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 current study uses analysis of variance, cluster analysis, and log-normal distribution to estimate the parameters of income variability that ascertain vulnerability levels and help us understand the poverty levels that climate change could potentially incur. The analytical results show that variances of rice income contribute to the agricultural income differences. Constant reduction of rice yield due to climate change in Bangladesh is not so severe problems for farmers. However, poverty rates in Mymensingh, Rajshahi, and Rangpur region would be affected by unexpected yield loss due to climate change. Therefore, research and development of adaptation measures to climate change for regions where farmers are largely dependent on agricultural income is important.

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Key Words: income distribution, cost distribution, vulnerable region, adaptation measures, Bangladesh

INTRODUCTION

Bangladesh experienced severe famines. However heavy investments in agriculture following those famines have given rise to enhanced food production and more specically, brought about significant increases in domestic rice production (Dorosh and Rashid, 2012). Both the cultivation techniques and cropping patterns relating to rice production have gradually changed in terms of yield potentials. Despite huge population pressures, the country has reached self-sufficiency in rice production (Israt *et al.*, 2016).

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 and development indicators (World Bank, 2012a). However, poverty still remains as tremendous social concerns in this country (Sulaiman and Misha, 2016).

Particular geographical location (and for other environmental reasons), Bangladesh is one of the world's most disaster-prone countries (Choudhury, 2002; Shimi *et al.*, 2010; World Bank, 2005 & 2012b). 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 (Wassmann *et al.*, 2009; World Bank, 2010). During last three decades temperature has been increasing in Bangladesh (GOB and UNDP, 2009; Sarker *et al.*, 2012) 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 (FAO, 2006; IPCC, 2007). 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 (Alauddin and

Hossain, 2001; UNDP, 2008; GOB and UNDP, 2009). Additionally, climate change is projected to affect agriculture and most likely to face significant yield reduction in future due to climate variability in Bangladesh (Yu *et al.*, 2010; Islam *et al.* 2010; IFPRI, 2013) and projected to rice production decline 8-17% by 2050 (BBS, 2005; IPCC, 2007). In Bangladesh nearly 80% of the total cropped area under rice production and which accounts almost 90% of total grain production (Alauddin and Tisdell, 1987, 1991; BBS, 2009; Asaduzzaman *et al.*, 2010).

Some previous studies project climate change impacts on food production and national food security (Kobayashi and Furuya, 2011; Salam *et al.*, 2016). However, studies from micro or regional points of view are very scanty. In order to consider suitable adaptation technologies and policies for farmers, impact projections in terms of regional characteristics is far more necessary. Furthermore, research that projects climate change impacts on poverty, or which pinpoints especially vulnerable regions, is still needed. Using statistical analysis, the current study delves to derive an understanding of regional characteristics in terms of income and agriculture, with an eye to determining regional vulnerability to climate change, and to projecting the potential effects of climate change on poverty in Bangladesh.

1. METHODS

1.1 Survey data

In its empirical analysis, this study uses cross-sectional data drawn from nine 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. 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 6,503 sample farmers across Bangladesh, vis-à-vis cultivated crops; the survey period is from December 1, 2010

Figure 1 Map of the objective regions of Bangladesh

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 (BBS, 2015).

1.2 Data compilation

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 input cost data into some important cost items. We then compiled and combined into one data set of households for all 6,503 farms. To overcome the resulting challenge (Ruane C. A. *et al.*, 2013), we categorized all sample farmers as per Bangladesh's main administrative areas (Figure 1): Barisal (700 sample farmers), Chittagong (300), Comilla (660), Dhaka (1,380), Khulna (1,020), Mymensingh (600), Rajshahi (580), Rangpur (543), 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 and fruits 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, this study considers all income sources, including income from agriculture. Net income 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.

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 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 (DAM, 2017) 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, 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.

1.3 Empirical model

This study used four types of statistical analysis.

1.3.1 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 5 summarizes the ANOVA results.

1.3.2 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.

1.3.3 Decomposition of variances

To understand the interregional diversity of cost and income, we decompose the variance of net cost and net income into different factors by using the following relations.

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

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

1.3.4 Log-normal distribution

Arata (2013) 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.

The log-normal distribution closely relates to the normal distribution. 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.

The probability density function of the log-normal distribution is

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

If we substitute a poverty line into x and integrate the probability density function up to x, we can obtain a poverty rate.

