose of this paper is to investigate the agrarian sub-national regional analysis of climate change vulnerability in Bangladesh under various climate change scenarios and its potential impact on poverty. This study is relevant to socio-economic research on climate change vulnerability and agriculture risk management and has the potential to contribute new insights to the complex interactions in household income and climate change risks to agricultural communities in Bangladesh and South Asia. The current study uses analysis of variance, cluster analysis, decomposition of variance and log-normal distribution to estimate the parameters of income variability that ascertain vulnerability levels and help us to understand the poverty levels that climate change could potentially incur. It is found that the income share in income sources revealed that income category shares across the various regions of Bangladesh are far from uniform. The variance decomposition of income showed that agricultural income in Mymensingh and Rangpur is the main cause of income difference. Moreover, large variance of agricultural income in the regions is induced by gross income from rice production. Additionally, constant reduction of rice yield due to climate change in Bangladesh is not such a severe problem for farmers, however, the extreme events like flood, flash flood, drought, sea level rise, and greenhouse gas emission based on RCPs could increase the poverty rates in Mymensingh, Rajshahi, Barisal, and Khulna regions that would be highly affected by unexpected yield loss due to extreme climatic events. Therefore, research and development of adaptation measures to climate change for regions where farmers are largely dependent on agricultural income is important.

Keywords: income distribution, cost distribution, vulnerable region, adaptation measures, Bangladesh.

1. Introduction

Bangladesh experienced severe famines [1-3]. However, heavy investments in agriculture following those famines have given rise to enhanced food production and brought about significant increases in domestic rice production [4-5]. Both the cultivation techniques and cropping patterns relating to rice production have gradually changed in terms of yield potentials [6-7]. Despite huge population pressures, the country has reached self-sufficiency in rice production [8-10].

Additionally, Bangladesh's economic situation is improving; as such, it is one among a rather small group of countries that have seen remarkable progress in terms of both economic performance

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and development indicators [11]. However, poverty still remains a critical social concern in this country [6,12-13].

Climate change will have a largely adverse impact on agricultural production in Asia [14]. For particular geographical location and other environmental reasons, Bangladesh is one of the world's most disaster-prone countries [15-18]. Given climate change impacts, natural resource constraints, and competing demands, agriculture and food systems continue to face considerable challenges. The livelihoods of the poor who are directly reliant on agriculture already faced a profound threat by the current climate change in Bangladesh [19-20] and which can affect the flow of people into poverty. At the household level climate change significantly affects the food production [21] which influences the higher food price and directly affects the poverty of low-income household [22-23]. Behind the social and economic development of a community it is historically been observed that household income plays the vital role. Income from agriculture might push for increasing per capita income, which in turn could boost further reduction of poverty because poverty and low income are causally related [24]. Agricultural income is the main source of total income for rural people, and this income is the significant factor including non-farm income for poverty reduction among agricultural households in the long-run [25-27]. Rural poverty reduction is generally sought in the role of agriculture in contributing to farm incomes [28].

Agriculture is strongly influenced by weather and climate which have potential impacts on agricultural productivity [29]. During last three decades temperature has been increasing in Bangladesh [30-31] and average day temperature is predicted to experiences an increasing rate of 1.0 ^{0}C by 2030 and of 1.4 ^{0}C by 2050 [32-33]. The annual rainfall is also unevenly distributed in some areas of Bangladesh. This unstable temperature and rainfall enhances the different extreme events such as drought, flood, and cyclones in coastal areas and adversely affect the rice production [7,30,34-36]. Additionally, climate change is projected to affect agriculture and most likely to climate change induces significant yield reduction in future due to climate variability in Bangladesh [37-39] and projected to cause a decline of 8-17% in rice production by 2050 [33,40]. In Bangladesh, nearly 80% of the total cropped area is under rice production and which accounts for almost 90% of total grain production [39,41-46]. Agricultural productivity, farm income and food security are significantly affected by seasonal growing temperature [47].

Some previous studies project climate change impacts on food production and national food security [48,49], climate change impact and agricultural production by collecting information under drought, rainfall, sea level rise, flood and temperature increase [39,43, 50], coastal flooding impact on rice [7,51-52]. However, there are fewer studies from micro or regional points of view and based on integrated household survey data, poverty measurement under yield reduction of crops by climate change vulnerabilities. Farmers' income is the main reinforcing factors for poverty trap, so this context of research is not enough. In order to consider suitable adaptation technologies and policies for farmers, impact projections in terms of regional characteristics and poverty is far more necessary. Alleviate the severity of climate change impact on farm production and poverty, adaptation strategies such as new crop varieties, changing planting time, homestead gardening, planting trees and migration are the vital approach [6]. Furthermore, research that projects climate change impacts on poverty, or which pinpoints especially vulnerable regions and the vulnerability of farm household's income to the impact of climate change, is still needed [53-54]. Using statistical analysis, the current study delves to derive an understanding of regional characteristics in terms of income and agriculture, assess the contribution of different components on the observed total variance of income and cost, with an eye to determining regional vulnerability to climate change, and to projecting the potential effects of climate change on poverty in Bangladesh. In this study we used, high-quality plot-level agricultural production and practice data under the nationally representative survey by International Food Policy Research Institute (IFPRI). We used different analytical techniques to evaluate the regional characteristics and to assess the potential climate change impact on farm production and poverty under newly developed representative concentration pathways (RCPs) and other climate scenarios. The objective of this study was to project the poverty on the impacts of climate change on crop production and provide possible adaptive measures.

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The paper is designed as follows: we draw a review of the related literature concerning climate change, vulnerability and poverty in section 2; section 3 is the methodology part where we describe the data source, compilation procedure and the analytical approaches of the data; in section 4, descriptive statistics and empirical results of the analysis with discussion are presented; and in section 5, we conclude by emphasizing the future research direction, and some policy guidelines.

2. Review of Literature

Research on climate change scenarios and poverty in terms of regional characteristics is outlined concisely in this section. Climate change is a reality which is happening and will increasingly touch the poor, moreover it is a serious threat to poverty eradication [55]. Poor agricultural communities are always disrupted by climate change impact on household food security and poverty [56,57]. Climatic shocks and stresses could be easily increase the inclination of household poverty which is well recognized by the scientific community [55]. Poverty as a dynamic and multidimensional condition is characterized by the interaction of individual and community features, socioeconomic and political issues, environmental process as well as historical circumstances. Particularly in less developed countries and regions through several direct and indirect channels, climatic variability and change may worsen the poverty [58].

Lade *et al*. review the socio-ecological relationship in rural development concept which emphasizes economic, biophysical, and cultural aspects of poverty. This study classifies the poverty alleviation strategies and developed multidimensional poverty trap models and stated that interventions that ignore nature and culture can reinforce poverty [59].

Multi-factor impact analysis framework developed in Yu *et al*. [39] and using this framework [50] Ruane *et. al.* provide sub-regional vulnerability analyses and quantify key uncertainties in climate and crop production. Climate change impacts increase under the higher emissions scenario, and on agriculture in Bangladesh is severely affected by sea level rise [50].

Over the period several attempts have been made in climate scenario development in Bangladesh using mainly Global Climate Models (GCMs) and in some cases Regional Climate Models (RCMs) [60-62]. From these studies, over-all conclusions include a rise in temperature and rainfall, different drought in seasons and impacts on crop production.

Projected future yield of rice cultivars in year 2030 and 2050 in different areas of Bangladesh by DSSAT crop modeling shows that Bagerhat, Dinajpur, Gaibandha, Maulvibazar, Panchagarh, Rangpur, Sirajganj and Thakurgaon districts have high yield loss due to climate change impact. Rainfall, temperature, and CO_2 affect the yield for *aman* rice in Rangpur and Khulna divisions, and for *boro* rice in Rajshahi, Barisal, and the south-west region [63].

Changing pattern of rainfall and temperature in different region of Bangladesh is significantly higher compared to IPCC prediction. For sustainable adaptation, location specific management of seed, crop, and irrigation are needed [21]. Soil tolerant, flood tolerant and shorter varieties of rice and other crops can be taken to adapt to the climate change impact [64].

Climate change is likely to have an adverse effect on rice and wheat production [5] and significant yield reduction in future due to climate variability [38] is also directly associated with extreme weather events [19] and due to the population pressure, future food production is challenging to meet the food security in Bangladesh [5].

Food demand may increase due to projected climate change by the intensity of drought and increasing temperature in Bangladesh. Combined effects on rice by major climatic variables are checked by Karim *et. al*. and they found that 33% of rice yield will decrease by both 2046-2065 and 2081-2100 for Rangpur, Barisal and Faridpur region [65].

Household income plays the vital role for social and economic development of a community or regions. Farm household income depends (among other variables) on the characteristics of agricultural production. There is a profound connection between household income and poverty; poverty and low income are causally related [24]. Farm households in Bangladesh are the most prone to the impact of climatic hazards. Uncertainty is high in farm income and it depends on wide fluctuations of yields and prices. Unexpected weather can easily damage the crop production which

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makes the farm more vulnerable [66]. In Bangladesh, farmers are fully depending on weather for their crop production which enhance the lower farm income if extreme climatic events happened. Unexpected yield reduction makes fluctuating farm income and increase the food insecurity and poverty. Income from agriculture might push for increasing per capita income, which in turn could boost further reduction of poverty. Participation of government program and off-farm income is significantly important for reducing the poverty [25].

There have been many research on climate change impact, adaptation, and projection in agriculture, IPCC fifth assessment report shows that food production in Asia will vary and decline in many regions under the climate change impact [37]. Rajendra *et al*. focus on climate change impact on farming in northern Thailand where vulnerability of farm household still exists to the negative impact of climate change [54]. Yamei *et al*. assess the adverse effect of future climate on the rice yield and provide potential adaptive measures [67]. Nazarenko, *et al*., examine the climate response under representative concentration pathway (RCP) for the 21st century [68] while there are fewer comprehensive scenarios in whole country for farm income and poverty projection.

In addition, in-depth empirical research on farm income distribution and regional vulnerability to climate change is lacking. Furthermore, most of previous studies under climate change impact on agricultural production is for specific region. However, a comprehensive study under climate change impact, which compares among the regions in Bangladesh, is enormous significant. One of the motivation of the study is to summarize the farmers net income scenarios for all the regions of Bangladesh, assess the contribution of different components on the observed total variance of income and cost, and possible poverty under climate change impact on agricultural production. Moreover, understanding farmers' local economic situation and coping strategies with climate change impact will be an immense significant in regional point of view. Based on the actual farm income, this study treasures the projected farm income under the scenario that extreme climatic events occur, and then find out the projected poverty to identify the vulnerable regions and to suggest the appropriate coping strategies, because people who lives in the rural areas of Bangladesh need to cope with severe poverty.

3. Methodology

3.1 Survey data

In its empirical analysis, this study uses cross-sectional data drawn from nine administrative regions across Bangladesh. These data were derived from the International Food Policy Research Institute (IFPRI), which adopted a multi-stage stratified random sampling method to collect primary data, first selection of primary sampling units (325 villages) and then selection of farm households (20 farms) from each primary sampling unit. The randomly selected villages with probability proportional to size (PPS) sampling using the number of household from the Bangladesh population census data in the year 2001. Randomly selected 20 farm households in each village from the aforementioned national census list. IFPRI researchers designed the Bangladesh Integrated Household Survey (BIHS)[1)], the most comprehensive, nationally representative household survey conducted to date. Plot-wise crop production data were collected via semi-structured questionnaire by the IFPRI from 6,500 sample farmers across Bangladesh, vis-à-vis cultivated crops; the survey period is from December 1, 2010 to November 30, 2011. The original data were collected in a typical agricultural year, according to rice production statistics, there was no severe crop loss in the 2010 or 2011 rice years in Bangladesh [69].

3.2 Data compilation

This study is to model the poverty rate change under climate change vulnerability in different region of Bangladesh. Based on the purpose of this study, to analyze the data, we applied both descriptive, inferential statistical, and multivariate techniques. Plot-wise raw data were compiled in line with the study objectives. We compiled data pertaining to many income sources for each separate household into some important sectors. In addition, for agricultural activities, we also compiled all kinds of input costs data into some important cost items and output value for each crop. We then compiled and combined into one data set of households for all 6,500 farms. Bangladesh consist of 30

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Agro-ecological zones (AEZ), those are overlapping with each other [69,70]. For the convenience of this research some homogenous agro-ecological zones were combined to the nine administrative regions with their geographical locations. In this way we tried to develop nine mutually exclusive regions for our research. To overcome the resulting challenge in consistency under the same impact of climate change in each region [50], we categorized all sample farmers as per nine administrative zones of Bangladesh those are called each division (Nine different colors indicates the individual division) (Figure 1): Barisal (700 sample farmers), Chittagong (300), Comilla (660), Dhaka (1,380), Khulna (1,020), Mymensingh (600), Rajshahi (580), Rangpur (540), and Sylhet (720).

We estimated the costs and incomes associated with 17 major crops that are produced by farmers in Bangladesh (each is considered an important crop); other crops (such as pulses, oil seeds, spices except chili and onion, vegetables, leafy vegetables etc.) and all kinds of fruits (such as banana, mango, pineapple, jackfruit, papaya, guava, litchis, orange etc.) were added to another group, "all other crops." The 18 groups are *aus*[2)] rice local, *aus* rice LIV, *aus* rice HYV, *aman* rice local, *aman* rice LIV, *aman* rice HYV, *aman* rice Hybrid, T *aus* rice HYV, *boro* rice HYV, *boro* rice Hybrid, wheat local, wheat HYV, maize, jute, potato, chili, onion, and all other crops.

