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Rapid Expansion of Boro Rice Cultivation Resulting Ground Water Contamination by Arsenic: a Study of Environmental Threat in West Bengal, India

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Abstract

Since the early-1990s, with the advent of globalisation in Indian economy, a notable progress of the State of West Bengal was witnessed in achieving food security. This phenomenon could largely be attributed to the practice of cultivation of winter boro paddy, in rotation with aman, using rapid expansion of groundwater irrigation. As boro cultivation was highly water intensive, private farmers invested commercially, in the groundwater extraction devices. The growth of private water market without any central control in the post monsoon season resulted massive and unrestrained withdrawal of groundwater for agricultural which led to widespread contamination of groundwater by arsenic. This paper traces the development of private investment in groundwater extraction mechanism and its environmental consequencesdue towidespread contamination of groundwater by arsenic in some parts of West Bengal. Itestablishes the direct relation between groundwater extraction for boro cultivation and contamination of groundwater by arsenic. This article also suggests alternative ways to ensure sustainability of groundwater in the region.

Keywords: Private Irrigation, Boro Rice, Groundwater, Environment, Arsenic Contamination.

Introduction

Groundwater is a prime natural resource in the earth. Groundwater plays a crucial role in increasing food and agricultural production, providing drinking water and facilitating industrial development.Groundwater irrigation is the primary source of water in the dry months of year and supplements rainfall in monsoon season if rainfall is low. Despite extreme population pressures and limited land resources, the notable progress of the state West Bengal, India in rice productionsince mid-1980s could largely be attributed to the cultivation of summerboro paddy in rotation with monsoonal aman paddy and the rapid expansion of groundwater irrigation.Boro rice is cultivated in waterlogged, low-lying or medium lands with irrigation during November to May.Boro cultivation in West Bengal was enabled by the rapid spread of groundwater irrigation, mainly through private investmentand without any central control over withdrawal of groundwater (Rogaly 1999 and Mukherji 2006).

Over the past two decades groundwater had become the main source of growth in irrigated areas, and now accounted for around 50 per cent of the irrigated area in the state (4th Minor Irrigation Census Report 2006-07). Initially, small and marginal farmers in West Bengal were directly engaged in the cultivation of boro paddy, mainly using privately-owned Shallow Tube Wells (STWs). In the early 1990s, Mini-Submersible Tube-Wells (MSTWs) began to take over from the earlier diesel power STWs in some rural areas due to the fast facing crisis of a rapidly shrinking groundwater table. The electrically powered MSTWs could easily raise water from more than 20 meters below the ground and thereby reached more secure water resources (Mukherjee 2017).Introduction of Submersible motor driven pump though came as a blessing to the cultivators, for it could draw water from far deeper depth, caused further lowering of the level of groundwater. Since the growth in groundwater irrigation had not been largely government or policy driven and had happened mainly through private investment, overexploitation of groundwater resources had resulted disaster on the ecology and environment resulting aquifer contamination with leached out arsenic in some parts of West Bengal, especially in parts of the districts of Nadia, Burdwan, Murshidabad, North 24 Parganas, Hoogly etc. (Acharya 2002).

Groundwater is under severe attack from contamination by leached out arsenic and fluoride on the one hand and massive withdrawal of it for boro rice cultivation on the other hand.Groundwater resources which are at stake in various parts of the state need immediate attention. Our research tries to explorethe relation betweenrapid expansion ofboro cultivation and contamination of groundwater by arsenic. It also suggests alternative ways to ensure sustainability of groundwater in the region.

Review of Literature

In order to describe the emerging environmental threat due to over exploitation of groundwater during summer crop boro rice cultivation in some districts of West Bengal, we have segregated the entire literature into two sections:

1. Rapid expansion of boro rice cultivation and private investment in groundwater market in West Bengal Agriculture
2. Groundwater over-extraction, aquifer contamination with leached out arsenic and its consequences in some parts of West Bengal

According to Harriss (1993), the agricultural transformation in West Bengal occurred essentially because of land reforms and the successful adoption of a new agricultural technology on a large scale across most parts of the state for cultivation of HYV boro paddy in the post monsoon season. Others, such as Sengupta and Gazdar (1997), Webster (1999), Moitra and Das (2004) etc. pointed out that this period had also witnessed a significant increase in private groundwater investments. They found that irrigation was the key engine of growth or leading input.