2. RESULTS AND DISCUSSION

2.1 Income status and the status of agriculture, by region

Agriculture is the key driver in reducing poverty in Bangladesh: there, it accounted for 90% of all poverty alleviation between 2005 and 2010 (World Bank, 2016).

Table 1 Household income (BDT/yr.) from different sources, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
Agril. crops	13226	10306	6875	16158	22711	18694	26791	20477	10937	16623
Main crops	6327	3661	2923	9837	12637	10613	16774	14189	7458	9702
Other crops	6900	6645	3952	6321	10075	8081	10017	6288	3479	6921
Fish	9603	1948	709	2601	9274	5621	4103	1091	3832	4602
Livestock	2277	1478	1855	4296	7189	4752	6348	2961	2175	4034
Non-Ag. profit	21604	24371	17675	25301	21141	16383	28072	14234	24294	21822
Remittance	11488	31633	51866	18698	8934	8453	6416	7252	21539	17671
Employment	40479	56143	38517	49008	45021	36215	55591	48330	53335	46558
Other income	5366	698	7550	3172	2603	2657	15828	1289	5061	4782
Total	104043	126578	125048	119232	116874	92775	143150	95635	121173	116093
Per-capita	25641	27950	31403	30060	30697	25533	35161	25627	25035	28833

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 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.

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.

Table 1 shows that agriculture continues to be the main source of income in Bangladesh, but that in all regions, nonagricultural profit and employment are also important income sources. 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 highest agricultural income is in Rajshahi and per capita income of this region is BDT 35161.

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

Table 2 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 BDT 51,866; Table 2); in comparison, the share generated by agricultural crops in Comilla was only 5.50%.

2.3 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 3; that table shows that rice and other crops were the main sources of income among the 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.

2.4 Comparison of income level among regions

Table 4 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 (Ferreira *et al.* 2012) to log-normal income distributions. From the result of the ANOVA (Table 5), there have been significant differences among the regions in terms of mean per-capita income.

Table 3 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

Table 4 Mean, median, and standard deviation of per-capita income (BDT/yr), by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
Mean	25641	27950	31403	30060	30697	25533	35161	25627	25035	27187
Median	24064	18080	20439	20158	21091	17848	23501	18840	17000	19334
SD	26124	34703	26080	33504	31773	23081	30935	20469	24985	28937
PR	0.51	0.49	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

Table 5 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				

The findings presented in Table 4 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. In terms of mean net income, incomes 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 (BDT 34,703), which reflects a large income gap among the farmers there.

The highest upper poverty rate (i.e., 0.51) was found in Mymensingh and Barisal (Table 4), 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 (World Bank, 2011; Poverty and Inequality in Bangladesh, 2015); 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. The problem for the former regions seems that mean income level was low. That for the latter region seems that income difference was large. These results show that these regions are vulnerable regions and should be the target of farmers' support policies.

2.5 Regional characteristics on income source

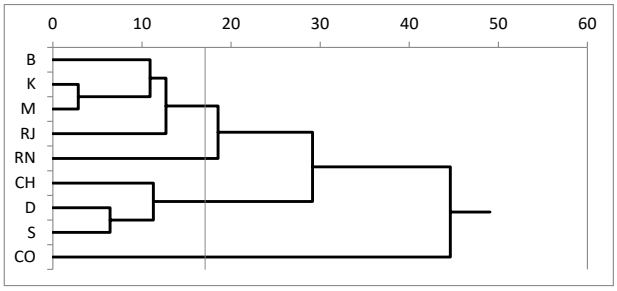

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Figure 2 Dendrogram of main income sources, by region

Table 6 Main income sources, by region

Cluster	Region	Main income source	Distinction
1	Barisal, Mymensingh, Khulna, Rajshahi	Agricultural. crops, Non-agricultural profit, Employment	
2	Rangpur		Dominant Employment
3	Chittagong, Dhaka, Sylhet	Non-agricultural profit, Remittance, Employment	
4	Comilla		Dominant Remittance

This section is to classify regions by cluster analysis to know regional characteristics on income source. Sectoral income shares from Table 2 are analyzed by cluster analysis.

In Figure 2 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.

Table 6 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.

Using the dendrogram Figure 3 (Table 3 is analyzed by cluster analysis), four clusters were determined (Table 7) as the clusters suitable for representing agricultural income sources among the regions. The selected clusters spoke to 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.

