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ASSESSING THE EFFECT OF ARSENIC CONTAMINATION ON MODERN RICE PRODUCTION: EVIDENCES FROM A FARM LEVEL STUDY

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Abstract

The southeastern and southwestern parts of Bangladesh are naturally contaminated with arsenic exposing more than 30 million people to unsafe levels of this element in drinking water and potentially threatening rice production. A study was undertaken in three arsenic contaminated upazilas namely Kachua, Bhanga and Faridpur, aiming at understanding the possible negative effects of arsenic contamination on crop production. Sample survey was carried out to generate primary data. Two-stage sampling technique was followed in selecting the sample farms. Using Cobb-douglas yield function, productivity variability and the factors influencing level of productivity were identified. Analysis reveals that the share of agriculture income was higher for the farms under Bhanga (48%) compared to that under Kachua (46%). More than 70% of the sample households faced various arsenic related problems in rice production. Arsenic contamination resulted in less tillering, shorter plants, uneven plant growth and finally, decreased yield. Rice farmers adopted few practices for overcoming the problem, such as draining out of water from the rice fields, applying adequate fertilizers to the rice fields. Land degradation due to continued use of arsenic contaminated irrigation was reported. Due to the application of extra fertilizer and labour, the cost of modern Boro rice production in the more arsenic contaminated plots was 5% higher compared to that in less contaminated plots. Yields of MV (Modern variety) boro rice in more contaminated plots were significantly low resulting in lower gross return and profitability. Power tiller cost (a proxy for use of tiller), distance of plot from the STW, labour use, frequency of irrigation etc were the dominant determinants of MV Boro rice production in the sample arsenic prone areas.

I. INTRODUCTION

In Bangladesh, the cultivation of irrigated winter (Boro) season rice has increased tremendously since 1970s and at present the area under Boro rice is about 4.81 million hectares which is about 42% of the total rice area contributing about 55.50% of the total rice production in the country (BBS 2011). Available statistics indicate that about 64% of the total cropped land is currently irrigated by shallow tube wells (BADC 2010). However, much of the groundwater in south-eastern and south-western parts of Bangladesh is contaminated with arsenic, exposing more than 30 million people to unsafe levels of arsenic in drinking water and potentially threatening rice production. Build up of arsenic in soil due to use of arsenic contaminated irrigation water has been shown to elevated levels of arsenic in paddy fields causing reduction in rice yield and eventually high arsenic concentration in rice grains (Islam et al. 2007; Hossain et al. 2008; Panaullah et al. 2009; Khan et al. 2010). The arsenic content

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of rice grain is generally higher than that of upland cereal crops because of the relatively higher presence of soil arsenic under reduced conditions (William et al. 2007).

The arsenic hazard is a great concern in Bangladesh since about 25% people are affected by arsenic contamination in different ways (WHO 2001, Jaim et al. 2007). Moreover, it is suspected that there will be possible reduction of crop production due to arsenic contamination if the issue remains unattended. The country can not afford these adverse effects since it is already struggling to meet food requirement for her increasing population. High concentration of arsenic has been found in groundwater from thousands of hand tube-wells in several districts across the country. The groundwater in these districts has been reported to be contaminated with arsenic at various degrees and that causes hazards both to the soil and field crops (Ghani et al. 2004, Huq et al. 2001).

However, adverse impact of arsenic contamination of ground water has been reported to be of two dimensions (Khuda 2001). The primary and visible impact is on the health of individuals who are exposed to arsenic poisoning through drinking ground water contaminated with arsenic. The other and important impact is on the field crops grown with ground water, by STW irrigation. Available research findings further indicate that arsenic contamination coupled with iron toxicity causes deterioration of soil health and produces adverse effect on plant growth at varying degrees (Islam et al. 2007; Ghani 2001; Meharg and Rahman, 2003). Study on all aspects of agriculture, such as effects of arsenic contamination on crop, animal and human health is very limited in Bangladesh. Taking into consideration of the above background, this study was undertaken to evaluate the impact of arsenic on modern Boro rice production in the selected arsenic contaminated areas of the country using basically the farm level evidences.