Acharya (2002) argued thatthroughout the world, the regions with high population density, groundwater based irrigation and poor surface water management were fast facing the crisis of a rapidly shrinking groundwater balance. He found that aquifer contamination with leached out arsenic and fluoride resulting from geological disturbance were a direct off-shoot of groundwaterover-abstraction in the Bengal Delta basin of Bangladesh and the state of West Bengal of India.Rogaly (1999) and Mukherjee (2017) pointed out that in that region in the backdrop of significant growth of summer rice cultivation, groundwater based irrigation had largely developed on an individual initiative and without any central control over withdrawal of groundwater.

Study Area, Data and Methodology

Our survey was aimed at collecting comprehensive data on some village households of Domkol block of Murshidabad district. Murshidabad District lies between the latitudes of 23˚43′30″N to 24˚50′20″N and longitudes of 87˚49′17″E to 88˚44′00″E. Murshidabad is 7th largest and 4th most populous district out of a total of 19 districts in West Bengal and it is 9th most populous district in India. As per Census 2011, population of Murshidabad district is 7102430, with area 5324 Sq. Km. The River Ganga forms its Northern and Eastern boundaries and separates it from Bangladesh. The Ganga and its tributaries Bhagirathi, Jalangi and Bairab, are the important rivers of the district. The district Murshidabadis taken as sample because it is one of the major boro rice producing districts of West Bengal, for the most part, boro cultivation is heavily dependent on groundwater extraction using submersible pump sets and it is also a severely arsenic affected district of the state. In many areas, the expansion of cultivation of boro paddy has led to a fall in the groundwater level in the post monsoon months and STWs can no longer be relied upon to provide an adequate supply of water in the critical months of April and May. In Murshidabad district 24 blocks (out of 26) are arsenic affected. Arsenic concentration in drinking water ranges between 3-3000µg/L (SOES, JU Study 2007). The average level of arsenic concentration in groundwater (national standard, 50µg/L) of Murshidabad district is 240µg/L (this is calculated by weighted average method on the basis of arsenic concentration in water samples given by SOES (JU), 2007 and PHED (WB), 2006). Our survey was based around a set of detailed interviews with both the large and the small farmers living in the Domkol block area to find out the relation between boro rice cultivation and groundwater arsenic contamination.

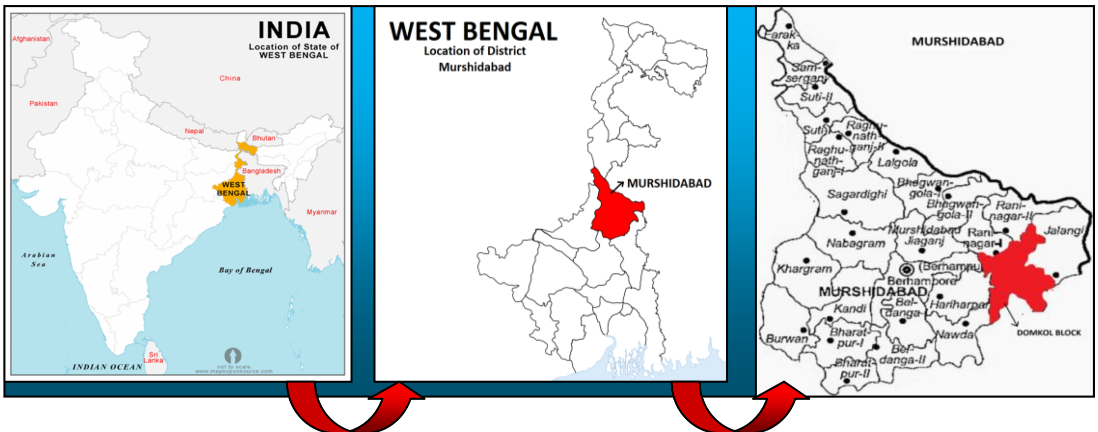

Figure 1: Position of the state West Bengal in India, Murshidabad district in West Bengal and our survey area, Domkol block in Murshidabad district.

We focused on boro paddy for two reasons: first, the area under winter boro paddy had exceeded that under allcrops other than khariff paddy and it was increasing day by day (Fig 2 & 3); and second, the crop required high doses of irrigation (Table 1).There were also several social factors which drove boro cultivation. Rice being the staple food in the Bengali diet, had a substantial demand for crop in the market. Since it was non-perishable, farmers could store it until they got a good price. The marginal farmers often grew the crop to meet their own food requirements.