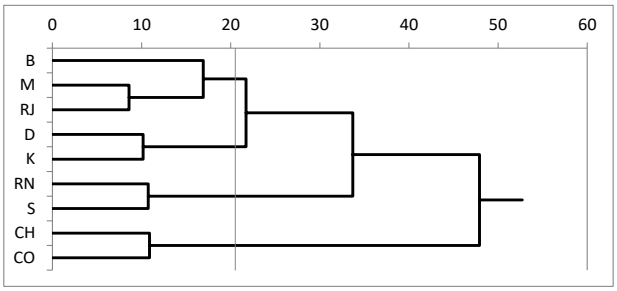

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Figure 3 Dendrogram of agricultural income sources, by region

Table 7 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	

Table 8 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

2.6 Reasons for broad income distribution within a region

To grasp the diversity of income from different sources in each region we applied decomposition of variances and the results are shown in Table 8.

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. We found from the Table 8, in Mymensingh and Rangpur, agriculture is one of the main contributors to income differences.

This result also denotes that remittance is the most important sector to induce income disparity in Comilla, and employment in Dhaka and Rangpur. In addition, other income sources is the vital sources to express the income disparity in Rajshahi.

2.7 Factors in agricultural income differences

The main factors of agricultural income differences are shows in Table 9 obtained by the decomposed variance method.

From Table 6 and 8, we identified that, agriculture is one of the main reasons for income differences in Mymensingh, Rangpur, Barisal, Khulna, and Rajshahi. Now the empirical estimates of Table 9, indicate that the main variation in agricultural income comes from *aman* HYV and *boro* HYV 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 (BBS, 2015; BER, 2017). For Mymensingh and Rangpur, variances in *aman* HYV and *boro* HYV rice are high. For other regions, variances in *boro* HYV are high.

Table 9 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	4.01		
2*Cov(g,m)								1.82		
2*Cov(g,p)							3.58	11.66		
2*Cov(m,p)						0.02		2.11		
2*Cov(o,p)			19.17			0.34		2.33		
2*Cov(e,j)							2.73			
2*Cov(g,s)							9.54			
2*Cov(j,s)							13.61			
2*Cov(k,p)							3.46			
2*Cov(d,j)					4.20					
2*Cov(e,j)	4.95									
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

Table 10 Costs and income (BDT/ha) associated with *aman* HYV rice production, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
b	4463	6211	6319	4469	2500	3763	3895	3161	4754	3908
c	5336	3166	5985	6632	5334	2819	3757	2554	3746	3967
d	110	380	667	2853	923	2241	3111	1032	469	1620
e	99	128	238	129	144	233	581	203	319	267
f	496	940	704	516	277	760	777	773	399	622
g	2185	3783	5012	4204	3374	5233	4105	4212	2292	3974
h	754	51	36	56	213	329	134	153	548	267
i	2207	3574	3130	2810	2080	2129	1856	2196	2576	2277
j	1459	1437	775	507	789	701	335	279	489	634
k	7121	12881	11103	14260	9401	9611	11144	8819	8937	10006
TC	24230	32551	33969	36435	25035	27820	29696	23381	24529	27541
TP kg/ha	3573	3655	1913	3131	2515	2776	3650	3500	2572	3023
GI	60976	58978	32153	51017	39648	47916	54925	55562	39573	48603
GI-TC	36746	26427	-1816	14582	14614	20096	25229	32181	15044	21061

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

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

According to the results of Table 9, it is important to know factors those are responsible for large variation of income from *aman* HYV and *boro* HYV.

From the Table 10, we can grasp 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 10). The highest net income comes from aman HYV production in Barisal and Rangpur.

Now, 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 11, that gross income are the 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 12.

Table 11 Decomposed variances share (%) of gross income and gross cost of *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.

Table 12 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	3.00	
2*Cov(h,g)									1.52	
2*Cov(k,f)		3.79		2.04			4.82			
2*Cov(k,i)		10.46	9.21				5.94			
2*Cov(e,f)					0.75					
2*Cov(k,e)				1.67						
2*Cov(c,k)		9.05								
2*Cov(c,g)		5.87								
2*Cov(b,c)		-2.36								
2*Cov(b,k)		-10.12								
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, 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.

From Table 9, we noticed that *boro* HYV also had an influence of agricultural income. Now, we can check the *boro* HYV rice production scenario from the Table 13. The results show that rental cost for land, seed, irrigation, fertilizer, and hired labor costs are higher for *boro* HYV cultivation.

Table 13 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.

