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ARTICLES

Analysing Varying Crop Productivity in Canal Irrigation: A Case Study of Damodar Valley Corporation (DVC) in West Bengal

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ABSTRACT

This empirical study has taken up one of the oldest and largest multipurpose major irrigation project, Damodar Valley Corporation (DVC), in West Bengal for micro level study to identify spatial effect of canal irrigation on the average productivity of major crops in the area. We have found that the location of cultivable land with reference to main canal course is a statistically significant determinant of its productivity. The spatial effect of canal irrigation not only explains variations of average crop productivity across different segments of canal network, it is an important factor also to explain variation of productivity at the intra-segment levels.

Keywords: Canal irrigation, Productivity variation, Spatial effect, Inter-segment, Intra-segment.

JEL: Q12, Q15, O13

I

INTRODUCTION

The agricultural growth in India is largely dependent on the behaviour of monsoon rainfall because about half of the area under cultivation is rainfed. It also depends on the continuous increase in land productivity given that increase in the gross cropped area can only be achieved through enhancement of cropping intensity by bringing in more and more rainfed land under irrigation. Irrigation, therefore, is a very crucial input for agricultural development. Availability of irrigation has been cited to be one of the important factors behind regional variations in agricultural productivity in India (Chattopadhyay, 2014). Insufficient irrigation was the key factor contributing 'agrarian impasse in Bengal' till the 1970s (Boyce, 1987) and this scenario changed dramatically in the late 1970s and in the 1980s mainly because of improvement in irrigation facilities during this period which enabled multi-cropping of land and adoption of new seed-fertiliser technology (Hariss, 1993; Rawal and Swaminathan, 1998; Rawal, 2001; Bhalla, 2007). Further, Parthasarathy (1971); Byres (1972); Sen (1975) and Farmer (1977) have argued that irrigation facility was one of the major factors which led to enhanced land productivity in India in the green revolution period.

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The surface irrigation contributed about 60 per cent of net irrigated area in India till 1965 of which 70 per cent used to come from canals. However, the prominence of surface irrigation has been reduced over time and the importance of ground water irrigation has increased substantially. Several studies tended to opine that the latter is the better source of irrigation in terms of area of irrigation potential and others (Wade, 1976; Mitra, 1986; Gulati *et al.*, 2005). However, the growing dependence on ground water has led to lowering of the water table and has adversely impacted on the availability and quality of drinking water. Thus, conjunctive use of surface irrigation and ground water irrigation has been emphasised upon. Without conjunctive use of surface and ground water and exclusive emphasis on the development of one source of water will not be sustainable particularly because most parts of India have a seasonally concentrated distribution of rainfall (Dhawan, 1987; Chattopadhyay, 2014).

In this study an attempt has been made to the explore the spatial effects of canal irrigation on productivity of major crops in the areas served by different segments of the canal (the entire canal network has been divided into three segments, namely head reach (HR), middle reach (MR) and tail-end (TE) segments) as well as in the areas corresponding to before and after lock-gates[1] situated in different segments of the canal. We have taken up one of the oldest and largest multipurpose major irrigation project, Damodar Valley Corporation (DVC) in West Bengal for our empirical study, which would help us in understanding the dynamics of canal irrigation problems and their impact on the agricultural activities. Hussain, 2004; Mony, 1995; Wade, 1976; IIMC, 2008; Government of India, 2003; Viswanathan, 2001; Jairath, 1985 have discussed similar issues; i.e., inter-segment impact of canal irrigation on productivity. These studies have identified the problems of water availability in the TE area of a canal network (command area) only. However, we have not found any study in the literature which has dealt with intra-segment impact of canal irrigation (i.e., in between before and after lock gate segments of a canal network irrespective of it being at the HR, MR or TE areas).

This study is based on both primary and secondary data and we have conducted field investigation in the area of our study apart from using necessary statistical data available from the secondary sources. The paper has been organised as follow: Section-II discusses sampling procedure and sampling size and in Section-III we explain our research methodology. We present and analyse our results in Section-IV and finally, in Section-V, we make concluding observations.

II

SAMPLING PROCEDURE AND SAMPLE SIZE

DVC canal irrigation system starts from Durgapur Barrage and it has two main canals: Left Bank Main Canal (LBMC) and Right Bank Main Canal (RBMC). The command area of the LBMC is about 3.18 lakh ha while the command area of the

RBMC is 78.6 thousand ha. For primary survey we have selected samples in the LBMC command area which covers three districts of West Bengal namely, Burdwan, Hooghly and Howrah and has 22 lock gates within its course. The entire area has been divided into three segments, namely, head reach (HR), middle reach (MR) and tail-end (TE) areas.[2] It is generally believed that to find out differentiated impact of canal irrigation on HR, MR and TE areas one should select those areas on the channel network where canal water has been flowing in a single sequence or chain (Hussain, 2004; IIM Calcutta, 2008). The following procedure has been adopted while selecting our samples.

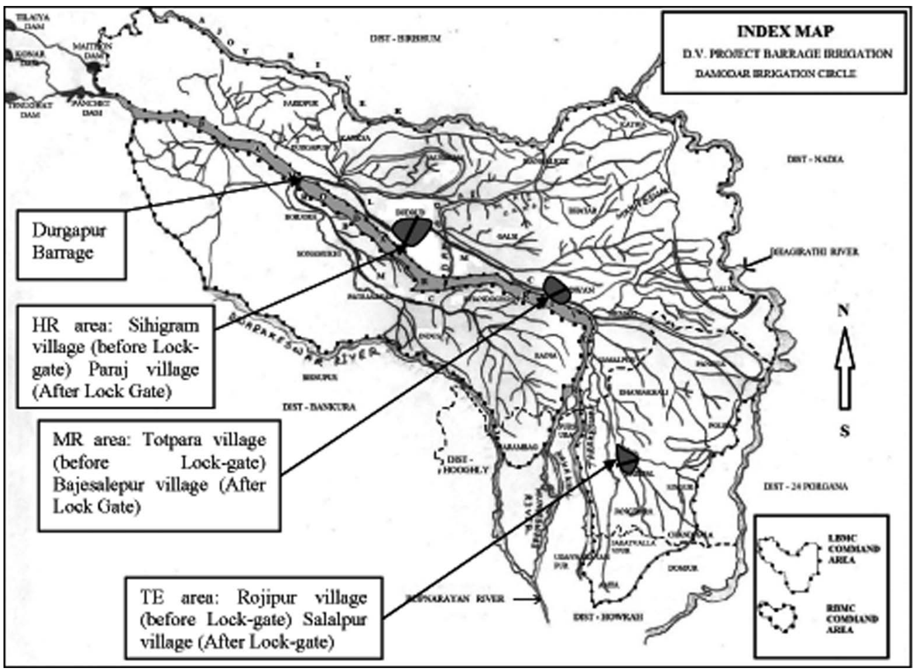
In this study we have selected one block from each segment which are more or less equal distant from one another and at least 20 km away from nearby town. Thus, the chosen blocks are Galsi-1, Burdwan-2 and Dhaniakhali blocks representing HR, MR and TE areas respectively. The first two blocks are in Burdwan district while the last one belongs to Hooghly district. Next we have selected one gram panchayat (GP) from each block on the basis of three parameters, namely, rank of the area covered by the Water Users' Association, rank of field channel area and rank in terms of area under canal irrigation. We have chosen two villages from each selected GP. The condition of selection is that at least last two parameters must be satisfied and the concerned village should be at least 20 km away from the nearby town. Further, we have selected one village such that it is situated before a particular lock-gate and another which is situated after the particular lock-gate in each of the HR, MR and TE segments.

Thus following the above, we have selected three gram panchayats, namely, Paraj from Galsi-1 block of Burdwan district, Borsul-2 from Burdwan-2 block of Burdwan district and Dasghara-2 from Dhaniakhali block of Hooghly district. We have selected two villages from each GP, one from before-lock-gate and other from after-lock-gate region.[3] We have presented DVC Circle map in Figure 1 which shows the entire command area of Left Bank Main Canal (LBMC) as well as the selected villages in the HR, MR and TE areas keeping in mind their position in terms of a particular lock-gate. Further, in this study our unit of survey is plot of land. Randomly we have selected 45 plots from before-lock-gate area and 45 plots from after-lock-gate area of the selected villages. In this way we have selected total 90 plots from each segment (HR, MR and TE areas) of the LBMC canal network of DVC which gives us a sample size of 270. Further, selection of 270 plots led us to select 187 households.[4] We have conducted our primary survey during December 2012 and March 2013.[5]

III

RESEARCH METHODOLOGY

We have conducted multiple linear regression[6] analysis involving three endogenous variables (namely, productivities (kg/*katha*) of monsoon and summer



Source: Authors' own sketch based on map of the Damodar Irrigation Circle, Irrigation and Waterway Directorate, Government of West Bengal.