To estimate per-capita income for farm household members for all nine administrative regions in Bangladesh, this study considers all income sources, including income from agriculture. Basic unit of analysis is each farm while farming is the only significant source of income among other sources such as employment, small business etc. for the family in one-year period. Net income for the farm household from agriculture was calculated by deducting total input costs from gross income:

$$\pi = \sum_i P_i Y_i - \sum_i \sum_j P_{ij} X_{ij}$$

where, π is net income, P_i is price of crop i, Y_i is production of crop i, P_{ij} is price of input j for crop i, and X_{ij} is input j for crop i.

Figure 1 Map of the objective regions of Bangladesh

This analysis used only the accounting costs to estimate net income from agriculture; these include the so-called explicit costs actually incurred by the farms. For this reason, this study regards supply of own land and family labor as part of agricultural income. The farm gate price of each crop

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for each household was used to estimate gross income derived from agricultural crops, livestock and poultry, and fish production; additionally, actual input prices were used to estimate the production costs cited by each farmer. For farmers with no information on farm gate price or input prices for their respective crops, we used the average prices from that region. This study crosschecked the farm gate prices and input prices with data pertaining to the average national retail price data of select commodities in Bangladesh [71] during the aforementioned study period. Farmers used farm gate prices to sell their crops, and for this reason, there was some divergence between national retail prices and the farmers' prices. To estimate per-capita income for each member of the farms, this study assumes that all negative returns tend towards zero so that we can calculate shares of income sources.

Income data were collected for each household, and these were used to calculate overall household income. Income was broadly classified into seven major sectors, as follows.

i) Agricultural crop income: income from all crop types produced by farmers throughout the year.

ii) Income from fish/shrimp farming,

iii) Income from livestock and poultry enterprises.

iv) Nonagricultural enterprises income: income from nurseries, food processing, fishing, nonagricultural day labor, retailer, wholesale, construction, manufacturing, wooden furniture, and other businesses,

v) Remittances: remittances within or from outside Bangladesh; the persons, who sent the remittances were excluded from their respective households,

vi) Employment: both formal and informal employment, income from self-employed and/or owned businesses that are not agricultural, income received from relatives and friends not presently living with the household etc.,

vii) Other income: income received from land rent or property rent; income from life and nonlife insurance; profit from share, gratuity, or retirement benefits; income from lotteries or prizes; interest received from the bank; charity assistance; other cash receipts; and/or other in-kind receipts.

These seven sectors of household income were used to determine the actual income and income sector shares, both of which reflect in significant ways in income distribution.

3.3 Analytical approach

This study used four types of statistical analysis.

3.3.1 Analysis of variance (ANOVA)

After dividing farm households into the nine aforementioned regions, we conducted single-factor analysis of variance (ANOVA) to examine differences among the farm households of the nine regions in Bangladesh, in terms of mean per-capita income. Table 6 summarizes the ANOVA results.

3.3.2 Cluster analysis

The cluster analysis (CA) technique was used to determine the main and dominant income sources in Bangladesh's various regions. Environmental (i.e., topographical) divergence is a common phenomenon in Bangladesh, and it diversifies farm production, although farm households within a certain region do tend to be similar. Ward's hierarchical method and the partitioning method can be used to determine the most appropriate clusters regarding the main income sources in each region. A dendrogram—a graphical representation of the hierarchy of nested cluster explanations—is a manifestation of Ward's method, and it provides the clue to find the preferable number of clusters regarding income sources.

3.3.3 Decomposition of variances

To understand the interregional differences and assess the contribution of different components on the observed total variance of input cost and income, different crops production data are used [72-75]. These data include per hectare crop yields, prices and all costs at the farm level and we decompose the variance of net cost and net income into different factors by using the following relations.

$$\mathrm{V}(X \pm Y) = \mathrm{V}(X) + \mathrm{V}(Y) \pm 2\mathrm{Cov}(X, Y)$$

where, X and Y are stochastic variables such as costs of inputs or incomes from different sectors, V ( ) is variance, and Cov ( ) is covariance.

3.3.4 Log-normal distribution

There are different types of probability distributions studied in probability theory. Lognormal distribution is one of the most important ones and were established long ago [76-78]. Lognormal distribution is a type of a continuous distribution. It is a probability distribution in which logarithm of the random variable is distributed normally. This distribution closely relates to the normal distribution. Lognormal distribution is quite commonly used in social science, economics, and finance [79].

Arata [80] points out that the income distribution among individuals is very important and is one of the main themes in economics. Income distribution is widely understood to be well described by a log-normal distribution.

Lognormal distribution generally has two parameters, mean (μ) and standard deviation (σ). If x is distributed log-normally with parameters μ and σ, then log(x) is distributed normally with mean μ and standard deviation σ. The log-normal distribution is applicable when the quantity of interest must be positive, since log(x) exists only when x is positive. A positive random variable X is log-normally distributed if the logarithm of X is normally distributed.

$$ln(X) \sim N(\mu, \sigma^2)$$

Let Φ and ϕ be respectively the cumulative probability distribution function and the probability density function of the N (0, 1) distribution

The probability density function of the log-normal distribution is

$$f_X(x) = \frac{1}{dx} Pr(X \leq x) = \frac{1}{dx} Pr(lnX \leq lnx)$$

$$= \frac{1}{dx} \Phi \left(\frac{lnx - \mu}{\sigma} \right)$$

$$= \varphi \left(\frac{lnx - \mu}{\sigma} \right) \frac{1}{dx} \left(\frac{lnx - \mu}{\sigma} \right)$$

$$= \varphi \left(\frac{lnx - \mu}{\sigma} \right) \frac{1}{\sigma x}$$

$$= \frac{1}{x} . \frac{1}{\sigma\sqrt{2\pi}} exp \left(-\frac{(lnx - \mu)^2}{2\sigma^2} \right)$$

$$f(x|\mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} exp \left\{ \frac{-(lnx - \mu)^2}{2\sigma^2} \right\}; \; x > 0$$

If we substitute a poverty line into x and integrate the probability density function up to x, we can obtain a poverty rate. Poverty line is put into the equation which is estimated by world Bank [12, 67].

From the actual percapita income of household members in the study areas we obtain actual distribution of percapita income by using the lognormal distribution. Next, we project the crop yield loss from the assumption of literature reviews and estimated the projected percapita income. From projected per-capita income by using lognormal distribution we obtained the estimated distribution of per-capita income. By simulating these two distributions we obtained the poverty rate graph.

4. Results and Discussion

4.1 Socioeconomic characteristics of farm households in objective regions

The family size is larger in the Sylhet region and consisting of nearly five members (Table 1). The average family size of Bangladesh is 4.8 [69], which is consistent with this sample average. Age of household head is highest in Barisal region and average age is more than 40 years and its indicating that they had experienced the climate change impact over the years in Bangladesh [54]. More than half of the sample household head can read and write across all regions except Mymensingh. In

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Khulna and Sylhet region, farm size is higher than the other regions and farmers are producing mainly rice crop.

Table 1 Socioeconomic Characteristics of each region

		B	CH	CO	D	K	M	RJ	RN	S	BD
Household (number)		700	300	660	1380	1020	600	580	540	720	6500
Family size (number)		4.17	4.6	4.28	4.11	3.93	3.9	4.12	3.92	4.97	4.19
Average age of HHH (years)		46.59	42.61	43.78	44.38	44.63	44.5	43.56	42.27	43.54	44.17
Education Level (%)	Cannot read, write	21	18.3	19.4	23.33	18.8	32.5	24.4	21.2	25.4	22.7
	Can sign only	26	28.3	27.2	30.72	28.6	33.3	31.3	37.2	28.6	30.1
	Can read only	0	0	0	0.14	0.09	0.16	0.17	0	0	0.07
	Can read and write	53	53.3	53.3	45.7	52.4	34	42.9	41.6	45.9	47.02
Average farm size (ha)		0.39	0.23	0.21	0.32	0.49	0.35	0.43	0.29	0.47	0.36
Dominant crop		Rice	Rice	Rice	Rice	Rice	Rice	Rice	Rice	Rice	Rice

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, BD= Bangladesh

4.2 Income status and the status of agriculture, by region

Agricultural income is a key driver in reducing poverty in Bangladesh there, it accounted for 90% of all poverty alleviation between 2005 and 2010 [81]. In terms of employment, Bangladesh's economy is primarily dependent on agriculture. About 85% of the population is directly or indirectly attached to the agriculture sector [38,69].

Table 2 Household income (US$/yr.) from different sources, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
Agril. crops	159.35	124.17	82.83	194.67	273.63	225.23	322.78	246.71	131.77	200.28
Main crops	76.23	44.11	35.22	118.52	152.25	127.87	202.10	170.95	89.86	116.89
Other crops	83.13	80.06	47.61	76.16	121.39	97.36	120.69	75.76	41.92	83.39
Fish	115.70	23.47	8.54	31.34	111.73	67.72	49.43	13.14	46.17	55.45
Livestock	27.43	17.81	22.35	51.76	86.61	57.25	76.48	35.67	26.20	48.60
Non-Ag. profit	260.29	293.63	212.95	304.83	254.71	197.39	338.22	171.49	292.70	262.92
Remittance	138.41	381.12	624.89	225.28	107.64	101.84	77.30	87.37	259.51	212.90
Employment	487.70	676.42	464.06	590.46	542.42	436.33	669.77	582.29	642.59	560.94
Other income	64.65	8.41	90.96	38.22	31.36	32.01	190.70	15.53	60.98	57.61
Total	1253.53	1525.04	1506.60	1436.53	1408.12	1117.77	1724.70	1152.23	1459.92	1398.71
Per-capita	308.93	336.75	378.35	362.17	369.84	307.63	423.63	308.76	301.63	347.39

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, BD= Bangladesh, Main crops= *Aus*, *Aman*, and *Boro* rice, and other crops= Wheat, Maize, Jute, Potato, Chili, Onion etc.

Table 2 shows that agriculture continues to be the main source of income in the sample households in all regions and this result is consistent with Hossain and Silva, 2013 [5]. However, in all regions, nonagricultural profit and employment are also important income sources and it is relevant in the sense of population parameter [45]. The amount of remittances varies by region; that in Sylhet is not the highest nationally, but the people there do consider remittances the main income source in the region. The agricultural income is higher in Rajshahi than other regions and per capita income of this

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region as per the study sample is US$ 423.6. Diversification of agricultural crops makes this region highest income from agriculture.

4.3 Share of each income sector in net income, by region

Table 3 shows significant differences in main income sources, among farmers in various regions in Bangladesh. Employment is the predominant income source in most regions, followed by nonagricultural profit and agriculture. The share of agriculture in total income varies by region. Among Bangladeshi farming households, the employment share is 40.10%, even though the overall share of agriculture in total income is 14.32%. Rangpur has the highest share of agricultural income in total annual income (21.41%); it was followed by the Mymensingh region (20.15%). Comilla's share of remittances in total annual income was highest (41.48% of a total income of US$ 624.9; Table 3); in comparison, the share generated by agricultural crops in Comilla was only 5.50%. Now a day's overseas workers are more from Comilla region compare to other regions in Bangladesh and a significant portion of them has been sending remittance that has become a vital source of income in Comilla region.

Table 3 Each income sector's share in total household income (%), by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
Agril. crops	12.71	8.14	5.50	13.55	19.43	20.15	18.72	21.41	9.03	14.32
Main crops	6.08	2.89	2.34	8.25	10.81	11.44	11.72	14.84	6.15	8.36
Other crops	6.63	5.25	3.16	5.30	8.62	8.71	7.00	6.58	2.87	5.96
Fish	9.23	1.54	0.57	2.18	7.93	6.06	2.87	1.14	3.16	3.96
Livestock	2.19	1.17	1.48	3.60	6.15	5.12	4.43	3.10	1.80	3.47
Non-ag. profit	20.76	19.25	14.13	21.22	18.09	17.66	19.61	14.88	20.05	18.80
Remittance	11.04	24.99	41.48	15.68	7.64	9.11	4.48	7.58	17.77	15.22
Employment	38.91	44.35	30.80	41.10	38.52	39.04	38.83	50.54	44.02	40.10
Other income	5.16	0.55	6.04	2.66	2.23	2.86	11.06	1.35	4.18	4.12
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, BD= Bangladesh, Main crops= *Aus*, *Aman*, and *Boro* rice, and other crops= Wheat, Maize, Jute, Potato, Chili, Onion etc.

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4.4 Share of net agricultural income in total income, by region

The shares of net income of the main crops of Bangladesh, as percentages, are presented in Table 4; that table shows that rice and other crops were the main sources of income among the

Table 4 Each agricultural crop's share in total net agricultural income (%), by region

Crops	B	CH	CO	D	K	M	RJ	RN	S	BD
Rice	45.51	33.66	32.99	37.39	43.52	55.62	51.27	57.72	67.05	47.22
Aus	6.37	2.89	1.51	0.64	3.03	0.84	1.11	1.39	5.19	2.24
Aman	24.36	17.83	6.42	5.22	15.55	15.37	17.27	22.12	18.45	14.96
Boro	14.78	12.95	25.06	31.54	24.95	39.42	32.89	34.21	43.41	30.02
Wheat	0.00	0.00	0.19	0.22	0.70	0.07	1.32	0.96	0.00	0.48
Maize	0.00	0.00	0.84	0.30	0.26	0.00	1.40	2.01	0.00	0.56
Jute	0.61	0.00	3.03	10.53	5.85	0.44	2.80	2.96	0.11	4.37
Potato	0.66	0.37	5.49	0.53	0.18	0.36	4.04	4.68	1.00	1.62
Chili	1.82	2.17	2.69	6.85	5.72	1.54	0.67	1.20	0.53	3.40
Onion	0.00	0.00	0.01	5.79	1.01	0.00	1.81	0.32	0.00	1.70
Other crops	51.39	63.80	54.77	38.38	42.76	41.96	36.67	30.16	31.31	40.65
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh

sampled farm households in the study areas. Incomes from maize and potato appear to be growing, but their respective shares remain small. There are regional land conditions and climate differences among the Bangladesh's regions, and so wheat, maize, onion, and potato production are not familiar to all farmers. Consequently, farmers in all areas of Bangladesh tend to focus on rice cultivation.