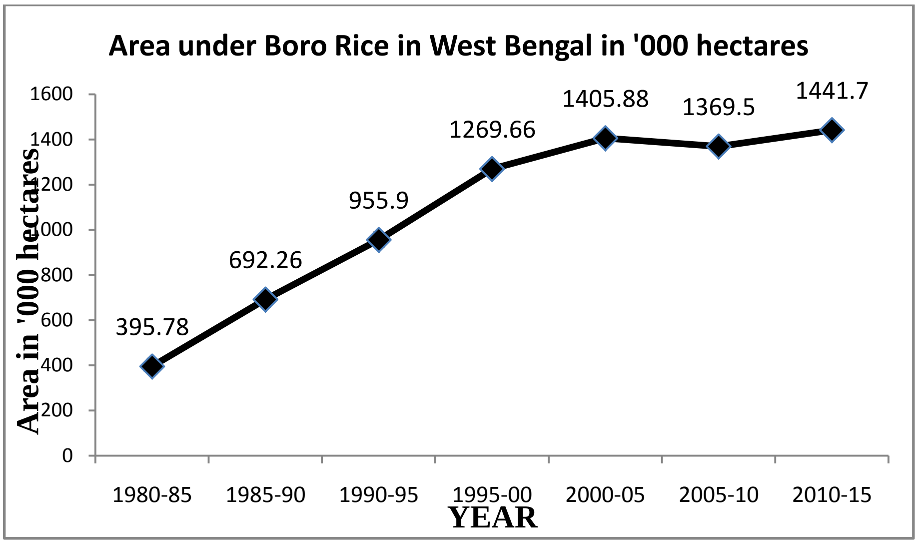

Figure 2: Area under bororice production in West Bengal from 1980-85 to 2010-15 (in '000 hectares)

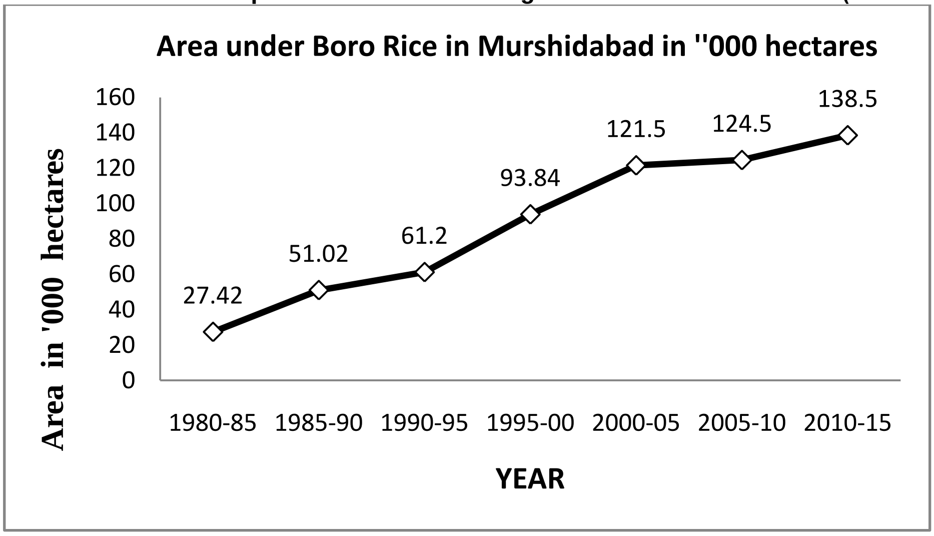

Figure 3: Area under bororice production in Murshidabad from 1980-85 to 2010-15 (in '000 hectares)
Source: Statistical Abstract, Bureau of Applied Economics & Statistics, Government of West Bengal (for both Fig. 2 & 3).

Water intensity was the highest for boro rice (Table 1), almost the total requirement was met by irrigated water. Being highly water-intensive, the growth of boro rice cultivation had triggered massive groundwater development leading to a series of damaging environmental consequences.Over time farmers installed STWs and later on MSTWs to draw groundwater.The immediate adverse impact of exploitation of groundwater for irrigation had been a lowering of the water tablebelow the centrifugal pumping limit for whichSTWs went dry.Introduction of MSTWswhich could draw water from far deeper depth, caused further lowering of the level of groundwater. Massive withdrawal of groundwater in the region had been leading to groundwater contamination by leached out arsenic. Bhattacharya (1997) opined that contamination of groundwater with arsenic was caused when a vacuum was created by a lowering of the water table due to excessive pumping of groundwater.