Note: In both LBMC and RBMC command areas canal water has been flowing from left to right direction.

Figure 1. Selected Areas in the LBMC of DVC Command Area for Primary Survey.

(*boro*) paddy and potato) and twenty exogenous variables[7] which may influence above endogenous variables in the DVC command area. To avoid problems of multicollinearity and simultaneity, we have built up two models (Gujarati, 2004, 2011; Wooldridge, 2008). We have used model-1 in each case to identify 'inter-segment' variation (i.e., among HR, MR and TE segments) of the respective dependent variable due to the variation of the respective independent variables. Similarly, model-2 is used to identify ''intra-segment' variation (i.e., variations in terms of location of the plots with reference to a particular lock gate in each segments: HR, MR and TE) of the same in the DVC command area. Further, we have used Fisher's –'t' test statistics to test statistical significance of productivity variations. The factors behind statistically significant variations of agricultural productivity have been explained using the following models:

$$Y_i^{sc} = \alpha_{sc} + \beta_{ksc}\left(\sum_{i=1}^{nsc} X_i + \sum_{i=1}^{nsc} D_i\right) + u_i \qquad ....(1)$$

$$Y_j^{slc} = \gamma_{slc} + \delta_{rslc}\left(\sum_{j=1}^{mslc} X_j + \sum_{j=1}^{mslc} D_i\right) + u_j \qquad ....(2)$$

where Y= productivity (kg/*katha*); s = segments (all segments, HR, MR and TE); c = crops (monsoon paddy, summer (*boro*) paddy and potato); k = number of explanatory variables considered (14, 12 and 10 explanatory variables have been considered for monsoon paddy, summer paddy and potato cultivation respectively); i = 1, 2, ……., n indicate the number of observations in model-1 while j = 1, 2, 3, …………., m indicate number of observation[8] in model-2; l = lock-gate (before and after); r = explanatory variables (7 variables for monsoon paddy and 6 variables for *boro* paddy); X = quantitative variable[9] and D = dummy variable.[10]

IV

RESULTS AND DISCUSSION

In the DVC command area *kharif* and *boro* paddy are the main crops in the monsoon and summer season respectively and in winter potato is the main crop. In this section we have tried to examine the spatial effect on productivity of crops across the plots in HR, MR and TE segments of the DVC canal (inter-segment variation) and also find out if there are any variations in productivity of crops in respect of land situated before a particular lock-gate and after the lock-gate in each segment separately of canal network in different seasons (intra-segment variation). Further, we have sought to identify the factors behind such variations in the DVC command area.

4.1 *Monsoon Paddy Productivity Variation in the Study Area*

In the DVC command area during monsoon or *kharif* season, 85 per cent of land is used to produce paddy with HYV seeds and in rest of the area traditional varieties of seed are used (DVCADA, 2010-11). We have observed from our field study that in the HR and MR area of DVC, all selected plots are used for paddy cultivation in this season but in the TE area about 90 per cent of land is used to produce paddy and remaining 10 per cent of land is used for cultivation of vegetables [parval (*potol*), lady’s finger, etc.]. Further, in the HR area apart from production of HYV paddy, some high-valued traditional varieties of paddy (such as *Khash Dhan* or *Gobindo Bhog* rice) are cultivated.

4.1.1 *Inter-Segments Monsoon Paddy Productivity Variation*

From our empirical study we have found that the average monsoon paddy productivity **(**MPP) in HR area is greater than MR area which in turn, is greater than TE area (HR>MR>TE).[11] Further, this result has been found to be statistically significant in terms of Fisher’s-‘t’ test statistics. Having identified the differences in productivity, the study seeks to identify factors behind such variations. For this we have used multiple linear regression (model-1) by using 14 variables and the result of regression analysis is presented in Table 1.

TABLE 1. RESULTS OF THE LINEAR MULTIPLE REGRESSION MODEL OF INTER-SEGMENTS MPP

	Regression coefficients value			
		Inter-segments		
Explanatory variables	All segments	HR	MR	TE
(1)	(2)	(3)	(4)	(5)
Percentage of family income from agriculture (X^{FIA})	0.04*	0.003	0.04**	0.07*
	(0.008)	(0.015)	(0.016)	(0.02)
Loan amount for monsoon paddy cultivation (X^{LAM})	0.014**	0.02*	-	-
	(0. 007)	(0.006)		
Cultivated land area total (X^{CLT})	-0.001	-0.001	-0.0001	-0.004
	(0. 001)	(0.002)	(0.002)	(0.003)
Category of cultivated land (D^{CCL})	2.02*	2.66*	1.64***	0.57
	(0.43)	(0.57)	(0.84)	(0.97)
Soil types (D^{ST})	-4.49*	-	-4.28*	-
	(0.65)		(0.77)	
location of plot in respect of HR segment of the canal (D^{LCH})	1.5**	-	-	-
	(0.75)			
location of plot in respect of TE segment of the canal (D^{LCT})	-4.32*	-	-	-
	(1.06)			
Seed types (D^{SED})	3.31*	3.17*	4.68*	1.59**
	(0.46)	(0.90)	(0.77)	(0.82)
Technique of paddy cultivation SRI (D^{TC-SRI})	13.46*	-	-	14.27*
	(1.38)			(1.85)
Technique of paddy cultivation BR (D^{TC-BR})	5.52*	-	-	4.81*
	(0. 75)			(0.95)
Fertilisers cost (X^{FC})	-0.001	0.01	-0.03	-0.01
	(0.03)	(0.04)	(0.10)	(0.04)
Pesticides cost (X^{PC})	0.03	0.03	0.08	-0.05
	(0.04)	(0.05)	(0.09)	(0.1)
Labour cost (X^{LC})	0.005	0.008	-0.003	-0.004
	(0.01)	(0.01)	(0.025)	(0.02)
Other costs (X^{OC})	0.01	-0.05	0.02	0.05
	(0.04)	(0.07)	(0.06)	(0.06)
Constant	32.31*	36.10*	32.52*	25.68*
	(2.49)	(2.90)	(7.40)	(4.20)
R^2	0.75	0.40	0.63	0.74
Adj R^2	0.73	0.33	0.59	0.70
F-value	51.87*	5.95*	14.92*	19.71*
Observation	261	90	90	81
Irrigation cost (X^{IC}) #	-0.54*	-1.26**	-0.93**	0.91*
	(0.09)	(0.49)	(0.48)	(0.19)

Source: Own calculation based on field survey data.

Note: Here (-) means no change of the respective value of variable in the respective area. *, ** and *** indicate 1, 5 and 10 per cent level of significance, respectively and values in parentheses are corresponding standard errors.

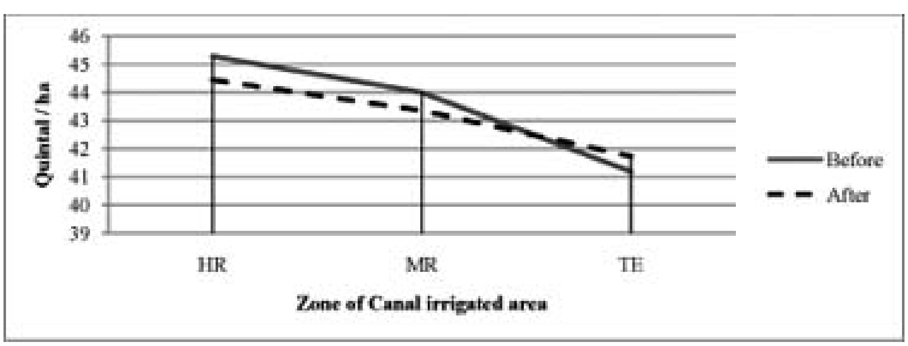
Irrigation cost is correlated with some factors in this model for which we have dropped it as an explanatory variable in model-1. But it is an important factor for inter-segment MPP analysis as revealed from the result of single linear regression model (last row of the above table), where monsoon paddy productivity (kg/*katha*) is dependent variable and irrigation cost is independent variable.