4.5 Comparison of income level among regions

Table 5 shows descriptive statistics of income status by region. Poverty rates were estimated by applying the poverty line and purchasing power parity of the World Bank [22] to log-normal income distributions. The findings presented in Table 5 indicate differences in mean, median, and standard deviation of net income among the nine regions in Bangladesh; using these findings, one can pinpoint relatively rich and poor regions.

Table 5 Mean, median, and standard deviation of per-capita income (US$/yr), by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
Mean	308.93	336.75	378.35	362.17	369.84	307.63	423.63	308.76	301.63	327.55
Median	289.93	217.83	246.25	242.87	254.11	215.04	283.14	226.99	204.82	232.94
SD	314.75	418.11	314.22	403.66	382.81	278.08	372.71	246.61	301.02	348.64
PR	0.51	0.48	0.46	0.46	0.42	0.51	0.33	0.47	0.49	0.46

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, SD=Standard Deviation, and PR=Poverty rate

In terms of mean net income, incomes of sampled farm households in Rajshahi are the highest, while those of Barisal, Mymensingh, Rangpur, and Sylhet are low. As some farmers had negative or zero per-capita income, the standard deviation is relatively large in certain regions. The highest standard deviation value is found in Chittagong (US$ 418.1), which reflects a large income gap among the farmers there.

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The highest upper poverty rate (i.e., 0.51) was found in Mymensingh and Barisal (Table 5), while the lowest (i.e., 0.33) was in Rajshahi; overall, the country's upper poverty rate is 0.46. The rates in Chittagong and Sylhet were also relatively low (i.e., 0.49). The officially estimated upper poverty rate and national average poverty rate are both in the vicinity of 0.35 [12,82]; this makes sense, as the original data were collected from rural agricultural farming-engaged people, and excluded affluent or single urban people.

Among regions where the poverty rates were high, Barisal, Mymensingh, and Sylhet had the lower mean incomes. On the other hand, Chittagong had the highest standard deviation compared to the other regions. The regions of Barisal, Mymensingh, and Sylhet appears that mean income level was low however the other regions mean income was large. These results show that these low-income regions are vulnerable regions and should be the target of farmers' support policies.

From result of Table 5, this study found that there is differences in mean, median, and standard deviation of net income among the nine regions in Bangladesh, for validation of this difference we analyzed the ANOVA and shows the results in Table 6. From the result of the ANOVA (Table 6), it is statistically concluded that there have been significant differences among the regions in terms of mean per-capita income.

Table 6 ANOVA mean differences across regions

Source of variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between groups	6.31E+10	9	7.01E+09	4.757462	2.39E-06	1.880604
Within groups	1.91E+13	12996	1.47E+09			
Total	1.92E+13	13005				

4.6 Regional characteristics on income source

This section intends to classify regions of Bangladesh to know regional characteristics on income source in each administrative region. Sectoral income shares from Table 3 are analyzed by cluster analysis and shows in Figure 2. Here dendrogram depicting the income source relationships among the regions. The horizontal axis of the dendrogram (in Figure 2) represents the distance or dissimilarity between clusters and the vertical axis represents the objects (regions) of cluster. From the cluster analysis this study tried to find the similarity and clustering with the dendrogram which visually displays a certain cluster shape. Regions that are close each other (have small dissimilarity) have the linked near the right side of the plot. In figure 2 we notice that Khulna and Mymensingh are very similar compared to the regions that link up near the left side are very different. For example, Comilla appears to be quite different from any of the other regions. The number of clusters the will be formed at a particular cluster cutoff value may be quickly determined from this plot by drawing a vertical line at that value and counting the number of lines that the vertical line intersects. In this study, we can see that if we draw a vertical line at the value 18.0, four clusters will result. One cluster contained four regions, one contained three regions, and two clusters each contained only one region which are shows in In Figure 2 that Barisal, Mymensingh, Khulna, and Rajshahi are more alike than they resemble Rangpur. In addition, Chittagong, Dhaka, and Sylhet are more alike than they resemble Comilla.

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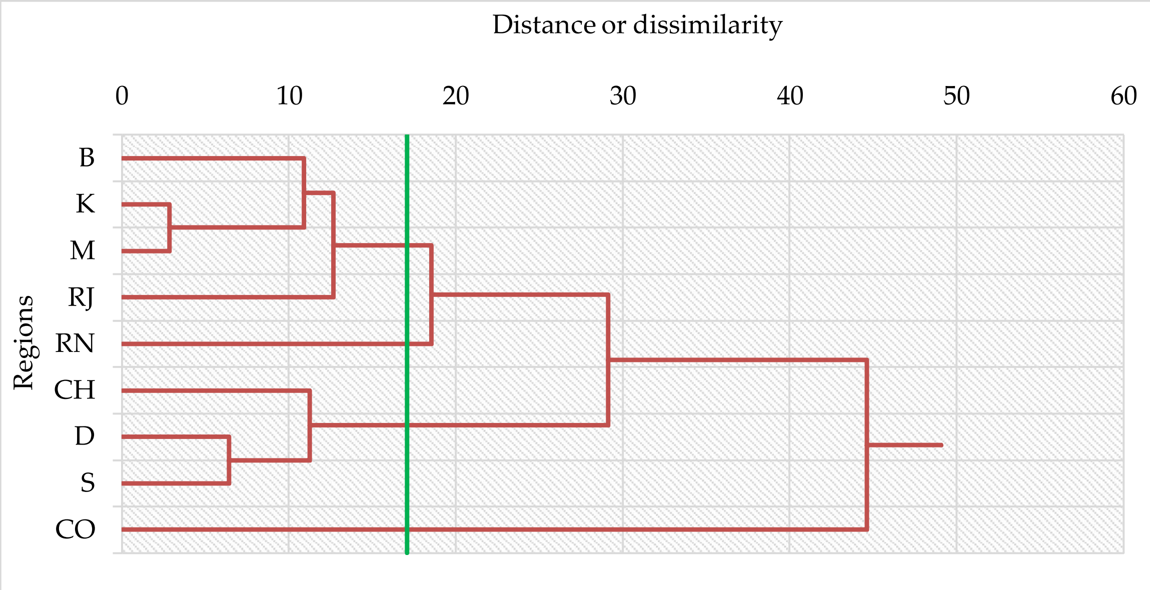

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh

Figure 2 Dendrogram of main income sources, by region

Table 7 summarizes regional characteristics on income source. Cluster 1 and 2 are largely dependent on agriculture. Cluster 3 and 4 are not largely dependent on agriculture. This result implies the importance of agricultural research for Cluster 1 and 2.

Table 7 Main income sources, by region

<table>
<tr><th>Cluster</th><th>Region</th><th>Main income source</th><th>Distinction</th></tr>
<tr><td>1</td><td>Barisal, Mymensingh, Khulna, Rajshahi</td><td rowspan="2">Agricultural. crops, Non-agricultural profit, Employment</td><td></td></tr>
<tr><td>2</td><td>Rangpur</td><td>Dominant Employment</td></tr>
<tr><td>3</td><td>Chittagong, Dhaka, Sylhet</td><td rowspan="2">Non-agricultural profit, Remittance, Employment</td><td></td></tr>
<tr><td>4</td><td>Comilla</td><td>Dominant Remittance</td></tr>
</table>

Using the dendrogram Figure 3 (Table 4 is analyzed by cluster analysis), four clusters were determined (Table 8) as the clusters suitable for representing agricultural income sources among the regions. We followed the same procedure for this dendrogram (figure 3) that followed in figure 2.

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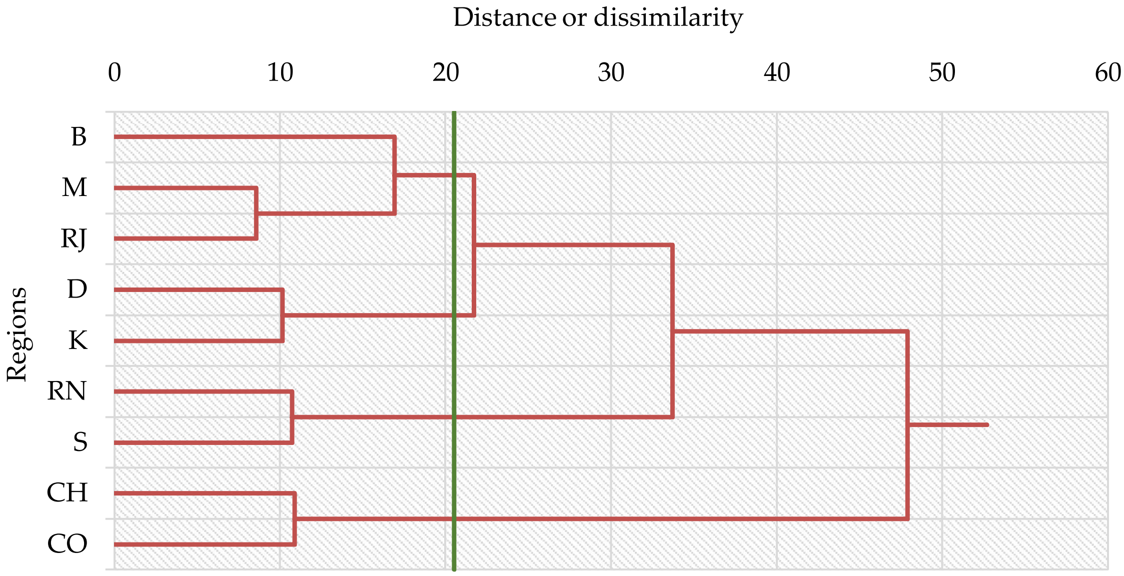

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh

Figure 3 Dendrogram of agricultural income sources, by region

The selected clusters show significant differences among the regions. Rice and other crops were identified as the main agricultural income sources of clusters 1, 2, and 3, whereas rice, jute, chili, onion, and other crops were those of cluster 4. The selected clusters produced the significant differences among the regions. In addition, rice predominated in cluster 2, while other crops predominated in cluster 3. These findings imply, for example, that rice is the main agricultural income source in Rangpur and Sylhet, while other crops were those of Chittagong and Comilla.

Table 8 Agricultural income sources, by region

Cluster	Region	Main income source	Distinction
1	Barisal, Mymensingh, Rajshahi	Rice, Other crops	
2	Rangpur, Sylhet		Dominant rice
3	Chittagong, Comilla		Dominant other crops
4	Dhaka, Khulna	Rice, Jute, Chili, Onion, Other crops	

4.7 Reasons for broad income distribution within a region

To grasp the diversity of income for sampled farm households from different sources in each region we applied decomposition of variances and the results are shown in Table 9.

The decomposed variances share was derived from annual per capita income from different income source sectors. Across Bangladesh, differences in remittances, other income, and employment are important factors that all contribute to income differences. If a family can find good employment both inside and outside its region, it can become relatively rich.

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Table 9 Decomposed variances share (%) of income sources

	B	CH	CO	D	K	M	RJ	RN	S	BD
V(b)	6.57	1.67	1.94	4.19	8.18	13.87	3.18	20.59	2.49	4.79
V(c)	20.03	0.19	0.03	1.57	35.73	8.17	1.11	0.23	1.98	6.42
V(d)	1.08	0.18	0.17	0.87	1.78	4.58	2.81	0.98	1.05	1.54
V(e)	17.39	13.64	6.33	16.50	13.47	11.90	5.09	7.84	19.73	11.63
V(f)	8.70	40.78	54.36	10.94	10.22	12.99	1.61	30.23	29.95	17.78
V(g)	4.84	0.05	14.76	1.16	0.61	2.38	69.70	0.37	2.82	21.63
V(h)	19.44	27.29	11.61	44.54	17.17	25.26	7.16	38.32	21.01	22.05
2*Cov(e,h)	21.95	15.22	10.81	20.22	12.85	14.22	7.32		20.96	14.16
2*Cov(b,c)								1.43		
2*Cov(c,h)							2.03			
2*Cov(f,g)		0.99								
2*Cov(c,e)						6.63				
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh; b= Agriculture, c=Fish, d= Livestock and poultry, e=Nonagricultural enterprise profit, f= Remittance, g= Other income, and h= Employment income

We found from Table 9, agriculture is one of the main contributors to income differences in Mymensingh and Rangpur regions, (Figure 5, and 6). In figure 4 shows total income distribution by income sources for the whole country, where 22% of income inequality of total income are explained by inequality of employment income. Furthermore, this result denotes that remittance is the most important sector to induce income disparity in Comilla, and employment in Dhaka and Rangpur. In addition, other income source is the significant source of income to confirm the total income disparity in Rajshahi.