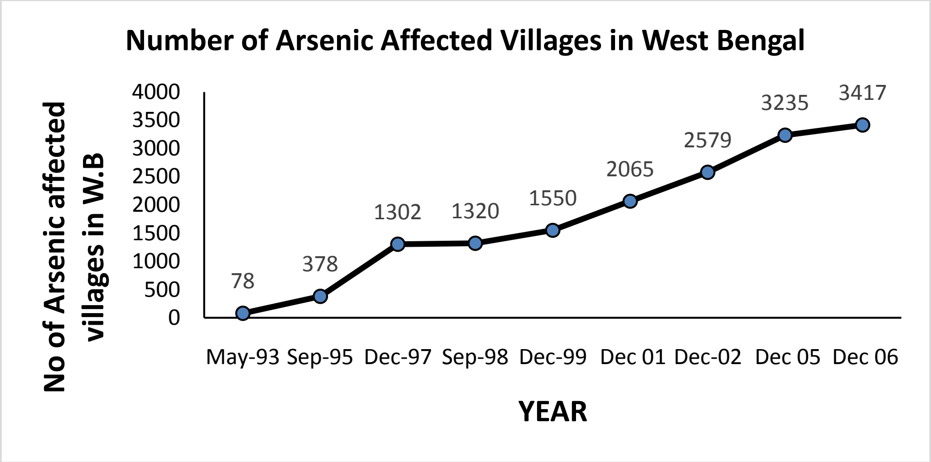

Figure 4: Number of Arsenic Affected Villages in West Bengal
Source: PHED, W.B. (2006) Report & SOES, J.U. (2007) Report

Table 1: Crop-Water Demand

Crop	Sowing Season	Growing Days	Water Demand (in cm)
Aman	July	91	104.5
Boro	January	95	150.5
Wheat	Nov	87	37.0
Cotton	April	88	110.5
Sun hemp (Fibre)	April	74	30.2
Tea	Whole Year	81	20.4

Source: Irrigation Department, Govt. of West Bengal statistics Irrigation Department, 2010

In our field survey it was found that the link between groundwater and electricity was rather direct – electricity was used for pumping groundwater from aquifers. Until the 1980s, State Electricity Boards (SEB) charged their tubewell-owners a low flat tariff which led to the over-exploitation of groundwater in the state. Later there had been a renewed interest in reforming the electricity sector and obtaining electricity connections for tubewells became difficult. In the late 1990s, in West Bengal the pumps used for the STWs were almost all diesel-operated with only 10% being electrically powered, compared to around 50% in India as a whole. Since 2004, the West Bengal State Electricity Distribution Company Ltd. (WBSEDCL) had virtually stopped sanctioning new electricity connections for agricultural tubewells as illustrated in Figure 4.

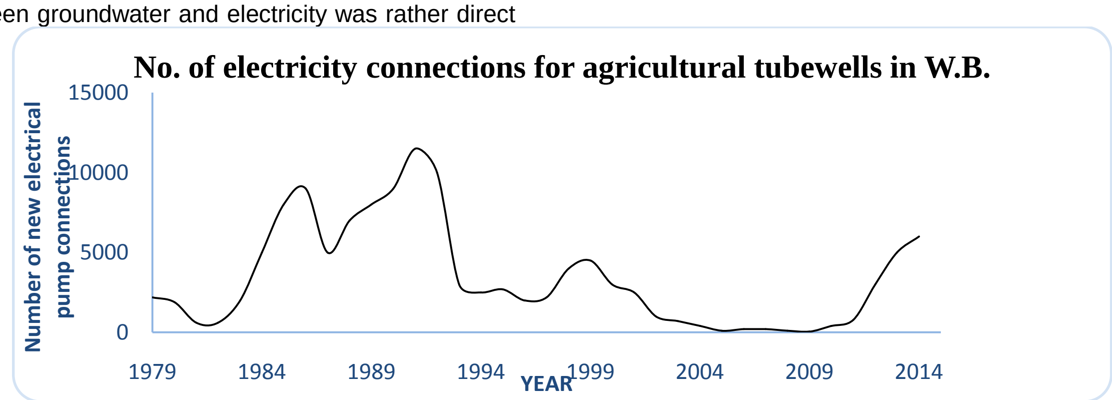

Figure 4: Number of Electricity Connections for Agricultural Tubewells in West Bengal
Source: AGWATER SOLUTIONS, 2014