It is observed (Table 1) that both regression coefficients of ‘location of plot in respect of HR segment of the canal’ are significantly positive and ‘location of plot in respect of TE segment of the canal’ is significantly negative. This means that monsoon paddy productivity is higher in the plots of the HR area as compared to that in TE area because of their respective locations vis-à-vis canal. We had got similar result using Fisher's-'t' test statistics. Thus there exists significant spatial effect of canal irrigation on monsoon paddy productivity in our area of study.

Further Table 1 also reveals that monsoon paddy productivity (MPP) is relatively high in the HR area due to higher credit facility, convenient land structure[12] and use of higher percentage of HYV seed (all are statistically significant). Other factors having positive impacts are prevalence of sticky soil and proper irrigation facilities. While for the MR area there are two positively and one negatively significant factor, viz, 'percentage of family income from agriculture' and 'seed type' have impacted positively while soil type has impacted negatively. Further, unavailability of canal water in need has impacted negatively on productivity in the MR area.[13] In the TE area MPP is the lowest because of more use of traditional varieties of seed (thus lower use of HYV seed) as the area is prone to flood, structure of cultivated land, unavailability of canal water in need, soil type (loamy) and excess use of pesticide. However, dependence of family members on agriculture and techniques of cultivation have positive impact on MPP in the TE area as revealed in Table 1. The higher dependence of family member on agriculture means less use of hired labour and family labour tend to adopt more efficient *bhanga-rowa* cultivation technique.

4.1.2 *Intra-Segment Monsoon Paddy Productivity*

From our study in the DVC command area we have observed that variations in monsoon paddy productivity not only exist across different segments (HR, MR and TE) but this variation also exists in between the plots which are situated before and after lock-gate regions in each segment of the DVC canal networks, which is clearly revealed in Figure 2. In fact, monsoon paddy productivity in the before-lock-gate areas of the HR and MR segments of the canal are higher than corresponding productivities in the after-lock gate areas. However, in the TE segment of the canal we observe role reversal, i.e., MPP in the plots of the after-lock-gate (ALG) region is higher than the same in the before-lock-gate (BLG) areas.



Source: Field survey.

Figure 2. Average Monsoon Paddy Productivity Variation at Before and After Lock-Gate Regions.

The results from the Fisher's-'t' test statistics indicated that in the HR and MR areas before and after lock-gate variation is significant in respect of average monsoon paddy productivity. While in the TE area, before and after lock-gate variation of average monsoon paddy productivity that we had observed in Figure 2 is statistically insignificant. The single linear regression model to explain productivity variations of land in respect of its position vis-à-vis corresponding lock gates in each segments has been found to be statistically significant.[14] This means that monsoon paddy productivity is relatively higher in the plots which are situated in the BLG region compared to the plots in ALG region. We had got similar result using Fisher's-'t' test. Let us now identify region-wise reasons for this variation. For this we have used a multiple linear regression model-2 by using seven variables and result of regression analysis is presented in Table 2.

TABLE 2. RESULTS OF THE LINEAR MULTIPLE REGRESSION MODEL OF INTRA-SEGMENT MPP

Explanatory variables	Regression coefficients value						
	All segments	Intra-segment					
		Head reach (HR)		Middle reach (MR)		Tail-end (TE)	
		BLG	ALG	BLG	ALG	BLG	ALG
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
X^{AFMP}	1.43**	0.11	1.56**	2.38*	1.96***	1.01	1.75
	(0.58)	(0.85)	(0.70)	(0.53)	(1.11)	(1.08)	(2.39)
X^{DH}	-0.30	-0.80	-1.29	-0.66*	-0.56	-1.31***	-0.35
	(0.30)	(0.49)	(0.70)	(0.19)	(0.63)	(0.77)	(0.64)
D^{CCL}	1.07***	1.19***	1.85***	0.42	0.28	-0.52	-1.46
	(0.59)	(0.71)	(0.80)	(0.54)	(1.08)	(1.48)	(1.62)
D^{SET}	2.95*	2.42**	-1.19	2.26*	5.11*	2.10**	4.97*
	(0.59)	(1.03)	(0.85)	(0.66)	(1.09)	(1.06)	(1.53)
$D^{TC\text{-}SRI}$	7.67*	-	-	-	-	8.39*	10.92*
	(1.52)					(2.03)	(2.38)
$D^{TC\text{-}BR}$	1.62***	-	-	-	-	1.09	5.48*
	(0.94)					(1.58)	(1.75)
X^{IC}	-0.75*	-0.84**	-0.58	-0.90**	0.79**	-0.10	0.01
	(0.07)	(0.40)	(0.57)	(0.46)	(0.31)	(0.12)	(0.19)
Constant	37.72*	43.20*	46.32*	38.58*	26.08*	31.06*	27.8*
	(0.95)	(1.81)	(2.13)	(1.71)	(2.07)	(2.04)	(4.12)
R^2	0.44	0.46	0.47	0.67	0.54	0.58	0.71
Adj R^2	0.43	0.40	0.41	0.62	0.48	0.49	0.64
F value	28.71*	6.78*	7.05*	15.60*	9.15*	6.97*	10.31*
Obs.	261	45	45	45	45	44	37
X^{DC} #	-0.006*	-0.04*	-0.03**	-0.04*	-0.01*	0.003	0.004
	(0.001)	(0.01)	(0.01)	(0.01)	(0.001)	(0.002)	(0.003)

Source: as in Table 1.

X^{DC} = distance of cultivated land from canal is correlated with category of cultivated land (D^{CCL}) and Irrigation cost (X^{IC}) for which we have dropped it from model-2. However, it is an important factor for intra-segment MPP analysis as revealed from the result of single linear regression model (last row of the above table), where monsoon paddy productivity (kg/*katha*) is dependent variable and X^{DC} is independent variable.

In the HR area, average MPP variation between before and after lock-gate is very high as compared to the other two segments. In the BLG region MPP is very high compared to the ALG region due to three major significant factors which are category of cultivated land or land structure, irrigation cost and type of seed used. The land structure in the BLG region is such that they are situated in the upland area compared to the plots in ALG region because of natural gradient of land around the course of the canal. When there is excess water in the BLG region either because of canal water or precipitation in the monsoon season, farmers can drain excess water on to the ALG region through field channel or by any other drainage system. As a result plots in the ALG region gets affected by this excess water in the monsoon season. In fact, excess water in the cultivated land reduces paddy productivity because it rots the plant roots, reduces efficiency of fertiliser used and attracts insects. In order to avoid these problems farmers in the ALG region uses local seeds which have higher resistance power and thus they have greater chance to survive in the existing situation but they are less productive [regression coefficient value of seed types (D^{SET}) in the BLG and ALG region is 2.42** and -1.19, respectively]. Thus, ultimately monsoon paddy productivity in the ALG region is lower than BLG region in the HR area.

In the MR area we have found similar result as in HR area in between before and after lock-gate regions in respect of MPP, but reasons are not same. Farmers in the BLG region in MR area are more dependent on agriculture compared to ALG region.[15] Similarly participation of adult family members in agriculture in the BLG region is higher than ALG region (β_1 value of BLG is 2.38 and ALG is 1.96). Further, average distance of cultivated land from home in the BLG region is lower than ALG region because BLG region is more fertile and cropping intensity is higher than ALG region for which β_3 is negative and significant in the BLG region but in the ALG region it is insignificant (Gao *et al*. 2012, also obtained the negative relationship between distance of home from cultivated land with farm productivity). On the other hand, canal water availability in the ALG region is relatively lower compared to BLG region due to structural reason (water has to travel longer distance with lower velocity to reach plots in the ALG region). Since water availability in the BLG region is sufficient and regular, we have found that 82 per cent of the farmers had adopted HYV technique while in the ALG region only 49 per cent of the farmers have used HYV technique due to uneven canal water availability. It may be noted that irrigation cost is positively correlated with MPP in the ALG region but negatively in the BLG region, this proves that canal water availability in the ALG region is worse than BLG region.