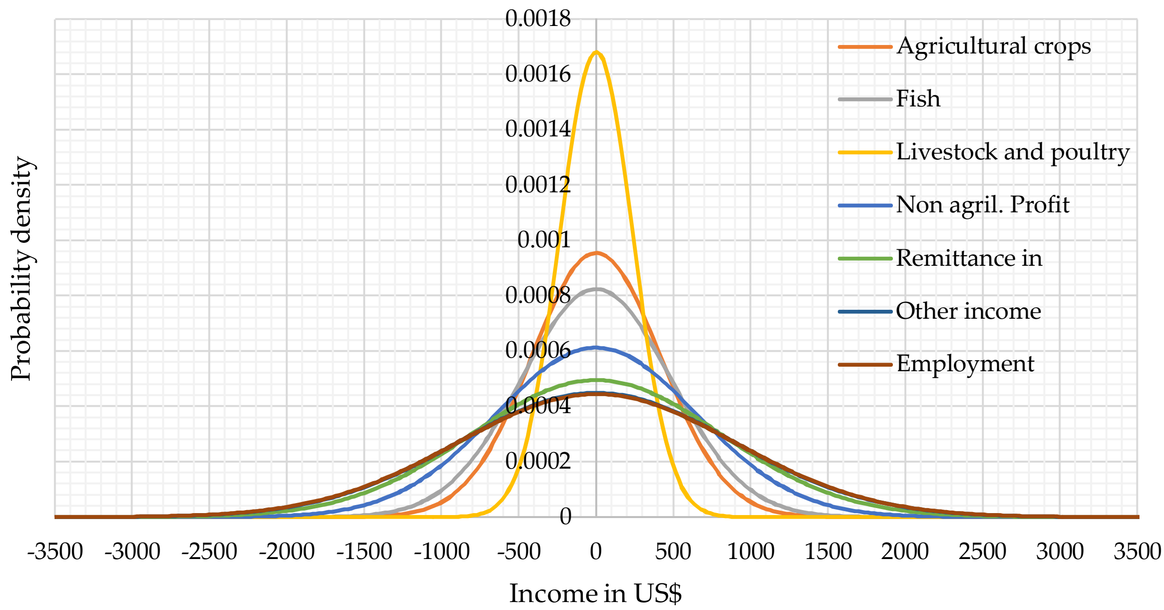

Figure 4 Distribution of total income for farm households in Bangladesh by income sources

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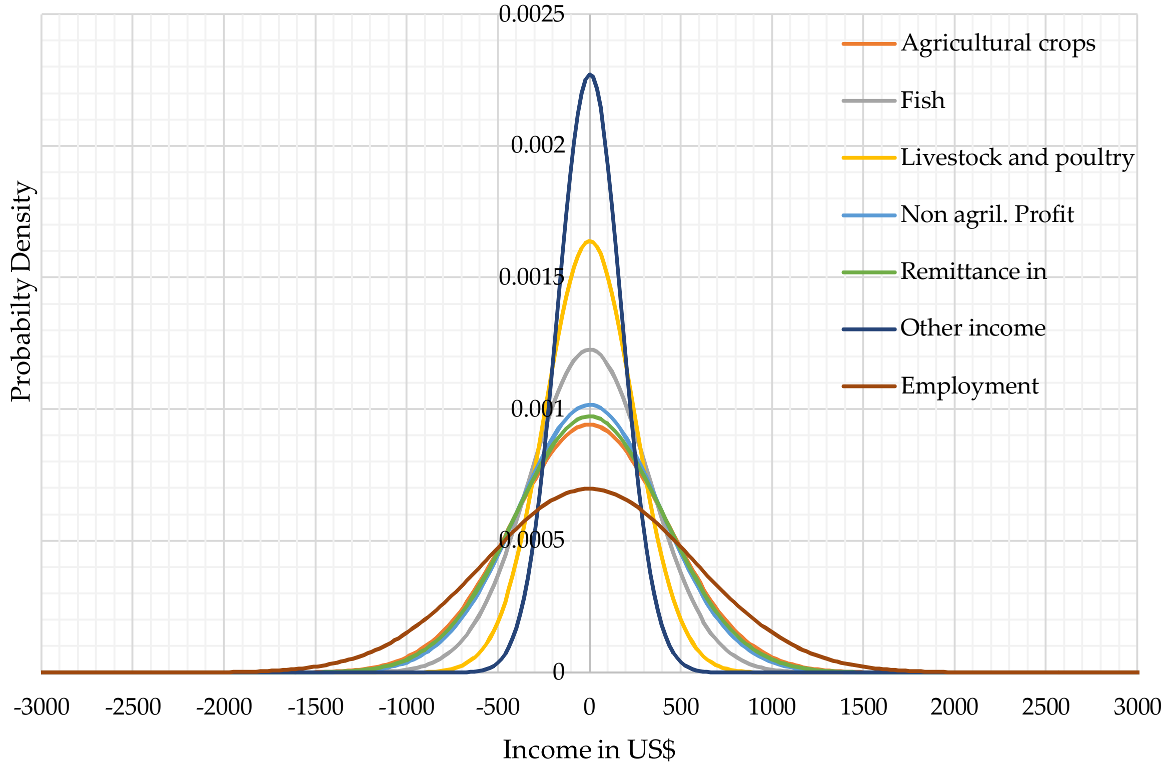

Figure 5 Distribution of total income (US$) for farm households in Mymensingh by income sources

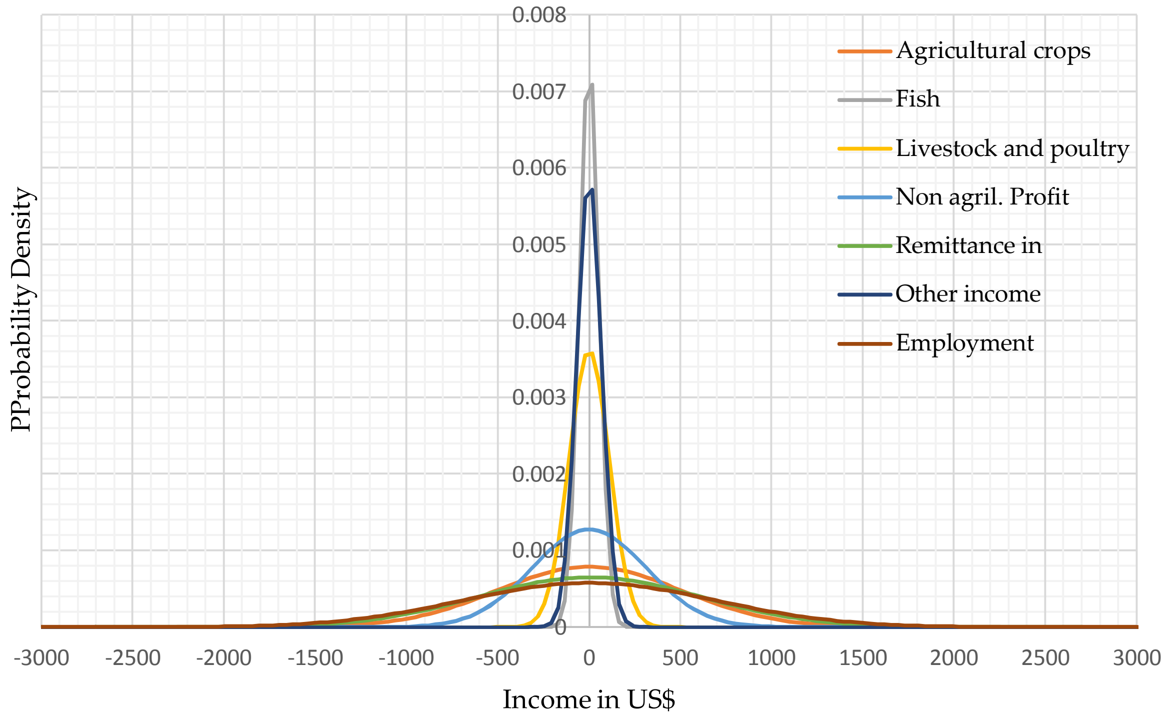

Figure 6 Distribution of total income (US$) for farm households in Rangpur by income sources

4.8 Factors in agricultural income differences

The main factors of agricultural income differences are shows in Table 10 obtained by the decomposed variance method.

Table 10 Decomposed variances share (%) of crops in total agricultural income, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
V(b)	0.35	0.07	0.03	0.15	0.10	0.00	0.01	0.00	0.36	0.11
V(c)	0.08	0.04	0.03	0.00	0.00	0.06	0.06	0.01	0.04	0.04
V(d)	0.64	0.43	0.01	0.02	1.54	0.06	0.13	0.13	1.06	0.53
V(e)	5.23	0.00	0.36	0.36	0.53	0.50	0.50	0.15	2.06	1.02
V(f)	0.47	0.02	0.16	0.02	0.07	0.06	0.01	0.15	0.00	0.10
V(g)	8.95	7.67	1.12	1.63	10.15	3.84	7.64	12.95	7.88	8.50
V(h)	0.02	0.00	0.00	0.00	0.09	0.09	0.05	0.11	0.00	0.06
V(i)	0.70	0.00	0.06	0.01	0.06	0.00	0.00	0.36	0.16	0.14
V(j)	6.36	4.32	8.13	34.03	17.72	20.89	17.72	14.03	48.26	25.30
V(k)	2.49	2.13	1.26	5.71	3.88	0.69	3.56	3.40	17.82	5.03
V(l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V(m)	0.00	0.00	0.01	0.04	0.15	0.00	0.23	0.18	0.00	0.11
V(n)	0.00	0.00	0.27	0.07	0.10	0.00	0.53	0.65	0.00	0.28
V(o)	0.26	0.00	4.28	4.74	2.46	0.04	0.91	0.93	0.14	2.38
V(p)	0.49	0.04	20.77	0.35	0.03	0.08	1.78	6.48	0.16	2.68
V(q)	1.65	0.90	0.81	11.56	12.40	0.98	0.17	0.49	0.08	6.00
V(r)	0.00	0.00	0.00	6.51	0.54	0.00	0.63	0.02	0.00	1.91
V(s)	67.37	75.85	43.55	29.35	44.77	62.62	16.16	24.67	21.98	44.00
2*Cov(o,r)				5.43	0.85		0.81			1.79
2*Cov(g,j)		5.75				9.73	11.64	13.34		
2*Cov(g,k)		2.79			0.37		4.55	7.94		
2*Cov(g,p)						0.02	3.58	11.66		
2*Cov(o,p)			18.45			0.34	6.19	2.33		
2*Cov(g,s)							9.54			
2*Cov(j,s)							13.61			
2*Cov(d,j)	4.95		0.72		4.20					
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, BD=Bangladesh; b=*Aus* rice local, c=*Aus* rice LIV, d=*Aus* rice HYV, e=*Aman* rice Local, f=*Aman* rice LIV, g=*Aman* rice HYV, h=*Aman* rice Hybrid, i=T *Aus* rice HYV, j=*Boro* rice HYV, k=*Boro* rice Hybrid, l=Wheat Local, m=Wheat HYV, n=Maize, o=Jute, p=Potato, q=Chili, r=Onion, s=All other crops

From Table 7 and 9, we identified that, agriculture is one of the main reasons for income differences in Mymensingh, Rangpur, Barisal, Khulna, and Rajshahi. The empirical estimates of Table 10 indicate that the main variation in agricultural income comes from *aman* HYV (g) and *boro* HYV (j) rice. Rice is the leading crop in Bangladesh, accounts for more than 90% of total cereal production covering 75% of Bangladesh's total cropped area [45,69]. For Mymensingh and Rangpur, variances in both

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aman HYV and *boro* HYV rice are high. For other regions, variances in *boro* HYV are high. All other crops is one of the main causes (44% variance share) of income differences for whole Bangladesh since all kinds of pulses, oil seeds, spices, vegetable, leafy vegetables, and fruits are included in the group of "all other crops".