In the 2011 W.B. state election, Trina Mool Congress (TMC) party came to power defeating the Left Front government. In November 2011, and again in November 2012, the new government made some policy changes to ease the process of electrification of irrigation pumps. Water Resources Investigation and Development Department (WRIDD) vide a memo dated November 2011, had changed a provision of West Bengal Groundwater Resources (Management, Control and Regulation) Act 2005, such that, farmers located in 'safe' groundwater blocks and owning pumps of less than 5 HP and tubewells with discharge less than 30m /hour would no longer need permits from State Water Investigation Directorate (SWID). Even by removing compulsory SWID clearance certification and providing electricity connections against a fixed connection fee, the new TMC Government of West Bengal had finally readjusted different interests in order to serve the interests of poor farmers in the state.Government institutions had shown a reluctance to invest in proper protection of the precious underground water resources from overexploitation for short-term material gain (Eckersley 2004).In a context of declining groundwater storage in the region, it had become questionable whether the new electrification policy of post 2011 period would keep the groundwater resource sustainable.Several studies (Acharyya 2002; Chakraborti 2003; Singh 2000) suggested that extensive pumping of groundwater was largely held responsible for groundwater contamination by arsenic in West Bengal delta basin and a co-relation between water extraction and contamination of underground aquifers with leached arsenic could be well established.

Research Design

Arsenic is highly toxic and long-term use of drinking water with its high concentrations can lead to a wide range of health problems in humans. Arsenic is carcinogenic, mutagenic, and teratogenic.

Carcinogenic means having the potential to cause cancer, mutagenic is an agent that increases the occurrence of mutations in genetic material andteratogenic is substances that can disturb the development of the embryo.Symptoms of chronic arsenicosis include skin cancer. More than 200 million people worldwide were estimated to be chronically at risk from drinking water with arsenic concentrations above the WHO guideline value of 10 micrograms per litre (10 µg/L).

The presence of arsenic in water and its effect on human health through both drinking and agricultural practices had become of serious concern in the state of West Bengal wherethousands of people began showing symptoms of arsenic-related diseases and12 districts had been declared arsenic-affected (CGWB 2007).Over exploitation of groundwater occurred because of the cultivation of boro crop (Norra et. al., 2005). To meet the demand for irrigation water, thousands of tons of arsenic were being put on agricultural land from arsenic-contaminated tube-wells in use for cultivation. This led to the presence of a high level of arsenic in rice and vegetables- the basic food of people. Under these circumstances, PHED Report (2007) suggested that the exploitation of deep water table should be banned for sustainable development.In our survey, a detailed study was carried out in Domkol, one of the 107 arsenic-affected blocks in West Bengal, India, to determine the factors of groundwater contamination with arsenic.

Table 2: Factors of Groundwater Arsenic Contamination

Arsenic Concentration Rate	Factor A	Factor B	Factor C	Factor D	Factor E	No of persons interviewed
Arsenic>200µg/L	23	11	26	20	19	41 (26)
151–200 µg/L	09	07	10	09	10	45 (11)
101–150 µg/L	19	14	21	17	19	62 (25)
51–100µg/L	03	03	03	04	04	52 (09)
10–50µg/L	--	--	--	04	02	55 (44)
< 10 µg/L	--	--	--	01	--	30 (30)

Note: The figures in brackets are the no. of persons in the sample who cultivated boro crop in the survey blocks in 2017.

Code

Factor A: Large land area under boro cultivation.

Factor B: Low price of electricity supply.

Factor C: Use of MSTWs (groundwater extraction technology) in cultivation.

Factor D: Non-availability of proper groundwater storage or recharge facility.

Factor E: Proper credit facility.

Source: Primary Survey by the author from field survey during 2017-18

Classical linear multiple regression model (clmrm)

Firstly, to study the impact of the explanatory variable factors X_1 , X_2 , X_3 and X_4 on Y, our methodology includes the Multiple Regression Analysis (MRA), the theory of Interval estimation and that of Hypothesis testing of the Regression Coefficients (slope coefficients) to test the significance of the individual partial regression coefficients (slope coefficients) for MRA

In case of MRA, the quantity known as Coefficient of Determination denoted by R^2 (Multi - variable regression) has been used to analyze the measure of the goodness of the fit of our regression equations. Verbally, R^2 will measure how far the proportion or percentage of the total variation in dependent variable (Y) [percentage of arsenic-affected areas] is explained jointly by all independent (explanatory) variables (Xs), Moreover, adjusted R^2 has also been used to compare our results of MRA. (Gujrati & Sangeetha, 2007).