The specific objectives of the study were as follows:

i. to assess farmers' perceptions about the level of arsenic contamination in rice production in the sampled areas of Bangladesh;

ii. to understand the possible effect of arsenic contamination on crop production and estimate the productivity differences between contaminated and non-contaminated rice farms in the study areas, and

iii. to delineate farmers practices in overcoming the problem of arsenic contamination in crop production.

II. METHODOLOGY

2.1. Study area selection

The Soil Science, Irrigation & Water Management and Plant Breeding Divisions of the Bangladesh Rice Research Institute (BRRI) carried out field experiments on the prevalence of arsenic in the irrigation water and crops in three selected locations of Bangladesh. The areas were Kachua upazila of Chandpur district, and Bhanga and Faridpur sadar upazila of Faridpur district. Based on the reports of earlier experiments, sample locations for the present socio-economic study were identified.

Two villages under each of the above Upazila were selected for carrying out in-depth socio-economic survey.

2.2. Sampling and data

Two-stage sampling procedure was followed in order to select the sample farms. At the first stage, two adjacent villages under each of the selected upazilas were identified purposively and then a comprehensive list of the rice producing farms in each village was prepared by taking help of Sub-Assistant Agriculture Officer (SAAO) of the respective areas. At the second stage, the farms those used STWs for crop production were identified and out of them 50 farms under each village were selected following random sampling technique. Data were collected through directly interviewing the selected farmers using pre-designed questionnaire during November 2009 to June 2010. Collected data were scrutinized, edited and compiled using appropriate computer software.

2.3. Analytical tools

Both descriptive and inferential statistics were employed in analyzing the data**.**

i) Test of significance

To examine the mean differences for different items of input use, productivity and profitability between rice fields near the shallow tube well (more contaminated) and far end of the command area (less contaminated), independent sample t-test of the following form was employed:

$$t = \frac{\overline{x1} - \overline{x2}}{s\sqrt{\left(\frac{1}{n1} + \frac{1}{n2}\right)}} \quad \text{with df} = n1 + n2 - 2$$

Where, s = Standard deviation

ii) Profitability analysis

Level of profitability in modern boro rice production under more arsenic contaminated and non/less contaminated fields were assessed using the following profit identity:

$$\pi = P_1 Q_1 + P_2 Q_2 - \sum P_{xi} X_i - \text{TFC}$$

Where,

π = Profit for the technology/practice under study; P_1 = Per unit price of the crop grown;

Q_1 = Quantity of output obtained; P_2 = Per unit price of by-product;

Q_2 = Quantity of by-product obtained;

P_{xi} = Per unit price of the ith (variable) input, X_i = Quantity of the ith input used for the crop, and TFC = Total fixed cost.

iii) Multivariate regression analysis

In estimating the relative contribution of different factors on yield variability of the farms under arsenic overwhelmed areas, the following Cobb-Douglas yield function was employed:

$$Y = \prod_{i=1}^{m} x_{ij}^{bi} e^{uj}$$

Taking logarithm in both sides the equation is formulated as:

$$LnY_i = \alpha + \sum \beta iLnX_i + \sum \beta_k D_k + \varepsilon_i$$

Where; Y_i = Yield of paddy in the plot (kg/ha)

X_i = input variables

D_k= are the dummy variables

B_i and B_k are the regression coefficients to be estimated.

3. Results and Discussion

Socioeconomic profile of the sample households

The socio-economic profile of the sample farm households are presented in Table 1. The average family size was slightly higher (6.0) in Kachua compared to those of other two locations. The overall family size was 5.57 which is higher than the national average of 4.8 (BBS, 2010). In terms of literacy, the proportion of people under primary education in all the three locations was more or less similar. About one-fourth of the household members in all locations were illiterate. It was also observed that the majority of the household members had either primary or secondary levels of education and the household members with SSC and above were considerably low in all the study locations.