In the TE area we observe opposite result, i.e., average MPP is relatively higher in the ALG region compared to that in BLG region. However, this variation is very low and statistically insignificant in terms of Fisher's-'t' test statistics. The reason for this may be found in the techniques of cultivation adopted in the region. Three techniques are generally used for cultivation in the region under consideration: Traditional (seed bed preparation and transplanting of sampling); System of Rice Intensification (SRI) and *bhanga roya* (process of twice re-plantation of paddy sapling) or 'BR'. In the HR and MR segments only traditional techniques of plantation is used. But in the TE segment the remaining two modern techniques (SRI and BR) are generally used either to cope with scarcity of water or to save plants from excess water respectively. It may be noted here that in the ALG region both this factors (D^{SRI} and D^{BR}) have relatively larger and positive impacts on MPP (statistically significant) compared to the BLG region (Table 2, last two columns).[16]

4.2 *Boro Paddy Productivity (BPP) Variation in the DVC Command Area in the Summer Season*

In the DVC command area *boro* paddy is the main crop during summer and HYV seeds are used for *boro* cultivation. We have observed from our field study that about 98 per cent of the selected plots are used for paddy cultivation in HR segment while 90 per cent plots in the MR segment and only 39 per cent in the TE segment are used for paddy cultivation.[17]

4.2.1 *Inter-Segments Boro Paddy Productivity Variation Analysis*

From our study we have found that average *boro* paddy productivity (BPP) is about 48 quintal per hectare in HR segment; it is about 45 and 41 quintal per hectare in MR and TE segments, respectively. Thus there exists variations in BPP which are also statistically significant in terms of Fisher's-'t' test statistics. Similar result has been found by Government of India (2003) and Hussain (2004). However, Mony (1995) has found that paddy productivity is higher in the MR area followed by HR and TE areas. Having identified the differences in productivity the study tries to identify factors behind such variations. For this we have used multiple linear regression model-1 and the result of regression analysis is presented in Table 3.

Our regression analysis clearly reveals that the location of plot in respect of canal course plays significant role in determining productivity of *boro* paddy as well as its variation across different locations. From Table 3 we observe that regression coefficient of 'location of plot in respect of HR segment of the canal' is positive and statistically significant and 'location of plot in respect of TE segment of the canal' is negative but statistically significant. This means that *boro* paddy productivity is higher in the plots of the HR area compared to that in TE area because of their respective locations vis-à-vis canal. Thus there exists significant spatial effect of canal irrigation on *boro* paddy productivity in our area of study.

The findings further revealed that dependence (for earning) of cultivators on agriculture, category of cultivated land, irrigation cost, cost on fertiliser and seed emerged as significant explanatory variables for higher productivity in the HR segment while cost of irrigation and pesticides have negative impact on its productivity. In the HR area the value of the regression coefficient of farmers' dependence on agriculture is relatively lower than in the other two segments which imply that it is not a very important factor behind higher productivity in the HR area. However, category of cultivated land is one of the important and significant factors contributing to higher BPP in the HR area coupled with sufficient availability of canal water, favourabe soil type (sticky), higher use of HYV seeds (98 per cent) and fertiliser. Singh (1972) and Mellor (1976) have showed that use of HYV seeds and fertiliser consumption are highly correlated. The use of HYV seeds, availability of canal water and good soil quality compel farmers of the HR areas to use comparatively higher dose of fertiliser and this results in higher productivity.

TABLE 3. RESULT OF THE LINEAR MULTIPLE REGRESSION MODEL OF INTER-SEGMENTS OF BPP

	Regression coefficients value			
		Inter-segments		
Explanatory variables (1)	All segments (2)	Head reach (HR) (3)	Middle reach (MR) (4)	Tail-end (TE) (5)
Percentage of family income from agriculture (X^{FIA})	0.06* (0.01)	0.04** (0.02)	0.07* (0.02)	0.05** (0.01)
Category of cultivated land (D^{CCL})	4.01* (0.54)	5.19* (0.77)	3.94* (0.96)	$
Soil types (D^{ST})	-1.54*** (0.85)	-	-1.38*** (0.84)	-
Plot position with reference to a lock-gate (D^{LG})	4.71* (0.58)	3.76* (1.00)	6.55* (0.89)	1.71 (1.12)
Location of plot in canal HR (D^{LCH})	5.25* (0.92)	-	-	-
Location of plot in canal TE (D^{LCT})	-3.36*** (2.09)	-	-	-
Technique of paddy cultivation SRI ($D^{TC\text{-}SRI}$)	12.12* (1.50)	-	-	11.04* (1.47)
Seed cost (X^{SC})	0.34** (0.12)	0.03 (0.24)	0.31*** (0.16)	1.04* (0.25)
Fertilisers cost (X^{FC})	0.04 (0.03)	0.1** (0.05)	0.16*** (0.09)	-0.15** (0.05)
Pesticides cost (X^{PC})	-0.05 (0.05)	-0.13** (0.06)	0.06 (0.10)	-0.26 (0.23)
Labour Cost (X^{LC})	0.02*** (0.01)	0.03 (0.02)	0.03 (0.03)	0.06** (0.03)
Other cost (X^{OC})	0.05 (0.04)	0.03 (0.06)	0.09 (0.06)	-0.11 (0.12)
Constant	20.72* (3.44)	27.90* (4.09)	11.08 (8.64)	23.85* (4.59)
R^2	0.74	0.66	0.74	0.85
Adj R^2	0.73	0.62	0.71	0.82
F value	45.53*	18.80*	22.61*	19.79*
Observation	204	88	81	35
Irrigation cost (X^{IC}) #	-0.50* (0.06)	-2.36* (0.52)	-1.44* (0.23)	0.59** (0.28)

Source: as in Table 1.

Irrigation cost is correlated with some factors in this model for which we have dropped it as an explanatory variable in model-1. But it is an important factor for inter-segment BPP analysis as revealed from the result of single linear regression model (last row of the above table), where *boro* paddy productivity (kg/*katha*) is dependent variable and irrigation cost is independent variable. $ We have dropped D^{CCL} due to negative value of Adj R^2.

In the summer season, DVC uses rotational method for canal water distribution.[18] There is always uncertainty about availability of canal water[19] for *boro* paddy cultivation for which DVC authorities earmark the available water for its use in the selected area of DVC. It is to be noted here that whatever be the procedure that DVC authority adopts for fair distribution of canal water in the command area, farmers of HR and MR areas always manage to extract their water at the cost of farmers in TE area even though they are not entitled to. This fact has also been corroborated by Wade (1976) and Jairath (1985).

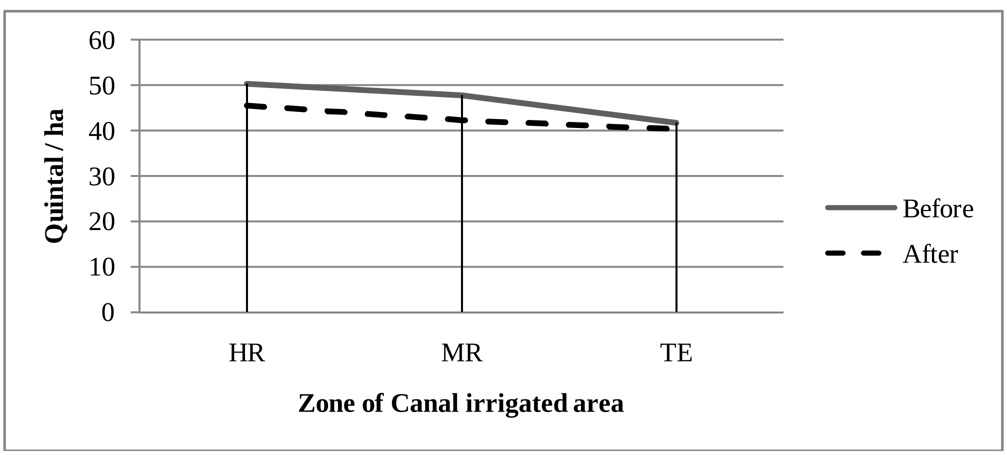
From our study we have observed that regression coefficient of irrigation cost is negative in the HR and MR areas but positive in the TE area (last row of Table-3) which seem to be very interesting. Canal water for irrigation is the source of low cost irrigation. Higher cost on irrigation implies inadequate supply of canal water and tapping of alternative sources like underground water which is costlier. We know that due to their locational advantage farmers in the HR and MR areas use seed and technique of production which are suitable with assured and sufficient water. The shares of irrigation cost in the HR, MR and TE area have been found to be 2 per cent, 3 per cent and 13 per cent respectively in our study area. Thus, higher cost of irrigation actually reflects inefficiency of canal irrigation. This explains negative association between BPP and cost on irrigation at the HR and MR areas. However, in the TE area this association is positive because canal water availability in this area as well as during this season has always been uncertain, uneven and very low in comparison with that in HR and MR areas. Therefore, farmers in the TE area depend on underground or other sources of irrigation which raised its share in total cost component. Thus, those farmers who spend less on other sources of irrigation and totally depend on canal irrigation have lower BPP and to raise BPP the cost on irrigation has to increase in this segment of the canal net work. Further, some farmers (20 per cent) in the TE area use SRI technique because it is a less water intensive paddy cultivation process and more productive compared to traditional technique.