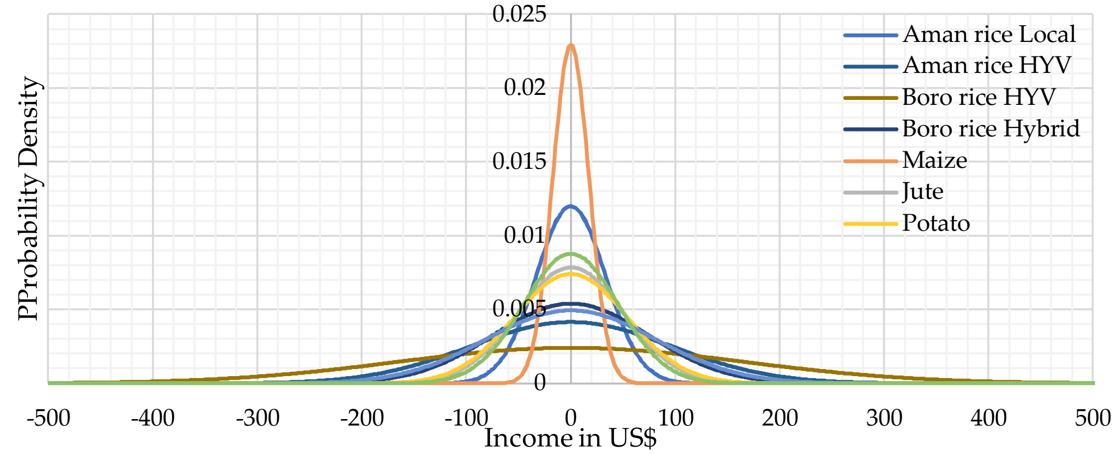

Figure 7 Distribution of agricultural income for farm households in Bangladesh by crop income

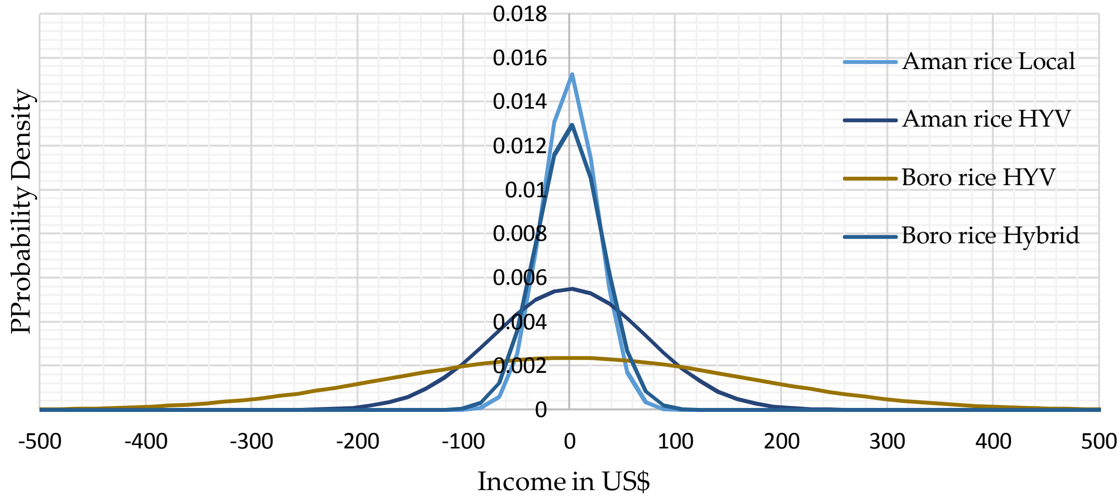

Figure 8 Distribution of agricultural income for farm households in Mymensingh by crop income

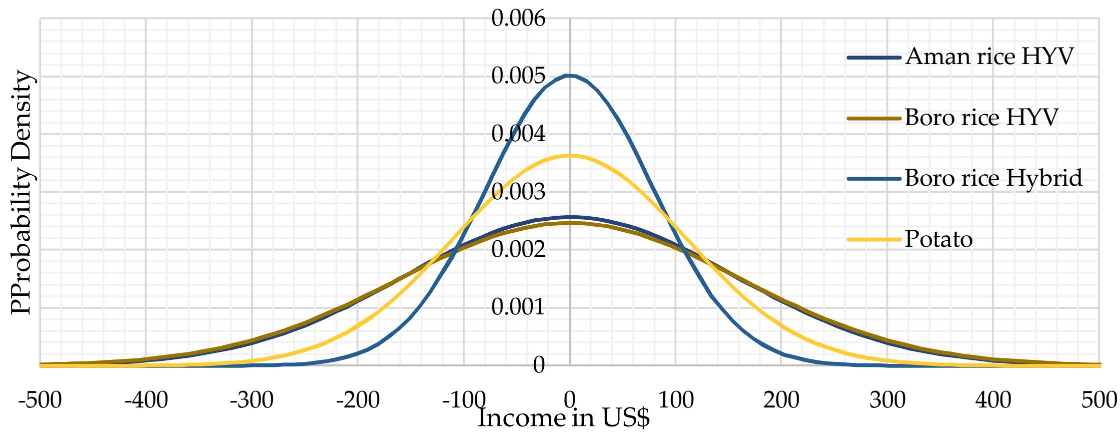

Figure 9 Distribution of agricultural income (US$) for farm households in Rangpur by crop income

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The distribution of crop income in total agricultural income for whole country shows in Figure 7 that followed in Figure 8 and 9 for Mymensingh and Rangpur respectively with selected crops which are mainly produced by farmers in that region. We found *boro* rice has the widest variation in both the region and *boro* HYV explained the inequality of total agricultural income.

4.9 Factors contributing to variations in income from *aman* HYV and *boro* HYV rice production

According to the results of Table 10, it is important to know those factors that are responsible for large variation of income from *aman* HYV and *boro* HYV.

Table 11 Costs and income (US$/ha) associated with *aman* HYV rice production, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
b	53.77	74.83	76.13	53.84	30.12	45.34	46.93	38.08	57.28	47.08
c	64.29	38.14	72.11	79.90	64.27	33.96	45.27	30.77	45.13	47.80
d	1.33	4.58	8.04	34.37	11.12	27.00	37.48	12.43	5.65	19.52
e	1.19	1.54	2.87	1.55	1.73	2.81	7.00	2.45	3.84	3.22
f	5.98	11.33	8.48	6.22	3.34	9.16	9.36	9.31	4.81	7.49
g	26.33	45.58	60.39	50.65	40.65	63.05	49.46	50.75	27.61	47.88
h	9.08	0.61	0.43	0.67	2.57	3.96	1.61	1.84	6.60	3.22
i	26.59	43.06	37.71	33.86	25.06	25.65	22.36	26.46	31.04	27.43
j	17.58	17.31	9.34	6.11	9.51	8.45	4.04	3.36	5.89	7.64
k	85.80	155.19	133.77	171.81	113.27	115.80	134.27	106.25	107.67	120.55
TC	291.93	392.18	409.27	438.98	301.63	335.18	357.78	281.70	295.53	331.82
TP kg/ha	43.05	44.04	23.05	37.72	30.30	33.45	43.98	42.17	30.99	36.42
GI	734.65	710.58	387.39	614.66	477.69	577.30	661.75	669.42	476.78	585.58
GI-TC	442.72	318.40	-21.88	175.69	176.07	242.12	303.96	387.72	181.25	253.75

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh; b=Rental cost of land, c= Seed cost, d= Irrigation cost, e= Manure/compost cost, f= Pesticide cost, g= Chemical fertilizer cost, h= Draft animal cost for land preparation, i= Rental cost for tools and machinery, j= Threshing cost, k= Hired labor cost, TC=Total cost, TP=Total production, and GI=Gross income

From the Table 11, we can easily understand the costs share for *aman* HYV production and per ha income in each region from this crop production. This study found that rental cost for land, seed cost, chemical fertilizer cost, and hired labor costs are the main cost for *aman* HYV rice cultivation (Table 11). The highest net income comes from *aman* HYV production in Barisal and Rangpur.

Table 12 Decomposed variances share (%) of GI and GC for *aman* HYV rice, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
V(GI)	75.31	74.34	98.38	53.87	76.53	57.17	66.88	74.25	45.49	69.45
V(GC)	80.97	33.57	35.80	91.18	36.13	49.23	55.56	30.27	55.10	45.67
-2*Cov(GI, GC)	-56.27	-7.91	-34.18	-45.06	-12.66	-6.39	-22.44	-4.52	-0.59	-15.11
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh; GI=Gross Income, and GC= Gross cost.

Next, we can find which factor causes the net income differences of *aman* HYV production. From decomposed variance of gross income and gross cost we found in Table 12, that gross income are the

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main factors for net income differences. It implies that even though farmers in same region and cultivated *aman* HYV rice, their gross income was different. These gross income differences mainly induce the net income disparity in Comilla, Khulna, Chittagong, and Rangpur while gross cost induce the income disparity in Dhaka and Barisal for *aman* HYV rice. Variances in gross costs were decomposed and presented in Table 13.

Table 13 Decomposed variances share (%) of costs for *aman* HYV rice, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
V(b)	3.64	3.73	3.79	0.97	3.66	5.50	3.72	8.79	4.32	3.24
V(c)	25.01	1.87	24.54	1.47	3.55	5.56	3.12	6.78	3.81	5.15
V(d)	0.53	1.79	1.04	1.32	8.33	2.04	4.15	6.70	0.67	3.69
V(e)	0.07	0.18	0.19	0.08	0.41	0.64	0.77	0.64	0.23	0.33
V(f)	0.54	0.48	0.28	0.07	0.65	0.10	0.65	0.54	0.14	0.35
V(g)	5.32	9.73	6.27	1.54	12.74	6.72	7.57	7.05	3.38	6.42
V(h)	0.98	0.06	0.01	0.04	0.30	2.76	0.05	0.57	1.42	0.50
V(i)	9.49	2.29	1.88	0.35	4.25	1.29	1.31	2.70	1.62	2.10
V(j)	3.47	0.58	1.62	0.10	0.44	0.70	0.15	0.26	3.04	0.69
V(k)	15.16	39.90	45.37	80.58	37.61	70.65	40.88	58.04	74.50	59.53
2*Cov(f,g)	1.72	2.37	1.33	0.33	2.14	0.77	3.05	1.26		1.41
2*Cov(i,f)	2.07		0.59	0.13			1.17	1.03	0.41	0.54
2*Cov(i,g)	11.50		3.88	0.77	5.69	3.26	4.29	4.69	1.94	3.32
2*Cov(k,g)	5.46	20.32		8.55	19.47		18.35			12.74
2*Cov(c,j)	15.04							0.95	4.52	
2*Cov(k,f)		3.79		2.04			4.82			
2*Cov(k,i)		1.90	9.21	1.67	0.75		5.94			
2*Cov(c,k)		11.0								
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh; b=Rental cost of land, c= Seed cost, d= Irrigation cost, e= Manure/compost cost, f= Pesticide cost, g= Chemical fertilizer cost, h= Draft animal cost for land preparation, i= Rental cost for tools and machinery, j= Threshing cost, and k= Hired labor cost.

The results show that for *aman* HYV rice production, variances in seed, chemical fertilizer, and hired labor costs are high. These costs were the main factors to induce the income differences in *aman* HYV rice production. This result implies the importance of farming knowledge and easy input access to this rice cultivation.

Table 14 Costs of and income (US$/ha) from *boro* HYV rice production, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
b	64.59	82.41	75.69	50.94	32.39	45.13	49.55	42.71	54.49	49.14
c	60.51	46.47	70.82	71.22	66.36	42.49	73.53	40.41	43.01	58.24
d	63.70	60.16	135.28	165.63	114.87	122.83	116.16	93.95	61.48	113.42
e	2.40	5.36	9.24	4.22	10.59	8.17	8.65	25.41	1.92	7.98
f	14.01	14.25	13.96	7.34	9.24	13.41	11.12	13.73	3.65	9.72
g	59.67	92.28	92.46	90.84	97.05	106.66	73.24	107.18	45.80	84.34
h	1.55	1.58	0.30	1.02	2.82	5.72	2.55	2.06	5.54	3.05
i	42.48	46.83	36.75	33.65	28.94	26.73	21.83	30.41	25.77	29.51
j	15.92	29.29	14.55	16.23	19.54	10.05	5.96	9.59	4.27	11.99
k	152.40	305.40	237.84	242.40	151.19	157.81	190.60	125.47	227.20	192.16
TC	477.24	684.02	686.89	683.49	533.00	539.01	553.19	490.92	473.14	559.55
TP kg/ha	56.13	58.08	61.88	74.47	61.71	59.64	72.59	69.07	50.82	63.90
GI	841.58	964.00	999.64	1169.99	1009.64	1082.65	1115.88	1115.55	749.11	1023.34
GI-TC	364.35	279.98	312.75	486.49	476.65	543.65	562.69	624.64	275.96	463.80

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, BD=Bangladesh; b=Rental cost of land, c=Seed cost, d=Irrigation cost, e=Manure/compost cost, f=Pesticide cost, g=Chemical fertilizer cost, h=Draft animal cost for land preparation, i=Rental cost for tools and machinery, j=Threshing cost, k=Hired labor cost, TC=Total cost, TP=Total production, GI=Gross income

From Table 9, we noticed that *boro* HYV also had an influence on agricultural income. Now, we can check the *boro* HYV rice production scenario from Table 14. The results show that rental cost for land, seed, irrigation, fertilizer, and hired labor costs are higher for *boro* HYV cultivation.

Table 14 also presents the highest net income in Rangpur and Rajshahi region from *boro* HYV rice production. However, farmers of Rangpur region used lower input than other regions.

Table 15 Decomposed variances share (%) of gross income & cost of *boro* HYV rice, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
V(GI)	101.34	46.75	264.6	62.73	79.59	70.15	69.81	80.61	67.68	91.68
V(GC)	43.86	79.49	97.26	41.17	40.46	47.38	60.96	28.25	84.98	54.04
-2*Cov(GI, GC)	-45.20	-26.24	-261.9	-3.90	-20.05	-17.53	-30.77	-8.86	-52.66	-45.72
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh; GI=Gross Income, and GC= Gross cost.

It is essentials to know the factors that are affected the net income variation for *boro* HYV rice cultivation. Table 15 summarizes the decomposed variance of gross income and gross cost from *boro* HYV rice production and shows that the gross income is the main factor for net income difference for *boro* HYV rice production except Chittagong and Sylhet.

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This implies that adaptation strategies such as low input costs have priorities on large gross income variances of *boro* rice cultivation. Next, we want to know what costs are main factors for income differences in *boro* HYV rice production. Table 16 shows the decomposed variances shares in cost expenditures of *boro* HYV rice production. We found the variance in seed, irrigation, chemical fertilizer, and hired labor costs are high in all regions.