Next, in the language of Hypothesis testing, a stated hypothesis or a null hypothesis (H_0) is constructed and is usually tested against the alternative Hypothesis testing (H_1) in the following methods of testing the statistical hypotheses of the regression models.

To test the significance of the individual partial regression coefficients (slope coefficients) of our Multiple Regression Model (MRM), two alternatives but mutually complementary approaches, namely, Confidence Interval Approach (CIA) and Test of Significance Approach (TOSA) (t test), yielding the same results and conclusions, have been used for deciding whether to reject or accept the null hypothesis. Moreover, Analysis of Variance (ANOVA) Technique (F – test) has been used for the Overall Significance of the Estimated Multiple Regression Models.In case of CIA, if the unknown parameter β (β_1, β_2, β_3, β_4) under (H_0: $\beta = 0$) falls within the confidence interval, H_0 is accepted and it is said that our finding is statistically insignificant. But, if it falls outside those confidence limits, then H_0 is rejected so that our finding is statistically significant.

Secondly, under TOSA Approach (t test) or in ANOVA Technique, from a two- tailed test, with the given critical values (table values) of t $_{\alpha/2,n-k}$, and F $_{\alpha,(k-1,n-k)}$, if the computed (absolute) t or F value of our estimated slope coefficients(β*s) exceeds their respective critical values at chosen level of significance (α = 5%), then H_0 is rejected with β*s being statistically significant: otherwise H_0 is accepted with their values being statistically insignificant. Alternatively, if the p-value (probability value) of the t statistic is sufficiently low, then also H_0 is rejected and all the β*s are then said to be statistically significant with increasing confidence.

For this, a time series analysis of the Classical Linear Multiple Regression Model (CLMRM), with one dependent variable (Y), and more than one independent variables (Xs), linear in their parameters, has been constructed with the following Multiple Regression equation,

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + u \quad (1)$$

Here, Y denotes the percentage of arsenic-affected areas. X_1 denotes the area under boro cultivation, X_2 denotes the price of electricity supply, X_3 denotes the use of MSTWs (technology) in cultivation, and X_4 denotes the availability of proper groundwater storage or recharge facility.

β_0 is the intercept which measures the mean or the average value of Y, when all X_1, X_2X_3 and X_4 are set equal to zero. β_1, β_2,β_3 and β_4 are the individual partial regression coefficients (slope coefficients) of X_1, X_2X_3 and X_4 respectively, which measures the change in the mean value of Y, per unit change in one independent variable, (say, X_1, X_2X_3 or X_4), holding the value of the other independent variables constant. That is, it gives the "direct" or "net" effect of a unit change in X_1, X_2X_3 or X_4 on the mean value of Y.

In order to test the significance of the individual partial regression coefficients (slope coefficients) of CLMRM, accordingly, the null hypotheses have been constructed:

[(H_0: βs = 0) as against (H_1: βs ≠ 0)] ; (change in all the explanatory variables X_1, X_2X_3 and X_4 have no linear influence on Y respectively. The regression results for MRM are given in Table 5.21.

Results and Discussion

Table 3: Summary statistics of Regression Analysis and ANOVA

Equation No.	Variables	Coefficient	Lower 95 percent	Upper 95 percent	t stat	P value	F	R^2	Adjusted R^2
1	Intercept	4.843	-25.65	35.34	2.02	0.293	60.71	0.996	0.9795
	X_1	1.344	-5.23	7.92	2.60	0.233			
	X_2	-0.975	-3.14	1.19	-5.73	0.109			
	X_3	0.238	-1.05	1.53	2.35	0.256			
	X_4	-0.539	-7.39	6.31	-1.00	0.499			

In case of MRM, from Table 3, corresponding to equation (1), the estimated multiple regression equationis

$$Y = 4.843 + 1.344X_1 – 0.975X_2 + 0.238X_3 – 0.539X_4 + u \quad (2)$$

From the summary statistics of Multiple Regression Data Analysis, it is found from the value of R^2 = 0.996, that almost 99.60 % of the total variation in the dependent variable Y is explained jointly by all the above explanatory variables X_1 , X_2 , X_3 and X_4.