Table 1: Socio-economic characteristics of household members in the selected study areas

Socio-economic characteristics	Kachua	Bhanga	Faridpur Sadar	All Locations (Average)
Average family size:	6.0	5.6	5.1	5.57
Male:	2.9	2.8	2.8	2.83
Female:	3.2	2.8	2.3	2.77
Education of the family members (%)				
Illiterate:	20	16	28	21.33
Primary:	39	36	32	35.67
Secondary:	21	32	30	27.67
Up to HSC pass:	18	13	8	13.00
Graduation & above:	2	3	2	2.33
Total:	100	100	100	100
Main sources of income (%)				
Agriculture	46	48	53	49.00
Business	23	13	20	18.66
Service	7	8	14	9.67
Wage	5	2	7	4.67
Remittance	16	26	4	15.33
Others	3	3	2	2.67
Total	100	100	100	100
Total annual income (Tk./HH):	131667	184659	151793	156,039

Household annual income was higher in Bhanga (Tk. 184,659) followed by Faridpur sadar (Tk. 151,193) and Kachua (Tk. 131,667). Agriculture was the main source of income of the households in all three locations. However, the share of agriculture income was higher (53%) for the sample farms under Faridpur sadar compared to that of Bhanga (48%) and Kachua (46%). In Faridpur sadar and Kachua, business was the second most important income source. However, share of remittance in household income was 26% in case of the households of Bhanga while it was 16% in case of the households under Kachua upazila.

Land holdings and tenancy

The sample farms were categorized into four farm-size groups, i.e. marginal, small, medium & large, and their distribution are presented in Table 2. The bulk of the sample farms in all three study villages (above 50%) fell under the small farm size category. The proportion of marginal farms was a bit higher in Kachua compared to those in Bhanga and Faridpur sadar. It is important to note that, the proportion of large farms were remarkably low in all the study villages.

Among the sample farms in the study villages, 50, 62 and 65% farms in Kachua, Bhanga and Faridpur sadar respectively, were the owner operators. However, the proportion of owner-cum tenant (i.e. part tenant) farms varied from 32 to 42% in different locations. It is important to note that the proportion of tenant farms was found much higher in Kachua compared to that of Bhanga and Faridpur sadar.

Table 2: Land holding and tenancy status of the sample households in different locations

Items	% of farms		
	Kachua	Bhanga	Faridpur sadar
Farm size:			
Marginal (< 0.49 acre)	32	13	20
Small (0.50 – 2.49 acre)	54	67	52
Medium (2.50 – 7.5 acre)	12	18	25
Large (> 7.50 acre)	2	2	3
Tenural status:			
Owner operator	50	62	65
Part tenant	42	36	32
Tenant	8	2	3

Effects of arsenic contamination in crops and crop fields

Farmers at all three locations mentioned about the deterioration of land quality due to arsenic contamination. About 83, 74 and 69% farmers of Bhanga, Kachua and Faridpur sadar pointed out that Boro rice fields were contaminated with arsenic. More than 80% farmers both in Bhanga and Faridpur sadar mentioned that, soil health has deteriorated due to arsenic contamination, while 63% farmers in Kachua also had the same notion. However, other arsenic related problems on rice fields were red coloration of both irrigation channel & rice fields and hardness of lands, decrease in soil fertility etc. These were reported by majority of the farm households in all three study sites (Table 3).

Table 3: Farmers' perceptions on the prevailing effects of arsenic contamination on crop fields.

Items	% farmers opined		
	Kachua	Bhanga	Faridpur Sadar
Crop fields contaminated with arsenic	74	83	69
Decreases soil fertility	63	87	87
Irrigation canals and rice fields become red	92	89	80
Land become hard	91	87	69
Rice yield near irrigation channel/STW is low	81	82	66
No effect/No idea	3	11	9

Note: Multiple responses considered

Use of irrigation equipments

Both shallow tube wells (STWs) and deep tube wells (DTWs) were used by the farmers for irrigation purpose. However, the present study concentrated mainly on STW users in each study village. The average depth of STWs in the study areas ranged from 80-90 ft (Table 4). In terms of average duration of installation, the highest was in Bhanga area (13 years), while the lowest duration was observed in Kachua (about 9 years).