Table 16 Decomposed variances share (%) of costs for *boro* HYV rice, by region

Crops	B	CH	CO	D	K	M	RJ	RN	S	BD
V(b)	2.87	0.66	0.50	1.88	2.66	4.11	1.32	5.32	2.63	2.27
V(c)	4.10	0.71	2.21	3.67	4.78	2.72	1.73	4.34	2.20	3.61
V(d)	8.89	2.70	4.06	22.93	22.39	22.42	10.70	16.00	7.57	18.01
V(e)	0.24	0.05	1.10	0.31	0.76	0.88	0.33	2.56	0.12	0.80
V(f)	0.89	0.09	0.18	0.16	0.48	0.33	0.31	0.60	0.07	0.33
V(g)	7.71	3.31	1.98	6.71	14.76	12.82	4.71	13.54	3.23	8.21
V(h)	0.04	0.03	0.00	0.05	0.79	10.08	0.13	0.38	2.04	1.16
V(i)	2.42	0.89	1.01	0.93	1.47	1.09	0.47	1.68	1.12	1.23
V(j)	0.98	0.20	0.15	1.08	0.75	2.24	0.24	0.39	0.18	0.78
V(k)	38.05	69.84	27.25	42.04	38.45	31.49	51.04	38.17	65.10	51.51
2*Cov(f,g)	3.91	0.73	0.66	0.90	2.15		1.49	3.46	0.50	1.55
2*Cov(d,g)	4.98		1.18				4.35			
2*Cov(f,i)	1.07	1.15	2.62	0.39	0.52		0.52	0.97	0.26	0.61
2*Cov(g,i)	4.68	2.70	1.99	2.87	5.47	3.76	2.14	5.69	1.99	3.43
2*Cov(g,k)	11.72	14.45	6.27	11.25			10.64		11.72	
2*Cov(i,k)	7.46		6.84	4.83	4.58	8.05	3.89			5.90
2*Cov(e,i)		2.50	9.58					1.25	0.22	0.60
2*Cov(f,k)			5.34				5.99			
2*Cov(e,g)			1.50					4.90	0.44	
2*Cov(e,f)			7.04					0.76	0.63	
2*Cov(d,k)			8.70							
2*Cov(e,k)			9.85							
Total	100	100	100	100	100	100	100	100	100	100

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh; b=Rental cost of land, c= Seed cost, d= Irrigation cost, e= Manure/compost cost, f= Pesticide cost, g= Chemical fertilizer cost, h= Draft animal cost for land preparation, i= Rental cost for tools and machinery, j= Threshing cost, and k= Hired labor cost

These inputs costs were made the net income differences in this rice production for sample farmer. From the findings of table 16, it is also important to mentioned that in Chittagong region variance in hired labor cost is highest while lowest in Comilla region. This result implies that reduction of input cost variances will ensure the low net income differences for this rice production.

4.10 Future projections

Productivity levels in agriculture, fishery, and livestock raising are projected to change, due to climate change [39,83]. We therefore sought to project the impact of rice yield change on the state of

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poverty in Bangladesh. If rice is a commercial crop, a price hike due to any damage from climate change may increase Bangladeshi farmers' living standards. However, rice is still a subsistence crop for among most Bangladeshi farmers; therefore, we assume that rice yield reduction will lead to a rice consumption reduction.

The effects of climate change on rice yields in Bangladesh, as has been estimated and shown by International Food Policy Research Institute [37], is that without adaptation to climate change impact, *aman* HYV and *boro* HYV rice yields will decline 10.2 % and 3.5% respectively in Bangladesh. According to the Geophysical Fluid Dynamics Laboratory (GFDL) scenarios if temperature change in 4.0 °C, then 17% decline overall rice in Bangladesh [84].

According to this projection, we assumed that due to climate change effects on *boro* HYV and *aman* HYV rice yields will be reduced by 10% and 4% respectively, and 17% of overall rice of the sample households. We applied log-normal distribution to project the poverty rate due to income reduction by yields loss on the effects of climate change.

Figure 10 shows the annual per-capita income (actual and projected) in US$ of the sample households across Bangladesh. In general, one can see from this figure that the sample population density (i.e., probability density) mostly lies within the low annual per-capita income range and that is lower than the poverty line. Additionally, the probability density of low-income range increases in the projected income distribution when one considers rice yield loss incurred by climate change.

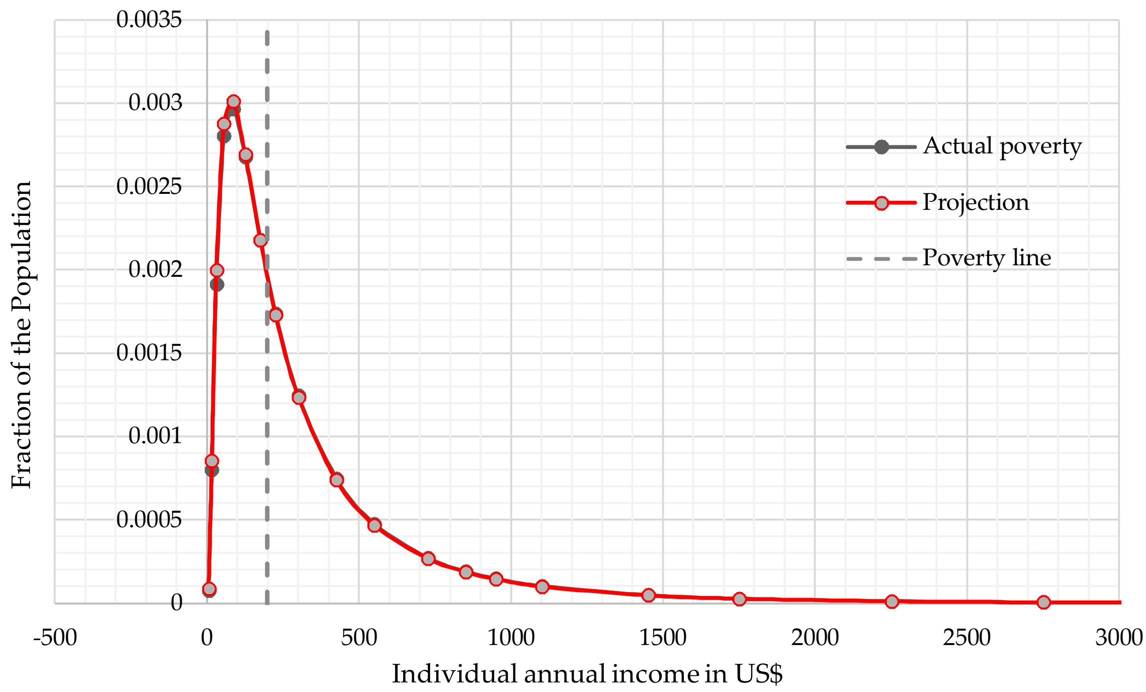

Figure 10 Annual per-capita income (US$) distribution of Bangladesh (17% loss of rice)

From the decomposed variances share of income sources in Table 9, we found agriculture was the main reason of income differences in Mymensingh and Rangpur. Now, we can examine the effects of climate change on rice production (10% and 17% loss) in these two regions by log-normal distribution.

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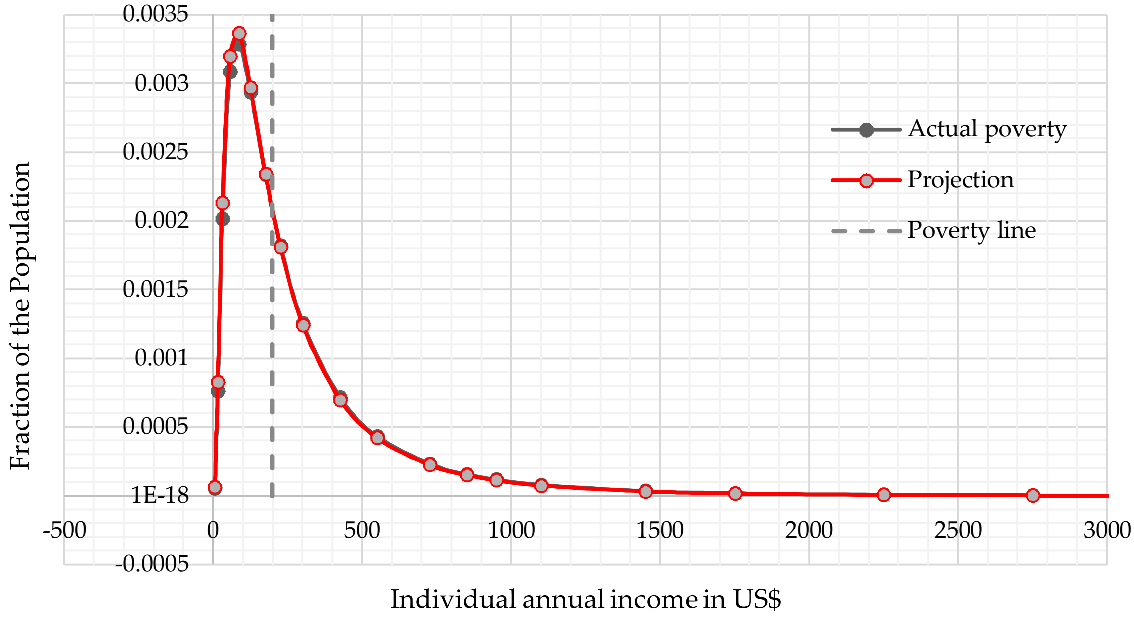

Figure 11 Annual per-capita income (US$) distribution of Mymensingh (17% loss of rice)

We analyzed and found that due to constant reduction of rice yield (10% loss) by climate change in Bangladesh is not such a severe problem for farmers. Because the change of net per-capita income is so small and there is not dramatically change of poverty rate. However, if the unexpected extreme events like flood, flash flood, drought, sea level rise occurs in specific areas of Bangladesh that creates more vulnerable situation for the farmers livelihood. In addition to that, probability density of low-income range increases (Figure 11 and 12) in both Mymensingh and Rangpur districts where due to rice income loss by climate change.

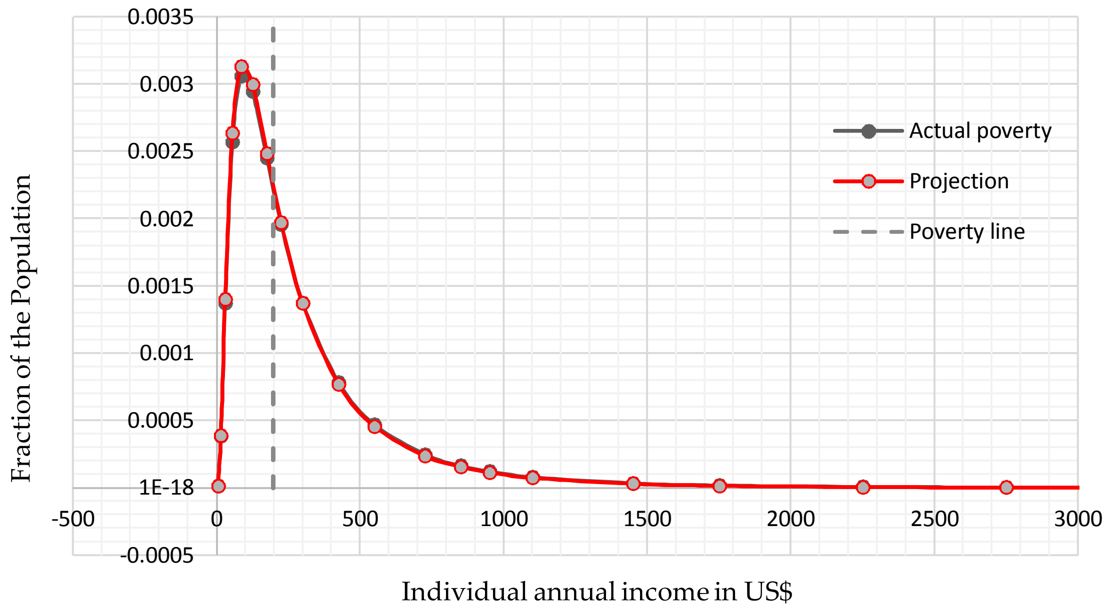

Figure 12 Annual per-capita income (US$) distribution of Rangpur (17% loss of rice)

We also applied the same analysis as Figure 10, 11, and 12 to all the regions and Table 17 shows the results of the poverty rate after incomes changed due to assumed yield loss of *aman* HYV, *boro* HYV rice and overall rice loss.

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Table 17 Change in poverty rate following a loss of rice yield due to climate change

		B	CH	CO	D	K	M	RJ	RN	S	BD
	Actual	0.507	0.484	0.446	0.455	0.415	0.496	0.323	0.462	0.484	0.454
10% loss	Projected	0.508	0.491	0.447	0.458	0.417	0.502	0.330	0.466	0.487	0.457
	Change	0.001	0.007	0.001	0.003	0.002	0.006	0.007	0.004	0.003	0.003
	Increase (%)	0.197	1.446	0.224	0.659	0.482	1.210	2.167	0.866	0.620	0.661
17% loss	Projected	0.513	0.494	0.449	0.460	0.422	0.511	0.335	0.473	0.490	0.461
	Change	0.006	0.010	0.003	0.005	0.007	0.015	0.012	0.011	0.006	0.007
	Increase (%)	1.183	2.066	0.673	1.099	1.687	3.024	3.715	2.381	1.240	1.542

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh

The estimated results suggest that rice yield loss would reduce the annual per-capita income of the sample farm households and increase the poverty rate in various regions across Bangladesh. It was found that the highest poverty rate increase (3.024 percent) will take place in Mymensingh, Rajshahi (3.715 percent), and Rangpur (2.381 percent). Rajshahi and Rangpur are in northwestern Bangladesh, and prone to drought; climate change would affect rice production specifically in the summer season, when *boro* rice is being produced. Mymensingh is affected by flood, flash floods and heavy rainfall each year, owing to the effects of climate change on *aman* and *boro* harvests.