From the positive slope coefficients β_1^* = 1.34, it is implied that one unit increase in X_1 leads to an increase of Y by 1.34 units i.e. ifin the affected blocks, the area under boro cultivation increases by one unit, there is a greater tendency of rise in arsenic-affected areas.

β_2^* = -0.975, this inverse relation between X_2 and Y shows that the lower the price of electricity supply, the greater is the tendency of rise in arsenic-affected areas.

β_3^* = 0.238 implies when STWs become ineffective and the farmers use Mini-Submersible Tube-Wells (MSTWs) for large scale boro cultivation, groundwater table further decreases andthere will be greater tendency of rise in arsenic-affected areas.

β_4^* = -0.54 implies that lower the availability of proper groundwater storage or recharge facility, the greater is the tendency of rise in arsenic-affected areas.

Further, from the Test of Significant Analysis, it is found that all the slope coefficients β_1^*, β_2^* and β_3^* are highly statistically significant at 5% level of significance as all their estimated 't' values are by convention > 2 i.e. much higher than their Table values. Hence, all null hypothesis i.e. H_1^0, H_2^0 and H_3^0 are rejected which implies that X_1 or X_2 or $X_3$are statistically significant i.e. change in either X_1 or X_2 or X_3 greatly influences Y.

Except, the slope coefficient β_4^* is statistically insignificant at 5% level of significance as its estimated't' value is < 2. So, null hypothesis H_4^0(β_4= 0) is accepted which implies that change in X_4(the availability of proper groundwater storage or recharge facility) does not have much influence on Y.

However, the estimated F value is much greater than table value to explain the overall significance of the model at 5% level of significance i.e. the change in all X_1, X_2, X_3 and X_4 greatly influences Y.

From the Multiple Regression Data Analysis, it can be summarized that there is a greater tendency of rise in arsenic-affected areas inorder to rise in the area under boro cultivation, in case of greater non-availability of electricity supply by charging higher electricity price, due to greater installation of MSTWs in order to meet high groundwater demand for boro rice cultivation and in case of non-availability of propergroundwater storage or recharge facility. However, the availability of proper storageor recharge facility poses a relatively insignificant factor in this respect.

However, among the above factors, low price of electricity supply,X_2, has the greatest influence on the tendency of rise in arsenic-affected areas i.e. it plays the role of dominant factor, because of its highest absolute estimated 't' value.

Conclusion

Sustainability is defined as the development that meets the needs of the present without compromising the ability of the future generations to meet their own requirements. The farmers are private agents and they disregard the social and environmental costs of present resource use. They also make under valuation of natural resources. All these lead to excess depletion of groundwater, degradation of land and soil fertility. In a market mechanism, social and environmental costs are overlooked by private agents. As a result, excess depletion of the resource takes place and agriculture becomes unsustainable in the long-run. The government intervention has now become inevitable to regulate the water use for socially optimum outcome.

Rain water is a renewable resource and it has multi-functional social benefits including irrigation, flood control, and conservation of the ecosystem. The rain water can be harvested through the development of social capital like dams and river projects, canals, reservoirs, watershed development, artificial recharge to the aquifer, etc.

Groundwater has in fact offered a great opportunity in alleviating rural poverty. The success of the groundwater management for the sake of ensuring sustainability largely depends on the awareness of people to possible alternatives.This indicates the possibility of saving substantial amounts of groundwater withdrawal through switching to alternative water-saving crops such as wheat, pulses, onions, oilseeds etc. in which there is every possibility of earning higher overall profit. This alternative crop mix is further justified from the point of view of huge deficits of pulses, oilseeds, and wheat and onion products in the stateof West Bengal.

The policy-makersshould make an attempt to see whether input and output prices can be used as policy instruments to ensure conservation of groundwater especially when input subsidy (electricity) and price support for boro crops lead to excess depletion of water.With the simplification of electrification procedure since 2011, the farmers of West Bengal had been able to make intensive use of groundwater for increasing their agricultural production. However, in a context of declining groundwater storage in the region, now it has become questionable whether the new electrification policy will keep the groundwater resource sustainable. We can think of the implementation of the revised pricing rules of electricity. Prices can be increased with the quantity of electricity consumed and therefore create an economic mechanism for limiting the extraction of groundwater beyond a certain level.Managing the externalities of groundwater use by minimising the negative impacts of over-exploitation, while preserving the benefits from such use, has emerged as the key challenge in West Bengal.

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