It is essentials to know the factors that are affected the net income variation for *boro* HYV rice cultivation. Table 14 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.

Table 13 Costs of and income (BDT/ha) from *boro* HYV rice production, by region

	B	CH	CO	D	K	M	RJ	RN	S	BD
b	5361	6840	6282	4228	2688	3746	4113	3545	4523	4079
c	5022	3857	5878	5911	5508	3527	6103	3354	3570	4834
d	5287	4993	11228	13747	9534	10195	9641	7798	5103	9414
e	199	445	767	350	879	678	718	2109	159	662
f	1163	1183	1159	609	767	1113	923	1140	303	807
g	4953	7659	7674	7540	8055	8853	6079	8896	3801	7000
h	129	131	25	85	234	475	212	171	460	253
i	3526	3887	3050	2793	2402	2219	1812	2524	2139	2449
j	1321	2431	1208	1347	1622	834	495	796	354	995
k	12649	25348	19741	20119	12549	13098	15820	10414	18858	15949
TC	39611	56774	57012	56730	44239	44738	45915	40746	39271	46443
TP kg/ha	4659	4821	5136	6181	5122	4950	6025	5733	4218	5304
GI	69851	80012	82970	97109	83800	89860	92618	92591	62176	84937
GI-TC	30241	23238	25958	40379	39562	45123	46703	51845	22905	38495

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

Table 14 Decomposed variances share (%) of gross income and gross 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.

Table 15 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(c,i)		0.81	1.95							
2*Cov(f,i)	1.07	0.34	0.67	0.39	0.52		0.52	0.97	0.26	0.61
2*Cov(g,i)	2.87	2.15	1.99	2.87	5.47	3.76	2.14	5.69	1.99	3.43
2*Cov(g,j)	1.81	0.55								
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		3.89			5.90
2*Cov(e,k)		2.16	7.84							
2*Cov(i,j)		0.34	0.30							
2*Cov(g,h)						8.05				
2*Cov(e,i)			1.44					1.25	0.22	0.60
2*Cov(d,f)			0.78				1.50			
2*Cov(f,k)			2.74				2.85			
2*Cov(d,i)			1.82				1.64			
2*Cov(e,g)			1.50					4.90	0.44	
2*Cov(e,f)			1.74					0.76	0.63	
2*Cov(c,d)			5.30							
2*Cov(d,k)			8.70							
2*Cov(e,k)			6.44							
2*Cov(j,k)			3.41							
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

This implies that adaptation strategies have priorities on large gross income variances of *boro* rice cultivation.

Now we want to know what costs are main factors for income differences in *boro* HYV rice production. Table 15 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. These costs were made the net income differences in this rice production. It is also important to mentioned that variance in hired labor cost is highest in Chittagong region 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.

2.9 Future projections

Productivity levels in agriculture, fishery, and livestock raising are projected to change, due to climate change. We therefore sought to project the impact of rice yield change on the state of 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 (IFPRI, 2013), 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 GFDL (Geophysical Fluid Dynamic Laboratory) scenarios if 4-degree temperature change, then 17% decline overall rice in Bangladesh (Hossain, 2013).

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 4 shows the annual per-capita income (actual and projected) in BDT 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.

From the decomposed variances share of income sources in Table 8, 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 (17% loss) in these two regions by log-normal distribution.

We analyzed and found that due to constant reduction of rice yield (10% loss) by climate change in Bangladesh is not so severe problems for farmers. Because the change of net per capita income is so small and there is not dramatically change of poverty rate. However, farmer's life will be fall in problem. In contrast, the extreme events like flood, flash flood, drought, sea level rise in specific areas of Bangladesh makes the vulnerable situation of farmers. In addition to that, probability density of low-income range increases (Figure 5 and 6) in both Mymensingh and Rangpur districts where due to rice income loss by climate change.

We also applied the same analysis as Figure 4, 5, and 6 to all the regions and Table 16 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.