3.10.1 Climate change impact scenario

Extreme events such as floods, droughts, and changes in seasonal rainfall patterns are negatively impact on crop yields in vulnerable areas [85-87]. In some of Asian countries, including Bangladesh rural poverty rate would be exacerbated [88] as a result of impacts on the yield of rice crop and increases in food prices and the cost of living [89-90]. The impacts of climate change on poverty will be heterogeneous among countries [91]. Due to the impact of climate change, rice production will decrease and some of rice exporting countries, such as Indonesia, the Philippines, and Thailand, would benefit from global food price rises and reduce poverty, while Bangladesh would experience a net increase in poverty of approximately 15% by 2030 [89,91].

Climate change refers as a change in climate that is attributed directly as temperature, precipitation, CO2 concentrations, and solar radiation or indirectly as river floods, flash floods, and sea level rise that alters the composition of the global atmosphere and to natural climate variability observed over comparable time periods [33,50].

4.10.1.1 Temperature increase

Temperature is an important factor for *boro* rice production and maximum temperature is always more vulnerable and negative impact on rice yield. In Bangladesh, seasonal temperature suddenly fluctuating, which cause the drastically decline the yield of *boro* rice. *Boro* rice yields reduce at maximum 18.7% due to increase of minimum temperature 2.0°C-4.0°C and 36.0% for 2.0°C-4.0°C maximum temperature increases in different location of Bangladesh in the year of 2008 [92]. According to the Intergovernmental Panel on Climate Change (IPCC), SRES emission scenario and climate models considered, global mean surface temperature is projected to rise in a range from 1.8° to 4.0°C by 2100 [93]. Following the previous assessment, the IPCC concludes in their fifth assessment report (AR5) that it will be difficult to adapt when large-scale warming, of around 4°C or above, which will increase the likelihood of severe, pervasive and irreversible impacts [91, 94-95].

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According to the previous projection of temperature fluctuation in Bangladesh, we assume that due to the maximum and minimum temperature fluctuation, in future the overall rice production will decrease about 17% of the sample farmers and results are show in Table 17.

4.10.1.2 Rainfall decreases (Drought)

Inadequate rainfall leads to greater drought frequency and intensity, while increased evaporation increases the chance of complete crop failure [96-97]. Drought is the most widespread and damaging of all environmental stresses [35,98]. In South and Southeast Asia including some states of India, severe drought affects rain-fed rice and yield loss as much as 40% while total area affecting 23 million hectares, amounting to $800 million [99]. Bangladesh experienced severe drought in the different years and the location in the districts of north-western border [100]. Erratic rainfall and drought will reduce crop production by 30 percent and 40 percent respectively [84]. *Boro* rice production will decrease due to rainfall in winter [92]. This study mentioned that if 5 mm and 10 mm rainfall reduction in future, as a result *boro* rice will reduce maximum 16.6% and 24.2% respectively in winter season. Drought caused 25% to 30% crop reduction in the northwestern part of Bangladesh on the data in 2008 [101]. Due to the high rainfall variability and dry, north-western region is the most drought-prone area in Bangladesh [102-103]. Rajshahi, Chapai-Nawabganj, Naogaon, Natore, Bogra, Joypurhat, Dinajpur, and Kustia districts are the drought prone areas in Bangladesh because of its moisture-retention capacity and infiltration rate characteristics [104].

According to the previous projection of drought, we assume that if rainfall decrease and drought occurred in future, the overall rice production will decrease about 20% of the sample farmers in north-western districts of Bangladesh.

Table 18 Poverty rate in drought prone districts

	BG	CN	DI	KU	NG	NT	RJ	JT
Actual	0.242	0.354	0.285	0.447	0.249	0.448	0.388	0.268
Projected	0.263	0.361	0.314	0.452	0.277	0.452	0.410	0.282
Change	0.021	0.007	0.029	0.005	0.028	0.004	0.022	0.014
Increase (%)	8.678	1.977	10.175	1.119	11.245	0.893	5.670	5.224

BG= Bogra, CN= Chapai-Nawabganj, DI= Dinajpur, KU= Kustia, NG= Naogaon NT= Natore, RJ= Rajshahi and JT= Joypurhatr

Table 18 shows the results of the poverty rate (Figure 13) after incomes changed due to assumed yield loss of overall rice by drought in north-western region in Bangladesh while Dinajpur (10.175 percent poverty increase), Rajshahi (5.670 percent poverty increase) and Naogaon (11.245 percent poverty increase) districts are utmost vulnerable on poverty. Dependency on agriculture with high variability of annual rainfall has made the northwestern parts is highly risky to droughts and makes the high poverty rates compared to other parts of the country. Conservation of water can play the important role to reduce the impact of drought and poverty alleviation in this area [103].

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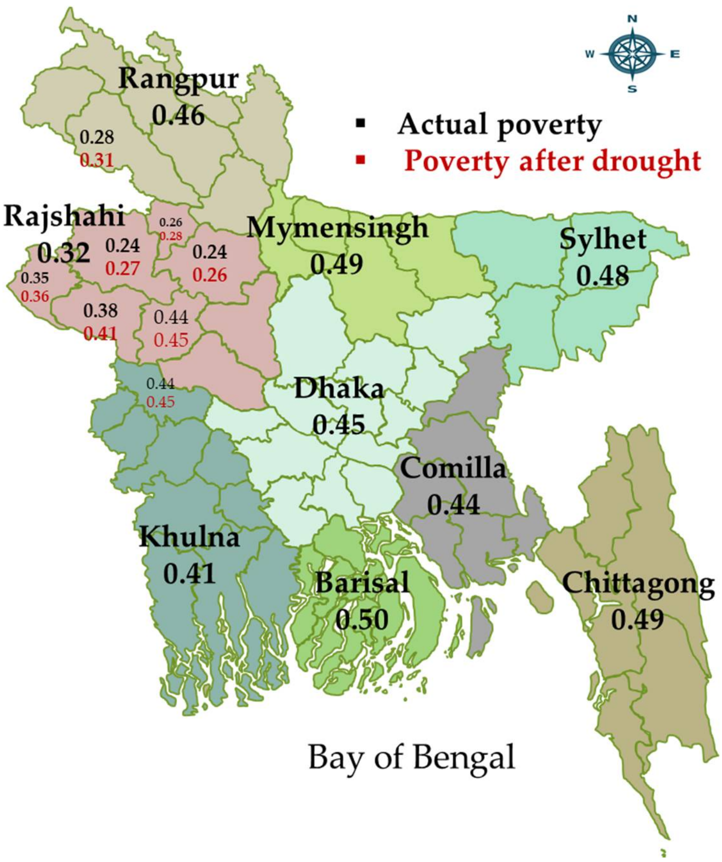

Figure 13 Changing poverty rate caused by drought in northwestern regions

4.10.1.3 Flood

From the GBM basins, the monsoonal discharge of water makes the seasonal floods and affects in most of the areas of Bangladesh with extents varying by year [50]. Flood affect almost every year and in 1998 flood, covered almost 70% of total land areas in Bangladesh and it was the maximum damage by flood in Bangladesh [105]. Parry [106] mention that according to IPCC 4th assessment report, the intensity and frequency of flood and cyclone will increase in near future. Moreover, IPCC fifth assessment report (AR5) predicts that greater risks of flooding will increase at regional scale [91,94-99]. In addition, the extreme event flood will reduce crop production by 80% in Bangladesh [37,84].

Mymensingh, Sylhet, Dhaka, Comilla, some part of Rangpur, and Khulna regions are the mainly river flooded areas in Bangladesh [50]. We assume that if extreme flood, as like as 1998 (the magnitude of that 1998 flood was the maximum in Bangladesh) will occur and farm production will reduce by 80% in the flood prone regions in Bangladesh. By log-normal distribution we project the poverty rate due to income reduction by yields loss on the effects of extreme flood. The results are shown in table 19.

Table 19 Poverty rate due to yield loss by flood

	CO	D	K	M	RN	S
Actual	0.446	0.455	0.415	0.496	0.462	0.484
Projected	0.465	0.502	0.479	0.554	0.529	0.519
Change	0.019	0.047	0.064	0.058	0.067	0.035
Increase (%)	4.260	10.330	15.422	11.694	14.502	7.231

CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RN=Rangpur, and S=Sylhet

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The estimated results of Table 19 suggest that rice yield loss would reduce the annual per-capita income of the sample farm households and increase the poverty rate in various regions across Bangladesh (Figure 14). It was found that the highest poverty rate increase in Rangpur (14.502 percent) and Khulna (15.422 percent).

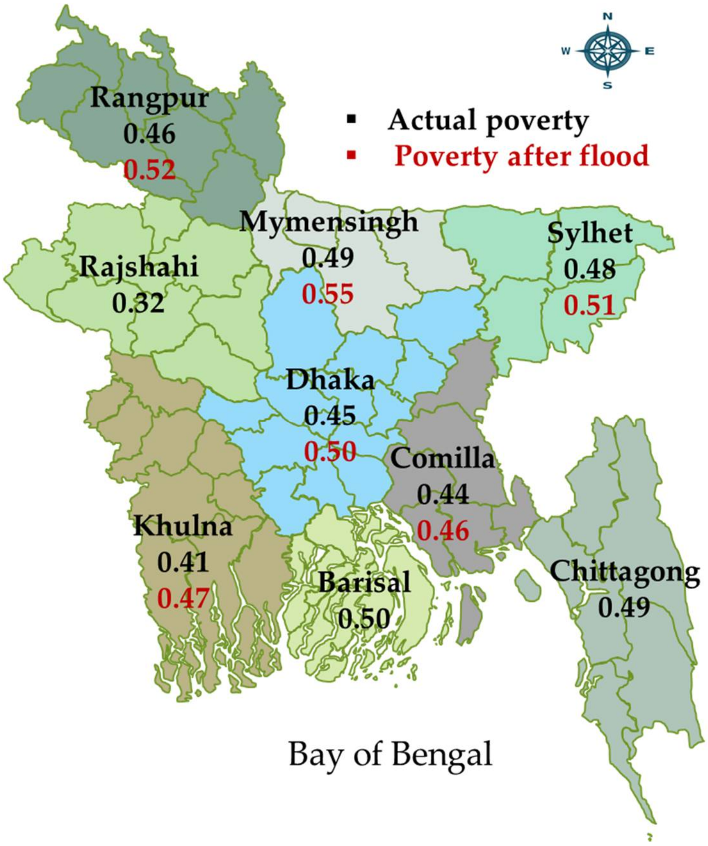

Figure 14 Changing poverty rate caused by flood in different regions

4.10.1.4 Flash flood

In the northeastern, part of Bangladesh mostly Sunamganj, Kishorganj, Netrokona, Sylhet, Habiganj, and Maulvibazar, are prone to flash flood during the month of April to November and this area are covered by many haors where water are remains stagnant [107]. Farmers of these districts are produced *boro* rice in almost 80% of their land while only about 10% area is covered by Transplanting *aman* production [108]. In 2017, the flash flood affected these areas and damaged almost 90% (maximum) of *boro* rice [109]. According to this scenario, we assumed that if in future this extreme event will occur in haor areas and *boro* rice yields will be reduced by maximum 90% of the sample households. We applied log-normal distribution to project the poverty rate due to income reduction by yields loss due to the effects of flash flood on *boro* rice yield by maximum 90%.

Table 20 Poverty rate in flash flood region

	HB	KI	MV	NT	SU	SY	TH
Actual	0.354	0.458	0.624	0.585	0.511	0.427	0.354
Projected	0.381	0.546	0.637	0.628	0.550	0.452	0.381
Change	0.027	0.088	0.013	0.043	0.039	0.025	0.027
Increase (%)	7.627	19.214	2.083	7.350	7.632	5.855	7.627

HB=Habiganj, KI= Kishorganj, MV=Maulvibazar, NT= Netrokona SU=Sunamganj, SY=Sylhet, and TH= Total Haor

Table 20 shows the results of the poverty rate after incomes changed due to assumed yield loss of *boro* rice in flash flood region in Bangladesh while Kishorganj district is utmost vulnerable on poverty (19.214 percent increase), if flash flood will occur (Figure 15).

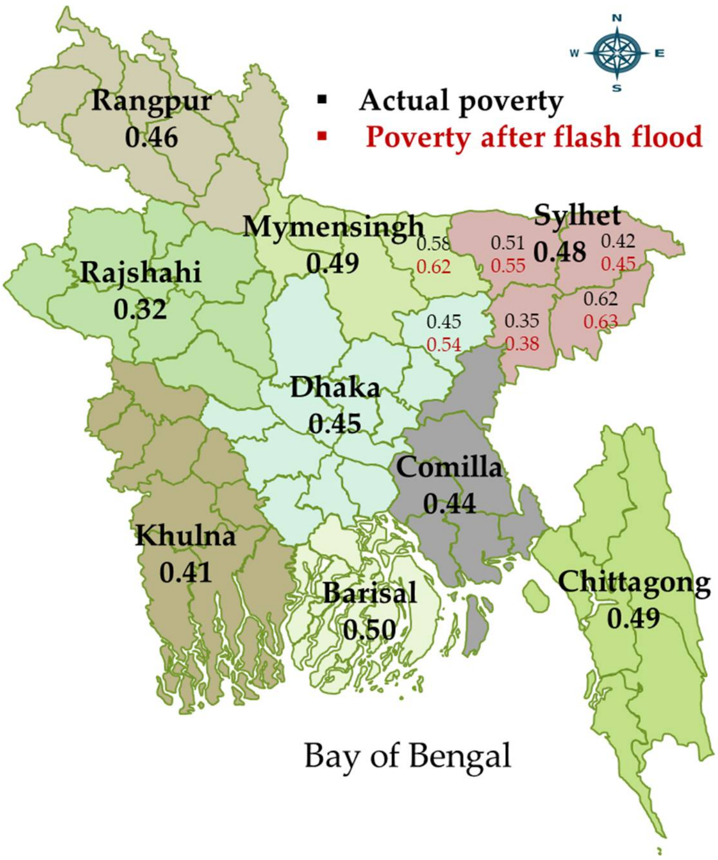

Figure 15 Changing poverty rate caused by flash flood in different districts

4.10.1.5 Sea level rise

About 80% of the land of Bangladesh is flatlands, while 20% is 1 meter or less above the sea level which is the coastal area (southern 19 districts beside the Bay of Bengal) and particularly vulnerable to sea level rise [110]. The coastal area covers about 20% of the country (include 19 districts beside the Bay of Bengal), which is about 30% of the net cultivable area and 25.7 percent of the population of Bangladesh [111-112]. Sea level rise will directly result in increased coastal flooding, which will increase in the event of storm surges. IPCC's fourth assessment report [33] depicts that a 1-meter sea level rise will displace around 14,800,000 people by inundating a 29,846 sq. km. coastal area [113]. Nicholls and Leatherman in 1995 [114] predicted that if 1m sea level rise it would affect 16% of national rice production loss in Bangladesh [115].