Table 4: Status of irrigation equipment and level of irrigation

Items	Upazila		
	Kachua	Bhanga	Faridpur sadar
Average depth of STW (ft)	80	90	82
Average frequency of irrigation for rice	16	28	22
Average years of installation	9.4	13	9.5

Effects of arsenic contamination on rice

Major problems encountered by the sample farmers in rice production due to arsenic contamination are furnished in Table 5. More than 70% farms in Kachua reported that they were familiar with various arsenic related problems in rice production which were: less tillering, shorter plants (height), plants do not flower timely etc. Similarly about 60% farmers opined that grains do not mature timely and more grains remain unfilled. Consequently, those problems resulted in reduction of rice yield as reported by 80% farmers in all the three study areas. It is important to note that comparatively higher proportion of farms under Bhanga were facing most of the yield retarding factors in growing MV Boro rice compared to Kachua and Faridpur sadar.

Table 5: Farmers' observation on the effects of arsenic contamination on rice

Items of visual effect	% farmers opined		
	Kachua	Bhanga	Faridpur Sadar
Less tillering	77	91	87
Plants become shorter in height	75	92	82
Plant growth not uniform	72	92	77
Plants do not flower uniformly	71	91	75
Plants do not mature uniformly	60	93	75
More unfilled grains	66	89	73
Decrease rice yield	84	89	82

Note: Multiple responses considered

Steps taken by the farmers for improving the crop condition

Most of the sample farms under all the study locations took different types of measures for improving the condition of the affected crops. In general, farmers had the tendency of applying more fertilizers in arsenic contaminated plots. It was evident that, nearly 70% farmers in Kachua observed applied more urea in the arsenic affected plots, while 64 and 32% farmers in Bhanga Faridpur sadar respectively also used more urea to overcome the problem (Table 6). In Kachua, almost 80% farms applied more gypsum and did mulching to the affected plots. On the other hand, 60% farms in Bhanga and 30% farms in Faridpur sadar did mulching. Usually, farms under the study areas apply less water or drying up the affected plot before mulching and this was practiced by 20% farms in all the sample areas. It was also observed that more than 50% farms under all three study areas applied zinc sulphate to overcome the arsenic problem. Apart from these activities, 56% farms in Kachua applied growth hormone to accelerate the growth of affected crops while in Bhanga and Faridpur, growth regulator was also applied by 45 and 30 % farms respectively (Table 6).

Table 6: Farmers' practices in reducing effect of arsenic on crop productivity

Steps taken	% farmers followed		
	Kachua	Bhanga	Faridpur Sadar
Drain out the water and allow the field to dry	21	29	20
Apply more urea	70	62	32
Apply more TSP	12	17	11
Apply more MoP	25	36	10
Apply more gypsum fertilizer	80	79	59
Apply more zinc sulphate	55	52	63
Did mulching	83	64	42
Apply cow dung	44	33	25
Apply Ash	23	16	16

Note: Multiple responses considered

Input use for more arsenic contaminated and less contaminated fields

The comparative input use level and corresponding cost for MV Boro production in more arsenic contaminated fields near the STW, i.e. within 400 meters of the STW (Linda and Stephen, 2007, Meharg and Rahman 2003, Islam et al. 2007) and less arsenic contaminated fields (periphery of the command area) under different study locations can be viewed in Tables 7 and 8. It is evident from the analysis that in general the cost of fertilizers for boro production was much higher for the more arsenic contaminated plots than the less arsenic contaminated plots. In terms of fertilizer by type, the use gypsum and zinc sulphate in arsenic contaminated plots was almost three times higher than that of less arsenic contaminated plots. The additional application of some of the chemical fertilizers and for doing mulching for the more arsenic affected plots, the level of human labour use was also much higher. The total cost of boro rice production for the arsenic contaminated plots was also much higher compared to that of less arsenic contaminated plots irrespective of study locations.