The category of cultivated land (D^{CCL}) is another important factor explaining variations in BPP across different areas with reference to canal network. It is well known that for paddy production plots of land that can retain water for longer period of time are more conducive than the others. Standing water in the plot is one of the necessary requirements for paddy plant growth. Thus plots of land in the low lying area (TE) should be more productive. However, in our study we have found that plots of land situated above the low lying areas in the HR and MR segments are more productive than the plots situated in their respective low lying areas and also the plots in the TE area defying expected behaviour. This indicates that farmers in the HR and MR areas store excess water in their plots and allow less water to flow downwards and thereby deprive TE farmers. This is one of the important causes for wastage of canal water and tail-end deprivation or uneven distribution of canal water between HR and TE areas. Dhawan (1989), Shah (2003), Gulati, *et al*. (1994) and Wade (1975) also reached similar conclusions in their respective studies.

From our regression analysis (Table 3) we have observed that regression coefficient of fertiliser cost is positive in HR (0.1**) and MR (0.16***) areas but it is negative in the TE area (-0.15**). In the TE area impact of fertiliser cost is negative because (a) most of the plots (69 per cent) are used to cultivate *boro* paddy after potato production and there is a tendency to apply less fertiliser[20] while the farmers apply relatively higher amount of fertiliser in those plots which are used only for paddy cultivation (both *kharif* and *boro*) but BPP is relatively low due to the uncertainty of canal water availability; (b) further, about one-third plots in the TE area *boro* paddy is cultivated using SRI technique which requires less fertiliser (Spandana, 2006). It is also to be noted that productivity of SRI is relatively higher than traditional technique.

4.2.2 *Intra-Segment Boro Paddy Productivity Variation*

Similar to what we had found in respect of monsoon paddy productivity variation, we observe that variations in productivity of *boro* paddy not only exist across different segments (HR, MR and TE); it also exists in between before and after lock-gate regions in each segment of the DVC canal networks, which is clearly revealed in Figure 3. However, our Fisher's-'t' test statistics reveal that these productivity variations are significant only in case of HR and MR areas.



Source: Primary Survey.

Figure 3. Average *Boro* Paddy Productivity Variation at Before and After Lock-Gate Regions.

It can be observed (Table 3) that the values of regression coefficients of 'plot position with reference to a lock-gate' are positive and statistically significant in HR and MR regions. This means that productivity of *boro* paddy is relatively high in the plots which are situated in the BLG region compared to those in ALG region. However this variation is not statistically significant in the TE area. Having identified differences in productivity, we would like to identify factors behind such variations.

For this we have constructed multiple linear regression model-2 the result of which is presented in Table 4.

TABLE 4. RESULT OF THE LINEAR MULTIPLE REGRESSION MODEL OF INTRA-SEGMENTS BPP

Explanatory variables	Regression coefficients value						
	All segments	Intra-segments					
		Head reach		Middle reach		Tail-end	
		BLG	ALG	BLG	ALG	BLG	ALG
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
X^{AFMP}	4.59*	4.70*	4.67*	5.06*	3.99*	1.88	2.66***
	(0.79)	(1.40)	(1.15)	(1.65)	(1.00)	(3.48)	(1.04)
X^{DH}	-0.72	-1.45**	-1.91**	-0.01	-0.87	-7.92***	-0.05
	(0.49)	(0.55)	(0.91)	(1.10)	(0.97)	(3.99)	(0.79)
X^{CLT}	-0.005**	-0.003	0.0001	0.0007	0.003	¥	#
	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)		
D^{CCL}	4.14*	2.78*	5.71*	3.88	3.03*	$	¥
	(0.68)	(0.54)	(0.96)	(1.27)	(0.89)		
$D^{TC\text{-}SRI}$	12.15*	-	-	-	-	8.16**	15.21*
	(1.85)					(3.35)	(1.46)
X^{IC}	-0.60*	-2.48*	0.71	-1.21	0.46**	0.54**	-0.23***
	(0.06)	(0.66)	(0.72)	(0.74)	(0.23)	(0.22)	(0.16)
Constant	37.68*	51.94*	32.05*	42.83*	24.25*	23.96*	29.34*
	(1.35)	(2.79)	(2.89)	(5.80)	(3.26)	(6.37)	(3.70)
R^2	0.60	0.69	0.75	0.53	0.64	0.62	0.94
Adj R^2	0.59	0.65	0.72	0.47	0.58	0.52	0.92
F value	48.60*	16.44*	23.43*	8.32*	11.15*	5.53*	48.01*
Observation	204	43	45	43	38	18	17
X^{DC} @	-0.01**	-0.05*	-0.08*	-0.002***	-0.09**	-0.007	0.014
	(0.001)	(0.02)	(0.02)	(0.001)	(0.02)	(0.006)	(0.01)

Source: as in Table 1.

We have dropped this variable because it is positively correlated with SRI technique of paddy cultivation (0.6) and participation of adult family member in agriculture (0.51). $ We have dropped this variable because it is negatively correlated (-0.50) with participation of adult family member in agriculture. ¥ implies Adj R^2 is negative. @ X^{DC} = distance of cultivated land from canal is correlated with category of cultivated land (D^{CCL}) [negatively] and Irrigation cost (X^{IC}) [positively] in each segment for which we have dropped it from model-2. However, it is an important factor for intra-segment BPP analysis as revealed from the result of single linear regression model (last row of the above table), where monsoon paddy productivity (Kg/*katha*) is dependent variable and X^{DC} is independent variable.

In the before-lock-gate (BLG) region of the HR area BPP is higher than after-lock-gate (ALG) region due to four important factors which are ‘participation of adult family member in agriculture’, ‘distance of cultivated land from home’, ‘category of cultivated land or plot’ and ‘irrigation cost or irrigation efficiency’. The impact of participation of adult family member in agriculture on BPP is positive and significant as well as relatively higher in the BLG region compared to the ALG region, while the impact of distance of cultivated land from home on BPP is negative and significant but this impact is relatively lower in the BLG region than ALG region. We have already explained that irrigation cost may be taken as a proxy of canal irrigation efficiency. From our study it is observed that regression coefficient of irrigation cost in the BLG region is negative, but in the ALG region it is positive for both HR and MR areas. This implies BLG region is better than ALG region in terms of irrigation efficiency. The irrigation efficiency variation has been observed between these two regions due to the variation of channel network structure in the HR area as well as in the MR and TE areas.[21] Thus, ultimately *boro* paddy productivity in the ALG region is lower than BLG region in the HR area.