In terms of number of people affected with respect to sea level rise Bangladesh has been rated as the third most vulnerable country in the world. By 2050, around 33 million people would be suffering from surging, supposing a sea level rise of 27 cm. A full 18 % of the total land area in Bangladesh would submerge, if 1m rise in sea level [116]. The IPCC fifth annual report (AR5), across all Representative concentration pathways (RCPs), global mean temperature (°C) is projected to rise by 0.3 to 4.8 °C by the late-21st century and global mean sea level (m) is projected to increase by 0.26 to 0.82 m [91]. Global Circulation Model (GCM) predicts an average temperature increase of 1.0 °C by

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2030, 1.4°C by 2050 and 2.4°C by 2100; the study revealed that the rate of sea level will rise 14cm, 32 cm 62 cm respectively. A rise in temperature would cause significant decrease in production of 28 % and 68 % for rice and wheat respectively [84].

According to this scenario, we assumed that due to sea level rise in southern part of Bangladesh, *boro* rice yields will be reduced by 30% of the sample households. We applied log-normal distribution to project the poverty rate due to income reduction by yields loss on the effects of sea level rise.

Table 21 Poverty rate in sea level rise region

	SK	KH	BT	PR	JL	BG	BS	PT	BL	LK	NK	FN	CT	CX
Actual	0.599	0.295	0.363	0.388	0.640	0.532	0.419	0.628	0.491	0.529	0.438	0.481	0.505	0.462
Projected	0.609	0.315	0.370	0.390	0.650	0.545	0.431	0.636	0.493	0.533	0.440	0.487	0.515	0.464
Change	0.010	0.020	0.007	0.002	0.011	0.013	0.013	0.008	0.002	0.004	0.002	0.007	0.010	0.002
Increase (%)	1.688	6.752	1.924	0.527	1.674	2.388	3.081	1.255	0.491	0.770	0.410	1.361	1.901	0.367

SK=Satkhira, KH=Khulna, BT=Bagerhat, PR=Pirozpur, JL=Jhalakati, BG=Barguna, BS=Barisal, PT=Patuakhali, BL=Bhola, LK=Lakshmipur, NK=Noakhali, FN=Feni, CT=Chittagong, and CX=Cox's Bazar

Table 21 shows the results of the poverty rate after incomes changed due to assumed yield loss of rice in coastal region by sea level rise while Khulna district is the most vulnerable on poverty and poverty will increase 6.752 percent. Changing continuous sea level rise in coastal region has no significant loss reducing for rice.

4.10.1.5 Representative concentration pathways (RCPs)

In assessing future climate change, the fifth assessment report (AR5) of IPCC selected four RCPs, those are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 [91] where RCP 4.5 and RCP 8.5 cover both medium and extreme scenarios. These four RCPs describe four probable climate futures which liable on how much greenhouse gasses are emitted over the next 85 years.

Table 22 Change in poverty rate following a loss of rice yield due to RCPS

		B	CH	CO	D	K	M	RJ	RN	S	BD
	Actual	0.507	0.484	0.446	0.455	0.415	0.496	0.323	0.462	0.484	0.454
25% loss of rice under RCP 4.5	Projected	0.516	0.490	0.455	0.462	0.424	0.510	0.345	0.471	0.497	0.463
	Change	0.009	0.006	0.009	0.007	0.009	0.014	0.022	0.009	0.013	0.009
	Increase (%)	1.775	1.240	2.018	1.538	2.169	2.823	6.811	1.948	2.686	1.982
47% loss of rice under RCP 8.5	Projected	0.524	0.500	0.460	0.470	0.438	0.526	0.357	0.488	0.507	0.474
	Change	0.017	0.016	0.014	0.015	0.023	0.030	0.034	0.026	0.023	0.020
	Increase (%)	3.353	3.306	3.139	3.297	5.542	6.048	10.526	5.628	4.752	4.405

B=Barisal, CH=Chittagong, CO=Comilla, D=Dhaka, K=Khulna, M=Mymensingh, RJ=Rajshahi, RN=Rangpur, S=Sylhet, and BD= Bangladesh

The IPCC fifth annual report (AR5), across all Representative concentration pathways (RCPs), global mean temperature (°C) is projected to rise by 0.3 to 4.8 °C by the late-21st century [68]. Increasing temperature will increase the number of growing days over time. Heat stress is a major issue for crop production and reduce the yields.

Climate change will certainly continue in next decades and affects the agricultural production. Yamei Li *et. al.*, worked on simulating total climate change impacts on rice production under RCP scenarios and projected average rice yield during the 2020s, 2050s, and 2080s would decrease by 12.3%, 17.2% and 24.5% under RCP 4.5; and 14.7%, 27.5%, and 47.1% under RCP 8.5 [67].

According to this scenario, we assumed that due to total climate change impact, rice yields will be reduced by maximum 47% based on RCP 8.5 of the sample households. We applied log-normal distribution to project the poverty rate due to income reduction by yields loss. The table 22 shows that under RCP 4.5 and RCP 8.5, the poverty rate will increase in all the region because of rice income reduction.

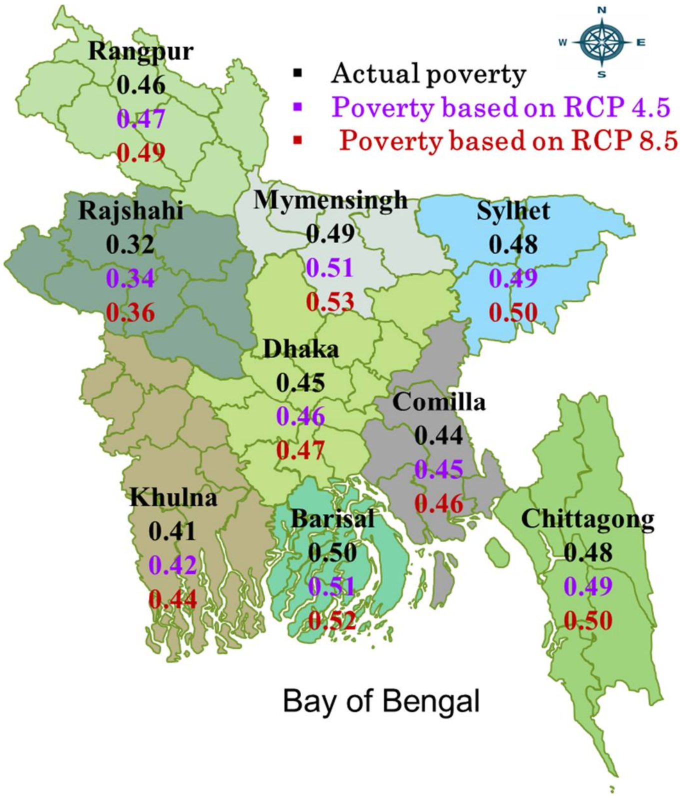

Figure 16 Changing poverty rate caused by total climate change impact based on RCP 4.5, and 8.5

Additional increases in average poverty occur in Rajshahi, Mymensingh, Rangpur, Khulna and Sylhet region under both RCP 4.5 and RCP 8.5 with variation of total climate change impact of rice production. Yield of rice is predicted to decrease more under RCP 8.5 than RCP 4.5 resulting the per-capita income decreases. Under RCP 8.5 scenario, this study predicts an increase in poverty maximum 10.526 percent in Rajshahi while the lowest 3.139 percent in Comilla (Table 22). It is possible that our predicted rice yield declines by RCP scenarios and relatively drought prone areas will be more vulnerable such as Rajshahi. Results from our drought scenarios are comparable to their results for RCP 8.5 and it is consistent that Rajshahi region are more vulnerable under climate change impact. In both scenario our predicted yield decline and resulting per-capita income decline which increase poverty. Climate change force to decline rice yield [117], suggest that the predicted decreases in heat stress yield can be mostly attributed to increase drought tolerant variety.

5. Conclusions

This paper has focused on the agrarian sub-national regional analysis of climate change vulnerability in Bangladesh under various climate change scenarios and its potential impact on poverty. It has drawn some significant evidence of regional vulnerability to climate change from regional characteristics, per-capita income, total income disparity, cost of production, and poverty

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based on statistical analysis of farm survey data. Our findings indicated the regional vulnerabilities to climate change impacts on agricultural production among the administrative regions of Bangladesh, and coping strategies and techniques.

Bangladesh farmers are producing crops, even though there is much uncertainty due to associated risk of climate. The results of our study show that from the income share in income source sectors, farmers in Mymensingh and Rangpur are largely dependent on agriculture. Of these regions, Mymensingh is one of the regions which has the highest poverty rates. The income share in income sources revealed that income category shares across the various regions of Bangladesh are far from uniform. Income share comparison and cluster analysis classified the regions into three groups as follows. (1) In some regions, which are Rajshahi, Khulna, and Dhaka, income from agriculture is important, and these regions receive relatively high income. (2) In other regions, which are Mymensingh, Rangpur, and Barisal, agriculture income is important, but the regions receive relatively low income. (3) The other regions, which are Comilla, Chittagong, and Sylhet, are not strongly dependent on agriculture, and Comilla region strongly rely on income from remittance. Principal target of agricultural research for poverty reduction is considered to be group (2).

Variance decomposition of income showed that agricultural income in Mymensingh and Rangpur is the main cause of income difference. Moreover, large variance of agricultural income in the regions is induced by gross income from rice production. This implies that rice yield can have large impact on income level. Therefore, research and development, and technical support for farmers to realize high and stable rice yield in these regions is important.

This paper, modeled to predict crop yield changes by different aspects of climate change under drought, flood, flash flood, sea level rise, and RCPs scenarios. We account for some uncertainty in crop yield and resulting reduction of per-capita income of farm household. The proposed lognormal distribution projected the poverty rate and examined the vulnerable region. The key is to understand that future projections of poverty rates on assumption of *boro* HYV and *aman* HYV rice yield's decline in each farm by the climate change impact, and climate volatility facing the poor with the poverty rate increasing in different region. Current climate change impact is not same in different regions, particularly different extreme climatic events in specific region often result in irreversible losses. One of the examples of interventions of climatic events is that dependency on agriculture with high variability of annual rainfall has made the northwestern parts highly risky to droughts and promoted the high poverty rates compared to other parts of the country. Extreme flood can increase the poverty rate in Rangpur, Mymensingh, and Khulna region. Kishorganj district is the utmost vulnerable on poverty (8.8% increase) if sudden flash flood occurs in northeastern part of the country. Due to the sea level rise, coastal areas will face the poverty.

Coping strategies and techniques with climate change for the regions where small-scale farmers are largely dependent on agriculture are important challenges. In the negative consequences of climate change impact, subsistence farmers are suffering more from the vulnerability like extreme poverty or hunger. However, adaptation techniques in agriculture is a vital tool to avoid the adverse impact of climate change [118]. Given the complex nature of drought, flood, flash flood, sea level rise as a phenomenon, development of drought tolerant, short maturing, and salt tolerant varieties are of critically important.

More general our results focused on farm income and poverty including regional vulnerability due to climate change impact on agricultural production. In recent years climate change impact plays the vital role for increasing the poverty rate and income variability among farm households in Bangladesh. Extreme environmental hazard is facing by farmers in this country and their net farm production decreases drastically, which increase the poverty rate while changes in weather condition has not so severe problem for farmers due to their involvement in other income activities. we actually did this study focusing to reveal the comprehensive impact of climate change on farm production and which crops are the most important for per capita income difference across the country that enhance the poverty rate by using the covariance and lognormal distribution method.

This study has attempted to bridge the gap between academic research and professional practices in the context of potential climate change impact on crop production and poverty. Because of the relatively large sample size, compilation and manipulation of the data was challenging. As the assessment of poverty and regional vulnerability due to climate changes, it is hoped that the study in general will assist in guiding authorities in terms of those interventions aimed at climate change risk reduction in Bangladesh. Therefore, we believe this research will unfold the mechanisms behind the per capita income difference and projected poverty rate of farm households based on different climate change impact scenarios across the Bangladesh. Future work might also be regionalized is essential to policy making, to test the root level poverty to further evaluate the impact of climate change on different crops and should include the model for poverty determinants to confirm the relationships in the study and adaptation.

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Notes

[1)] In this study, we used the primary data from Bangladesh Integrated Household Survey (BIHS 2011-12) by IFPRI, https://dataverse.harvard.edu/dataset.xhtml?persistentId=hdl:1902.1/21266

[2)] "*aus*" is former rainy season, "*aman*" is rainy season, and "*boro*" is dry season irrigated rice

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