Table 7. Comparative input use level in more arsenic contaminated and less arsenic contaminated boro rice plots during 2010

Items of inputs/cost	Kachua, Chandpur		Faridpur sadar		Bhanga, Faridpur	
	Arsenic affected plots	Non-affected plots	Arsenic affected plots	Non-affected plots	Arsenic affected plots	Non-affected plots
Human labor (man-days /ha)	153	144	151	139	159	145
Seed (kg/ha)	57	61	73	81	64	59
Manure (kg/ha)	2712	2812	1599	1048	1337	474
Chemical fertilizer:						
Urea (kg/ha)	248	238	327	295	320	314
TSP (kg/ha)	89	87	106	106	98	102
MP (kg/ha)	59	59	67	60	67	73
Gypsum (kg/ha)	81	27	166	68	103	58
Zinc sulphate (kg/ha)	2.3	0.6	6	3	4	1

Table 8. Comparative costs of MV Boro rice cultivation in more arsenic contaminated and less arsenic contaminated plots during 2010

Items of inputs/cost	Kachua, Chandpur		Faridpur sadar		Bhanga, Faridpur	
	More arsenic affected plots	Less arsenic affected plots	More arsenic affected plots	Less arsenic affected plots	More arsenic affected plots	Less arsenic affected plots
Human labour (Tk./ha)	22937	21597	21108	19399	19138	17382
PT/DP cost (Tk/ha)	3428	3299	2904	3147	3544	3635
Seed (Tk/ha)	1149	1229	1469	1622	1275	1171
Manure (Tk/ha)	2712	2812	1599	1048	1337	474
Chemical fertilizer (Tk/ha)	**7458**	**6651**	**10081**	**8409**	**9018**	**8599**
Urea (Tk/ha)	2973	2859	3922	3536	3840	3773
TSP (Tk/ha)	2224	2185	2656	2658	2439	2547
MP (Tk/ha)	1304	1302	1475	1321	1465	1610
Gypsum (Tk/ha)	813	270	1664	675	1034	578
Zinc sulphate (Tk/ha)	144	35	364	219	240	91
Insecticide/Pesticide cost (Tk/ha)	1753	1434	1161	1025	731	708
Theovit (Tk/ha)	458	52	141	97	33	19
Herbicide cost (Tk/ha)			143	19		
Irrigation cost (Tk/ha)	8904	8993	12336	12672	12155	12318
Total variable cost (Tk./ha)	48799	46067	50942	47438	**47217**	**44320**
Interest on operating capital @ 9%	915	864	955	889	885	831
Rental value (Tk/ha)	14500	14500	13500	13500	12500	12500
Total cost (Tk./ha)	**64214**	**61431**	**65397**	**61827**	**60602**	**57651**

Productivity and Profitability

The level of grain yield obtained by sample farms and other pertinent economic analysis for different locations are presented in Table 9. The grain yields of boro rice in the more arsenic contaminated plots in all three locations were substantially low compared to that of less arsenic contaminated plots. Consequently, the gross return from the more arsenic affected plots was also very low. In particular, per hectare gross return for arsenic affected plots in Kachua and Faridpur sadar were Tk. 55708 and Tk. 59385 respectively, while gross return for non affected plots of those two areas were Tk. 80,188 and Tk. 91,449 respectively. The net return was negative for the arsenic affected plots for those two sites. The return from investment (BCR) was only 0.87 and 0.91 for the arsenic affected plots of Kachua and Faridpur implying that, for each taka investment in Boro production for the arsenic affected plots, farmers earned less than a taka.

Table 9. Productivity and Profitability of MV Boro rice cultivation in more arsenic contaminated and less arsenic contaminated plots during 2010.