In the MR area also we observe variation in BPP between BLG and ALG regions and reasons are quite similar. Farmers in the BLG region are much more dependent on agriculture compared to ALG region. Similarly participation of adult family members in agriculture in the BLG region is higher than ALG region. And average distance of cultivated land from home in the BLG region is lower than ALG region. On the other hand, canal water availability in the ALG region is relatively low compared to BLG region. Further, negative impact of distance of cultivated land from canal on BPP is lower in the BLG region than ALG region (-0.002 and -0.09, respectively). The regression coefficient of irrigation cost of BLG region is negative but positive in the ALG region (-1.21 and 0.46*, respectively). This means that in the BLG region farmers fully depend on canal irrigation but when there is shortage of canal water they are compelled to tap other sources. Thus, due to the shortage of canal water and use of alternative sources of irrigation leads to lowering of BPP in the BLG region. While in the ALG region, farmers have knowledge about the scarcity of canal water in the summer season for which about 43 per cent of plot owners depend on both canal and well irrigation permanently. That's why regression coefficient of irrigation cost in the ALG region is positive and statistically significant. We have observed that in the TE area BPP variation between before and after lock-gate is positive but statistically insignificant. The reasons may be found in (a) greater participation of adult family member in agriculture in the ALG region in comparison with BLG region (regression coefficient 2.66 > 1.88) and (b) The regression coefficient value of distance of cultivated land from canal is negative in the BLG region (-0.007) while in the ALG region this value is positive (0.014). This means that the plot which is far away from canal has lower BPP in the BLG region while we find opposite picture in the ALG region because most of the farmers in the ALG region remain prepared with alternative source of irrigation and naturally BPP does not fluctuate as in the BLG region. (c) Canal water availability in the BLG region is relatively better than ALG region for which BPP in the BLG region is better than ALG region.[22] (d) Technique of cultivation (SRI) is an important factor which might have reduced the gap of BPP variation between BLG and ALG in the TE area. Canal water availability in the BLG region is relatively higher than ALG region for which 29 per cent farmers in the ALG region has adopted SRI technique (16 per cent in BLG region) since it required less water but productivity is relatively higher than traditional technique. Thus, in the ALG region of the TE area positive effect of SRI technique and participation of adult family members in cultivation make variations in BPP in between ALG and BLG insignificant.

4.3 *Potato Productivity Variation in the DVC Command Area in the Winter Season*

In the winter season potato, mustard and wheat are the main crops in the DVC command area. In this season about 70 per cent area is used to cultivate potato, 25 per cent is used for mustard and the rest is used for wheat and vegetable (DVCADA, 2010-11). About 70 per cent of plots remained unutilised in the HR area during this season and only 1 per cent of total plots are used to produce potato. In the MR area about 44 per cent plots are used to produce potato, and about 40 per cent plots remain unutilised and the rest are used to cultivate mustard, wheat, vegetables, etc. But in the TE area about 82 per cent of plots are used to produce potato, 1 per cent for mustard cultivation while the remaining plots are used for production of vegetables. Since potato is not a significant crop in the HR area we have dropped this area from our analysis and considered only two segments viz., MR and TE areas.

4.3.1 *Inter-Segment Variation of Productivity*

We have observed from our primary survey that there exists distinct variation in potato productivity in respect of the MR and TE segments of the DVC canal. While average potato productivity is about 200 quintals per hectare in MR segment, it is about 265 quintal per hectare in TE segment and this variation has also been found to be statistically significant. The regression model-1to identify factors behind such variation clearly shows spatial impact of canal irrigation on productivity (Table 5). The regression coefficient of 'location of plot in canal TE' is not only positive (19.75) but also significant at 1 per cent level. This means that potato productivity is higher in the TE area compared to the MR area because of the former's location in respect of the canal network. Other important factors which explain variation of potato productivity (PP) in between MR and TE areas are dependence of household on agriculture, category of cultivated land, soil and seed types. In Section 4.2, we have observed that dependence of household in agriculture in the TE area is relatively higher than MR area for which this variable creates positive (significant) impact on potato productivity in the TE area. In the TE area entire soil is loamy type which is favourable for potato production. Thus, upland category of land coupled with loamy soil have led to enhanced potato productivity in this area while in MR area there are both types of soil (loamy and sticky) in 6:4 ratio.

From our previous analysis we have observed that in the TE area both monsoon and *boro* paddy productivities are very low compared to that in HR and MR areas for which farmers in this area always cultivate potato to earn profit. Therefore, farmers of the TE area use better quality of potato seed (HYV types) compared to the farmers of MR area which is another factor explaining higher potato productivity in the TE area. It is to be noted that DVC authority only release canal water for Lower Damodar Irrigation (LDI) Division or for the TE area during this season. But farmers in the

TABLE 5. RESULT OF THE LINEAR MULTIPLE REGRESSION MODEL OF INTER-SEGMENTS PP

Explanatory variables	Regression coefficients value		
		Inter-segments	
	All segments	Middle reach (MR)	Tail-end (TE)
(1)	(2)	(3)	(4)
Percentage of family income from agriculture (X^{FIA})	0.18*	0.07	0.22**
	(0.07)	(0.10)	(0.09)
Distance of cultivated land from home (X^{DH})	-2.30	-11.52**	3.19
	(4.62)	(5.75)	(7.15)
Cultivated land area total (X^{CLT})	-0.002	-0.01	-0.01
	(0.01)	(0.01)	(0.02)
Category of cultivated land (D^{CCL})	18.48*	2.87	20.42*
	(6.09)	(17.41)	(7.26)
Soil types (D^{ST})	23.04*	24.58*	-
	(7.1)	(5.80)	
Location of plot in canal TE (D^{LCT}) @	19.75*	-	-
	(6.27)		
Plot position with reference to a lock-gate (D^{LG})	5.79	5.83	5.85
	(5.36)	(8.50)	(7.32)
Seed type (D^{SET})	12.01**	5.04	11.59***
	(5.89)	(6.90)	(8.88)
Canal water availability (X^{CWA}) $	-0.07	0.07	-0.15
	(1.00)	(0.14)	(0.15)
Total cost except irrigation (X^{TCEI}) #	0.003	0.13***	0.001
	(0.03)	(0.08)	(0.04)
Constant	128.74*	61.62	170.14*
	(27.45)	(68.46)	(35.63)
R^2	0.36	0.60	0.20
Adj R^2	0.31	0.49	0.11
F value	6.00*	5.20*	2.08**
Observation	114	40	74

Source: as in Table-1. Note: potato productivity (Y^{PP}) kg/*katha* is dependent variable.

$ Per cent of required irrigation water drawn from canal during the period of potato cultivation. @ Location of plot in respect of canal has two categories: MR and TE area. Dummy variable D^{LCT} = 1 for TE and 0 for MR. # We have merged costs on seed, fertiliser, pesticides, labour and other cost to obtain this variable to avoid high multicollinearity problem with seed type, soil type, category of cultivated land and location of canal. Further, plot position in respect of lock-gate is highly correlated with irrigation cost in this model.

MR area taking advantage of their geographical position vis-à-vis irrigation canal illegally withdraw large amount of canal water following 'power theory of canal water distribution' (Viswanathan, 2001) for which canal water availability in the TE area is relatively low than in MR area. That's why regression coefficient of canal water availability is positive in the MR area and negative in the TE area.

4.3.2 *Intra-Segment Potato Productivity Variation*

We have found from our field survey that average potato productivity in the before and after lock-gate regions are about 203 and 199 quintals per hectare respectively in the MR area while in the TE area these figures are 267 and 264 quintal per hectare. This implies variations in potato productivity between before and after lock-gate region is negligible in both MR and TE areas. Fisher's-'t' test statistics for the equality of two mean (average productivity of potato in BLG and ALG regions) for both MR and TE segments suggest statistically insignificant variations. Therefore, it may be presumed that there does not exist much difference in productivity in between BLG and ALG regions. This may be due to the fact that potato is a commercial crop and cultivating farmers of the either side of the lock-gate remain prepared with alternative sources of irrigation to protect themselves from uncertainties of canal water and potato crop needs less water compared to paddy.

V

CONCLUDING OBSERVATIONS

The study intended to find out empirically spatial effects of canal irrigation on productivity of major crops in the areas served by a canal network. For the purpose of our analysis we had divided the entire canal course into three segments: HR, MR and TE following established procedure. So our research question had been to find out if there has been any variation of productivity of major crops across different segments of the main canal. Further, for the purpose of regulation and distribution of canal water in the command area many lock gates are constructed at different points of the canal network. We have also tried to capture if the location of cultivable land vis-à-vis canal lock gate situated at different segments (HR, MR and TE) has any influence on the productivity in the respective areas or, if there exists any intra-segment variation of productivity of crops because of location of the land with reference to a particular lock-gate. Based on empirical study in the DVC command area we may conclude that there exists significant spatial effect of canal irrigation on the productivity of major crops across different segments of the canal course. The location of land has been found to explain productivity variation of major crops both at the inter-segment and intra-segment levels. Thus, average productivity of monsoon and summer paddy has been found to be the highest in the HR area followed by MR and TE areas. Similarly average productivity in BLG areas has been found to be greater than ALG areas. In case of potato, however, because of the nature of the crop spatial effect has led to higher average productivity in TE area compared to MR area.