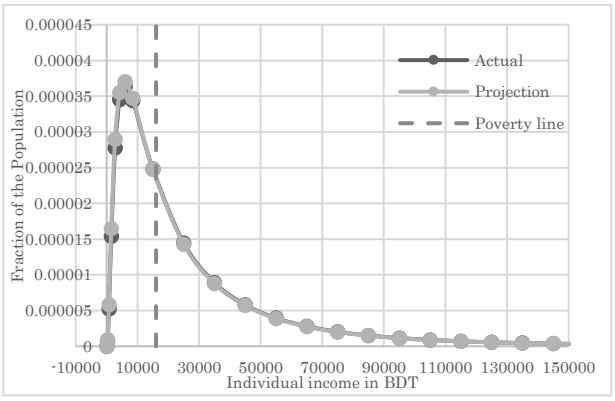

Figure 4 Annual per-capita income (BDT) distribution of Bangladesh (17% loss of rice)

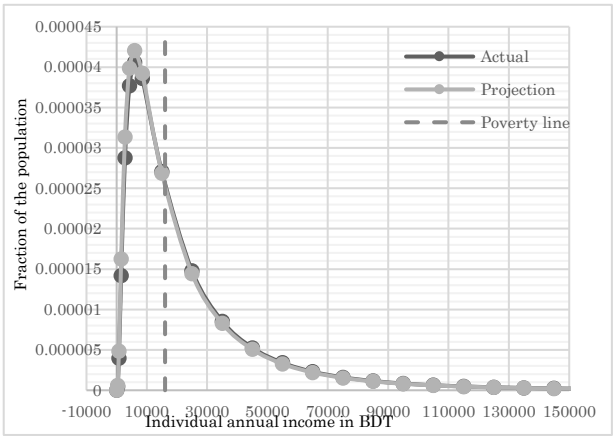

Figure 5 Annual per-capita income (BDT) distribution of Mymensingh (17% loss of rice)

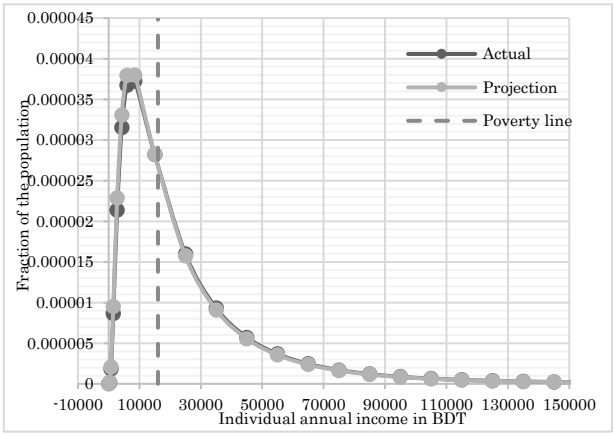

Figure 6 Annual per-capita income (BDT) distribution of Rangpur (17% loss of rice)

Table 16 Change in poverty rate following a loss of rice yield due to climate change

		B	CH	CO	D	K	M	RJ	RN	S	BD
10% loss	Actual	0.507	0.490	0.446	0.455	0.415	0.496	0.323	0.462	0.484	0.454
	Projected	0.508	0.491	0.447	0.458	0.417	0.502	0.330	0.466	0.487	0.457
	Change	0.000	0.001	0.001	0.003	0.003	0.006	0.007	0.005	0.003	0.003
	Increase (%)	0.03	0.12	0.08	0.33	0.27	0.60	0.69	0.46	0.29	0.29
17% loss	Actual	0.507	0.490	0.446	0.455	0.415	0.496	0.323	0.462	0.484	0.454
	Projected	0.513	0.494	0.449	0.460	0.422	0.511	0.335	0.473	0.490	0.461
	Change	0.006	0.004	0.003	0.005	0.007	0.014	0.012	0.011	0.006	0.007
	Increase (%)	0.58	0.37	0.27	0.47	0.74	1.43	1.18	1.12	0.60	0.68

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 (1.43%) will take place in Mymensingh, Rajshahi (1.18%), and Rangpur (1.12%). 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.

CONCLUSIONS

This study analyzed regional characteristics of farmers' income, based on statistical analysis of farm survey data, to think about regional vulnerabilities to climate change and adaptation policies.

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 have 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. (a) In some regions, which are Rajshahi, Khulna, and Dhaka, income from agriculture is important, and these regions receive relatively high income. (b) In other regions, which are Mymensingh, Rangpur, and Barisal, agriculture income is important, but the regions receive relatively low income. (c) 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 (b).

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.

The future projections of poverty rates on assumption that boro HYV and aman HYV rice yields decline in each farm, showed poverty rate increases in different region are not significant.

However, if extreme event occurred and fully damage the agriculture production it would be increase the poverty rate. Adaptation measures to climate change in regions where small-scale farmers are largely dependent on agriculture are important challenge. As the assessment of poverty and regional vulnerability due to climate change, 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.

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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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