Items	**Kachua, Chandpur**		**Faridpur sadar**		**Bhanga, Faridpur**	
	Arsenic affected plots Quantity	Non affected plots Quantity	Arsenic affected plots Quantity	Non affected plots Quantity	Arsenic affected plots Quantity	Non affected plots Quantity
Yield: Grain (kg/ha)	3220	4635	3483	5364	3896	5934
Straw (kg/ha)	2576	3708	2786	4291	3117	4747
Gross Return (Tk./ha)	**55708**	**80188**	**59385**	**91449**	**66425**	**101174**
Grain (Tk/ha)	53131	76480	56599	87158	63309	96427
Straw (Tk/ha)	2576	3708	2786	4291	3117	4747
Gross Margin (Tk./ha)	6909	34121	**8443**	**44011**	**19208**	**56854**
Net Return (Tk/ha)	-8506	18757	-6012	29622	5823	43523
BCR (Undiscounted)	0.87	1.31	0.91	1.48	1.10	1.75

However, in case of Bhanga, although the profitability level for arsenic affected plots was a bit better, BCR was far worser compared to that obtained for the plots with less contamination. The rate of returns for the sample farms under Bhanga were 1.10 and 1.75 for the arsenic affected and less contaminated plots respectively. These results further imply that, due to arsenic contamination in Boro rice, farmers had to incur higher cost in producing rice; on the contrary they obtained low yield which eventually led to low profitability in irrigated Boro production. This result is in consonance with that of few earlier studies (Roy, 2007; Khan, 2007).

Significance of the differences in input use and cost and return

Results of 't' test for different items of production and cost & returns for different locations are presented in Tables 10. It was found that per hectare human labour cost for the more arsenic contaminated plots was higher by Tk.1756, Tk.1706 and Tk.1340 in Bhanga, Faridpur sadar and Kachua respectively compared to the less arsenic contaminated plots. These differences were highly significant implying that there was significant difference in the use of human labour for producing Boro rice in more arsenic contaminated and less contaminated plots. It might have happened due to additional use of labor for mulching and fertilizer application to the arsenic affected plots. There were significant differences in the use of gypsum and zinc sulphate between the arsenic contaminated and less contaminated plots in all the locations. This seems quite reasonable, because additional gypsum and zinc sulphate were applied to the arsenic contaminated plots when crops became yellowish/red. Differences in the cost of producing Boro rice between more arsenic contaminated plots and less contaminated plots were Tk. 2898/ha, Tk. 3504/ha and Tk. 1565/ha, respectively. This difference were also statistically significant implying that, the difference in total variable cost for producing Boro rice in more arsenic contaminated and less contaminated plots were really substantial. However, farmers obtained much lower gross return and gross margin for the arsenic contaminated plots than that of less contaminated plots in all three study locations. The differences in gross return were Tk. 34749/ha, 32064/ha and Tk. 24480/ha for Bhanga, Faridpur sadar and Kachua respectively. This result further imply that, although farmers apply significantly higher amount of inputs in more contaminated plots, probably the recovery in the crop dose not happen that much due to arsenic infestation and eventually they reap less output and thus harness less benefit.

Table 10: Operation-wise mean differences of cost and return for producing Boro rice in more arsenic affected and less affected plots at the study areas.