Our study has also revealed existence of both inter-segment and intra-segment variations in respect of size of operational holding, farmers' dependence on agriculture, cropping intensity, crop diversification and market structure. Many factors are responsible for these variations but canal water availability is one of the important factors among these. Some studies identified the problems of water availability in the tail end area of a canal network (command area) only, but they did not look into intra-segment inequality in canal water distribution with reference to a lock-gate (irrespective of it being at the head reach (HR), middle reach (MR) or at the tail-end (TE) areas). Involvement of *gram panchayats* in the canal water distribution may be useful to solve this problem. There is also need for maintenance and proper management of the canal network and lock-gates to stop illegal canal water withdrawal from its head reach and middle reach segments and to reduce variation of canal water availability in the plots which are situated before and after a particular lock-gate. Finally, there is an urgent need for renovation of the existing canal network which has become worn out. The field channel network may be extended and these may be made of concrete to reduce seepage loss and increase the flow of canal water.

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NOTES

1. Lock-gate in the canal network is generally used to regulate and distribute canal water to the respective command area for better management. It helps to augment water level before the lock gate when it remains closed and helps to irrigate adjacent areas while there will be less water in the after lock gate course of the canal during the period the concerned lock gate remained closed.
2. This division has been made on the basis of water availability and physical structure of canal network. This follows the procedure adopted by a study conducted by the Indian Institute of Management, Calcutta (2008) in the DVC canal network. They have also divided the entire canal network in the same way. The executive Engineer of Damodar Head works Division had also suggested these divisions.
3. This has been done so as to observe the impact of Lock-gates in respect of efficiency of canal irrigation.
4. It may be noted here that since our unit of survey is plot of land, same land owner had the possibility of owning more than one plot in our selected sample. Therefore, number of household is less than number of selected plots.
5. In this period climate condition was in a normal situation compared to last 10 years rainfall status in the DVC project area.
6. We cannot apply Cobb-Douglas production function since zero value of any variable would make the entire function zero for the concerned observation. Similarly, Log-linear, Lin-log, log-reciprocal and reciprocal models are also not applicable because of the use of dummy variables. The result of log-lin model is less satisfactory compared to linear models in terms of R2, Adj R2, and F values. Therefore, we have applied multiple linear regression models.
7. The exogenous variables are: percentage of family income from agriculture, work participation of adult family member in agriculture, amount of agricultural loan, distance of cultivated land from canal, distance from home, category of cultivated land, total land holding size, soil types, plot position in respect of the lock-gate, plot position in respect of location of canal, technique of paddy cultivation [systems of rice intensification (SRI), *bhangha rowa* system or 2nd time sapling re-plantation (BR) and traditional system of paddy cultivation], canal water availability, seed types, cost of seed, fertiliser, pesticides, labour, irrigation and others.
8. Number of observations in our study

	Model-1				Model-2						
	All segments	HR	MR	TE	All segments	HR		MR		TE	
						BLG	ALG	BLG	ALG	BLG	ALG
Monsoon paddy	261	90	90	81	261	45	45	45	45	44	37
Boro paddy	204	88	81	35	204	43	45	43	38	18	17
Potato	114	*	40	74	#						

*Potato production in the HR area is almost zero. # Fisher-t test revealed insignificant variations of productivity of potato in respect of before lock gate (BLG) and after lock gate (ALG) regions in all segments of the canal network and thus we have not considered it in model-2.

9. XAFMP = number of adult family members participated in agriculture, XFIA = percentage of family income from agriculture, XDC = distance of cultivated land from canal (meters), XDH = distance of cultivated land from home (km), XLAM = loan amount for monsoon paddy cultivation, XLAS = loan amount for summer (*boro*) paddy cultivation, XCLT = cultivated land area total, XSC = seed cost, XFC = fertilisers cost, XPC = pesticides cost, XLC = labour cost, XIC = irrigation cost, XOC = other costs.
10. DCCL = category of cultivated land (1 - upland, 0 – down land), DST = soil types (1- loamy, 0 – sticky), DLCH = location of plot in respect of HR segment of the canal (1-HR, 0 - otherwise), DLCT = location of plot in respect of TE segment of the canal (1 – TE, 0 - otherwise), DLG = plot position with reference to a lock-gate (1 – before, 0 – after), DSET = seed types (1 – HYV seed, 0 – otherwise), DTC-SRI = technique of paddy cultivation (1 –

systems of rice intensification, 0 – otherwise), DTC-BR = technique of paddy cultivation (1 – *bhanga rowa*, 0 – otherwise).

11. Average MPP in the HR, MR and TE areas are 44.86, 43.67 and 41.46 quintal/ha, respectively.

12. In the DVC command area, land structure is such that lands in the HR and MR areas lie above TE area when compared in terms of the height from mean sea level. As a result, in monsoon season there has a tendency to pass excess canal water along with rain water from HR and MR areas to the TE area by main or branch or other channel network leading to possibility of flood in the TE area causing lower productivity.

13. Irrigation cost is a proxy of canal water availability or canal irrigation efficiency because if canal water is available as per requirements then irrigation cost would be low (cost of availing canal irrigation is lower than the cost of availing water from underground or other sources) and farm productivity should increase in the respective command area (Narayanmoorthy, 1997; Singh *et al*., 1997; Hussain, 2004; Shah, 2008 and Chand *et al*., 2011). This implies that if in any segment irrigation cost falls or irrigation efficiency increases then farm productivity in that segment will increase and corresponding regression coefficient would be negative. From our study we have observed that irrigation cost is negatively related with MPP in all the segments of the LBMC command area except TE area.

14. In a linear regression analysis with a dummy variable, one seeks to know whether the dummy variable (here before-lock-gate) sufficiently explains dependent variable (MPP) or not. Now, we have found out that though in the HR and MR segments (involving 180 plots) BLG productivities are greater than the ALG, in case of TE segment (involving 81 plots) we have found opposite result. This fact has reduced the level of significance of the dummy variable used to explain all segment analysis. In all segment analysis we observe that regression coefficient of 'plot position of lock-gate' is positive (1.26***) and significant However, the result reveals expected sign of the coefficient.

Now, If we consider linear regression analysis of YMP i = ω1 + ω2 DLG i +Ui for each segment then we would observe that plots position of lock-gate is positively (and significantly) related with MPP in the HR and MR area (ω2 = 1.79* for HR, ω2 = 5.55* for MR) but negatively significant in the TE area (ω2 = -3.47*). In model-1, we have not considered plot position of lock-gate because it is highly correlated with irrigation cost, techniques of cultivation and category of cultivated land, for which we have considered these variables separately by single linear regression model.

15. Accepted at 6.3 per cent level of significance.

16. In the TE segment, in 48.65 per cent and 16.22 per cent of total plots BR and SRI techniques are used respectively in the ALG region while in the BLG region corresponding figures are 31.82 per cent and 6.82 per cent, respectively. In the remaining plots traditional technique is used.

17. MR segment also produces oil seed or *til* (about 10 per cent of plots). But in the TE area summer paddy is not the main crop. Apart from *boro* paddy (39 per cent), variety of agricultural crops such as vegetables (30 per cent), oil seed (7 per cent), jute (8 per cent), *Dhonche* (5 per cent), fruits (2 per cent), ground nut (2 per cent), etc., are cultivated.

18. In the summer season canal water distribution is a rotational process in the DVC command area to meet shortage of available water. Generally, DVC selects those areas which have not received canal water in the previous year. This rotational process is more applicable in the TE area rather than in HR or MR area because of their positional advantage farmers in HR and MR areas manage to get canal water for *boro* paddy cultivation.

19. Because water availability in DVC reservoirs depends on rainfall in the monsoon season in its catchment area and there are increasing water demand for other uses (industrial, power generation and municipality uses). During last 30 years no new reservoirs were constructed by DVC but 16 new thermal power plants were built up (Government of India, 2013). Further, water supply for industrial and municipal uses increased from 550.45 MCM in 2009-10 to 1539.70 MCM in 2011-12 (DVC, 2010 and 2013).