Items	Bhanga		Faridpur sadar		Kachua	
	Mean Differences (Tk/ha)	t value	Mean Differences (Tk/ha)	t value	Mean Differences (Tk/ha)	t value
Human labor	1756	23.6*** (632)	1709	11.4*** (1269)	1340	7.1*** (1547)
Manure	863	3.2** (2270)	551	1.1 (4200)	-100	-0.2 ns (3687)
Urea	67	0.3 ns (1835)	386	2.4** (1353)	114	1.1 ns (845)
Gypsum	456	4.0*** (968)	989	4.0*** (2123)	543	12.1*** (370)
Zinc sulphate	150	3.1** (416)	145	2.5** (488)	109	3.1*** (291)
Total fertilizer	419	2.09** (3924)	1672	3.9*** (3765)	807	5.0*** (2003)
Insecticide	23	0.1 ns (2341)	137	0.6 (2101)	319	1.8* (1476)
Total variable cost	2897	3.3** (7495)	3504	3.0*** (9960)	2732	3.1*** (4185)
Gross Return	-34749	-10.5*** (28013)	-32064	-7.7*** (35251)	-24480	-5.3*** (37979)
Gross Margin	-37646	-11.4*** (27937)	-35568	-8.6*** (34893)	-27212	-5.7*** (37576)

***, **, * indicate significant at 1%, 5% and 10% level.

Note: Figures in the parentheses indicate standard deviation of the mean

3.10. Determinants of Boro rice yield

Important determinants of modern Boro yield in the arsenic-prone areas were evaluated through employing multivariate regression analysis. In this connection Cobb-Douglas yield function was estimated using a number of explanatory factors potentially associated with the yield of MV Boro. The explicit form of the model was as follows:

$$Ln\,Y = \alpha + ß_1 Ln\,Ptill + ß_2\,LnSeed + ß_3\,Lnferti + ß_4\,LnHlabor + ß_5 LnFirrig + ß_6\,LnDistan + ß_7 LnFarm + D_1 Mulch + D_2 Arsenic + D_3\,Variety + U_i$$

Where,

Y = Yield of paddy in the plot (kg/ha)
Ptill = Power tiller cost(Tk/ha)
Seed = Seed use cost (Tk/ha))
Ferti = Fertilizer cost for the plot (Tk/ha)
Hlabor = Human labor cost (Tk/ha))
Firrig = Frequency of irrigation
Distan = Distance of the plot from the STW (in meter).
Farm = Farm size in decimal
Mulch = Mulching dummy (taking 1 if mulching done, otherwise 0)
Arsenic = Plot Arsenic dummy (arsenic contaminated plot=1, otherwise 0)
Variety = Variety dummy (taking 1 for BR 28, otherwise 0),
U_i = Disturbance term

The results of the double log OLS estimates are furnished in table 11. For most of the variables included in the model, estimates were found in line with the priori expected sign. The power tiller cost (a proxy for use of tiller) was found positively influencing rice yield and significantly contributing to the productivity in both the areas. Distance of the field/plot from the STW was found to be positively related with the yield of modern Boro rice implying that rice yield was higher in the plots those are at distant from the irrigation machine. it is because arsenic concentration in STW water decreases substantially with increase in the path of water flow in the canal (Linda and Stephen, 2007, Islam et al. 2007 and Meharg and Rahman, 2003). The earlier studies proved that, effect of arsenic in water decreases drastically after 400-500 meters of water flow. Therefore, plots with longer distance have less arsenic concentration and causes less infestation and therefore have better yielding ability. The coefficient of labour had positive influence on yield indicating that paddy yield would increase with more use of labour. It is also reasonable because, in the arsenic-prone areas mulching in the paddy field is done by the farmers in order to till, dry and clean the plot more which in fact reduce the effect of arsenic as opined by the crop scientists (Heikens et al. 2007 and Meharg and Rahman, 2003). Therefore, it seems that mulching in the rice fields which involves use of more labor in the arsenic-prone areas is effective in reducing the level of arsenic infestation and thereby increase paddy yield.

Table 11: Results of Cobb-Douglas production function for MV Boro rice cultivation in the study areas.

Variables	Kachua		Bhanga	
	Reg. coeff	t-ratio	Reg. coeff	t- rtatio
Intercept	2.662	1.089	8.934	1.997
LnPtill	0.151 **	2.388	0.158***	3.172
LnSeed	0.103	1.350	0.142	1.190
LnFerti	0.051	0.798	0.063	0.891
LnHlabour	0.078	1.031	0.201*	2.09
LnFirrig.	-0.154 *	-1.974	-0.051**	3.304
LnDistan	0.072 *	1.873	0.006 **	2.974
LnFarm	0.032	0.453	-0.012	-0.857
Mulch dummy	0.002	1.021	0.063*	1.984
Arsenic dummy	-0.726 ***	-6.778	-0.442***	-4.10
Variety dummy (BR 28 =1, otherwise 0)	0.007	0.867	0.023	1.0421
R^2	.633		.522	

***, **, * indicate significant at 1%, 5% and 10% level.

Frequency of irrigation in Boro fields was negatively influencing rice yield indicating that with the increase in number of irrigation, Boro yield showed significant decreasing trend. It is because, in the arsenic-prone areas more deposition of STW water reasonably enhances the level of arsenic infestation which aggravates its effect and this eventually causes yield deterioration. Arsenic contamination dummy refers to the intensity of contamination in rice fields. Plots with less distance were taken as the base or reference point. The coefficient of arsenic contamination dummy was highly significant, implying that MV Boro yield in the plots with less contamination were much higher compared to those with more/high contamination.

IV. CONCLUSIONS AND POLICY IMPLICATIONS

Farmers' awareness and perceptions on arsenic contamination were assessed in the present study. It was evident that about 70% of the sample rice farmers under the arsenic prone areas were acquainted with various arsenic related problems in growing rice. Categorically the problems were: less tillering, shorter plants, red coloration of rice plants and canal, un-uniform maturity, unfilled grains etc. These problems eventually resulted in reduction of rice yield. Rice farmers, however, adopted few practices to overcome the problem. The majority of the farms applied more gypsum and did mulching to the plots. Due to the application of extra fertilizer and additional labour, the cost of boro rice production for the arsenic affected plots was much higher compared to that of non-affected plots in all the locations. On an average the yield of Boro rice in more arsenic contaminated plots was 40-50% low compared to that of less arsenic contaminated plots.

It can be inferred from farmers' opinion that, soil health has been decreasing due to arsenic contamination resulting to low soil productivity. Although farmers were using higher doses of fertilizers in Boro fields, the yield did not increase indicating that land degradation had arisen due to arsenic contamination through irrigation water.

Results of multivariate regression analysis reveal that power tiller cost (a proxy for use of tiller), distance of plot from the STW, labour use etc are the dominant determinants of modern variety of Boro rice cultivation in the sample arsenic prone areas. Frequency of irrigation in Boro fields was negatively influencing rice yield indicating that with the increase in number of irrigation, Boro yield showed a significant decreasing trend. The coefficient of arsenic contamination dummy was highly significant, implying that MV Boro yield in the plots with less contamination were much higher compared to those with more/high contamination.

Policy implications

i) For growing Boro rice in the study areas, farmers used mainly Shallow Tube-well (STWs) for irrigating Boro rice. Research findings indicated that STW water is the main source of arsenic contamination. In this respect, government efforts should be strengthened in order to supply more DTWs replacing the STWs for irrigating Boro rice.

ii) It was observed in the study areas that, farmers from own perceptions applied more chemical fertilizers (e.g. urea, gypsum, zinc sulphate etc.) in the Boro rice fields to overcome the arsenic problem. Due to the excess use of arsenic contaminated irrigation water and chemical fertilizers, soil health might have been deteriorated. Researchers should come forward and carry out needed research to develop appropriate technology so that, through applying those technologies the soil could be saved and thus congenial environment could be created for crop production in the future.

iii) Research findings showed that, Boro rice production in the severely arsenic affected plots were losing concern due to low yield and because of this rice farmers would feel discouraged in cultivating rice. This would eventually cause low rice production and create food shortage in the study areas. The relevant research Institutes should take necessary step in carrying out needed research works to solve the arsenic problems in crop production.

iv) Farmers may be advised to grow Boro rice with less irrigation practices e.g. bed planting, strip tillage and to grow non-food crops e.g. Jute.

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