20. Because for potato cultivation farmers apply huge amount of fertiliser per unit of land and part of it stays in the field.

21. As per the construction of the canal, plots in the ALG region would receive canal water through some outlet point started from both sides before a lock-gate. This made canal users after the lock-gate dependent on users of before-the –lock-gate. In fact, farmers of the BLG region would always block these outlet points until their requirements have been fulfilled.

22. Proportion of required water drawn from the canal or canal water availability (CWA) is an important variable but it is strongly correlated with irrigation cost and distance of cultivated land from canal, for which we have dropped it from our regression analysis in equation-2. Now if we consider it by single linear regression model YiSP = a1 + a2 XiCWA + Ui then we have observed that a2 = 0.01** (0.004) in the BLG region and a2 = 0.009* (0.002) in the ALG region.

REFERENCES

Bhalla, G.S. (2007), Indian Agriculture since Independence, National Book Trust, New Delhi.

Boyce, J.K. (1987), *Agrarian Impasse in Bengal: Institutional Constraints to Technological Change*, Oxford University Press, Oxford.

Byres, T.J. (1972), "The Dialectics of India's Green Revolution", *South Asian Review*, Vol. 5, pp. 99-116.

Chand, R.; L.P.A. Prasanna and A. Singh (2011), "Farm Size and Productivity: Understanding the Strengths of Smallholders and Improving Their Livelihoods", *Economic and Political Weekly*, Review of Agriculture, June 25, Vol.XLVI, No.26 and 27, pp.5-11.

Chattopadhyay, Apurba Kumar (2014), Water Resources in India: Some Issues in Irrigation Management', in S. Pan (Ed.) (2014), *Economic Reforms and Common Property Resources: Issues and Challenges*, Regal Publications, New Delhi, pp. 140-153.

Damodar Valley Command Area Development Authority (DVCADA) (2010-11), *Annual Report* (1999-2000 to 2011-12), Water Resources Investigation and Development Department, Government of West Bengal, Purta-Bhavana, Burdwan.

Damodar Valley Corporation (DVC, 2010), *Annual Report 2009-10*, Kolkata.

Damodar Valley Corporation (DVC, 2013), *Annual Report 2012-13*, Kolkata.

Dhawan, B.D. (1987), "Irrigation and Water Management in India", *Indian Journal of Agricultural Economics*, Vol.41, No.3, July-September, pp.271-81.

Dhawan, B.D. (1989), *Studies in Irrigation and Water Management*, Common Wealth Publishers, New Delhi.

Farmer, B.H. (1977), "Technology and Change in Rice-growing Areas" in B.H. Farmer (Ed.) (1977) *Green Revolution? : Technology and Change in Rice-growing Areas of Tamil Nadu and Sri Lanka* , Palgrave Macmillan U.K., pp.1-6.

Gao, L.; J. Huang and S. Rozelle (2012), "Rental Markets for Cultivated Land and Agricultural Investments in China", *Agricultural Economics*, Vol. 43, pp. 391-404.

Government of India (2003), "Tail-enders and Other Deprived in the Canal Water Distribution", Planning Commission, December-6, dsc@satyam.net.in, pp.5 and 18.

Government of India (2013), *Storage Status of Important Reservoirs in the Country - as on 31.01.2013*, Weekly Report of 84 Important Reservoirs in India, Central Water Commission.

Gujarati, D.N. (2004), *Basic Econometrics*, Fourth Edition, Tata McGraw-Hill Publishing Company Limited, New Delhi.

Gujarati, D.N. (2011), *Econometrics by Example*, Palgrave Macmillan Publishers Limited, U.K.

Gulati, A.; R.M. Dick and K.V. Raju (2005), *Institutional Reform in Indian Irrigation*, International food Policy Research Institute, SAGE Publications, New Delhi, pp.78-79, 130.

Gulati, A.; M. Sevensen, R. Choudhury and Nandini (1994), "Major and Medium Irrigation Schemes: Towards Better Financial Performance", *Economic and Political Weekly*, Vol.29, No. 26, 25 June, pp. A72- A79.

Hariss, John (1993), "What is Happening in Rural West Bengal? Agrarian Reform, Growth and Distribution", *Economic and Political Weekly*, Vol. 28, No. 24, 12 June, pp. 1237-1247.

Hussain, Intizar (Ed.) (2004), *Pro-Poor Intervention Strategies in Irrigated Agriculture in Asia*, Country Report India, International Water Management Institute, ADB, Colombo, Sri Lanka.

IIM (Indian Institute of Management) Calcutta (2008), *IPC-IPU Gap Analysis in West Bengal and the North-East*, Final Report, October, pp.10-28.

Jairath, J. (1985), "Technical and Institutional Factors in Utilisation of Irrigation: A Case Study of Public Canals in Punjab", *Economic and Political Weekly*, Vol. 20, No. 13, 30 March, pp. A2-A10.

Mellor, J.W. (1976), *The New Economics of Growth*, Cornell University Press, Ithaca.

Mitra, A.K., (1986), "Under-Utilization Revisited: Surface Irrigation in Drought Prone Areas of Western Maharashtra', *Economic and Political Weekly*, Vol.21, No.17, 26 April, Pp.752-56.

Mony, K.S. (1995), "Economics of Irrigation-A Case Study of Kuttiadi Irrigation Project", Ph. D Thesis, Department of Applied Economics, *Cochin University of Science and Technology*, Kerala, August.

Narayanamoorthy, A. (1997), "Crop Diversification and Yield Response to Fertilizers", *Productivity*, Vol.38, No.1, pp.118-125.

Parthasarathy, G. (1971), *Agricultural Development and Small Farmers*, Vikas Publication, Delhi.

Rawal, Vikas (2001), "Expansion of Irrigation in West Bengal: 1980-81 to 1995-96". *Economic and Political Weekly*, Vol. 36, No. 42, 30 October, pp.4017-4024.

Rawal, V. and M. Swaminathan (1998), "Changing Trajectories: Agricultural Growth in West Bengal, 1950 to 1996", *Economic and Political Weekly*, Vol.33, No.40, 3 October, pp.2595-2602.

Sen, B. (1975), *The Green Revolution in India*, Wiley Eastern, New Delhi.

Shah, A. (2003), "Tail-Enders and Other Deprived in Canal Irrigation Systems: Gujarat", Paper presented at National Workshop on Tail-Enders and Other Deprived in Canal Irrigation Systems, Ahmedabad, India, November.

Shah, M. (2008), *Irrigation, Agricultural Productivity and Poverty Alleviation: A Case Study of Chashma Right Bank Canal (CRBC)*, Ph. D Thesis, Department of Economics, Gomal University, February.

Singh, I.J., K.N. Rai and J.C. Karwasra (1997), "Regional Variations in Agricultural Performance in India", *Indian Journal of Agricultural Economics*, Vol.52, No.3, July September, pp. 353-372.

Singh, K. (1972), "Impact of New Technology on Agricultural Wage Rates and Employment in I.A.D.P. Districts", *Indian Journal of Agricultural Economics*, Vol. 27, No. 4, October-December, pp. 223-27.

Spandana, J. (2006), "SRI in Large Irrigation Projects in Andhra Pradesh, India", South India Farmers Organization for Water Management, jalaspandana@yahoo.co.in, 7th Cross, C.T. Street, Vasanthnagar, Bangalore-560 052.

Viswanathan, P.K. (2001), *Economics of On-Farm Development: A Study of Major Irrigation Projects in Kerala*, Ph. D. Thesis submitted to the Department of Economics, University of Mysore, Mysore, Ecological Economics Unit, Institute for Social and Economic Change, Bangalore-560072.

Wade, R. (1975), "Administration and Distribution of Irrigation Benefits", *Economic and Political Weekly*, Vol.10, No.44/45, 1 November, pp.1743.

Wade, R. (1976), "Performance of Irrigation Projects", *Economic and Political Weekly*, Vol.11, No.3, 17 January, pp.63-66.

Wooldridge, J.M. (2008), *Introductory Econometrics a Modern Approach*, Fourth Edition, Published by South-Western, April-15.