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Toxicity and Profitability of Rice Cultivation under Waste-Water Irrigation: The Case of the East Calcutta Wetlands

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Abstract

The paper reports the results of an empirical study on profitability of rice cultivation in the East Calcutta Wetlands (ECW) region where untreated sewage from the city of Kolkata (earlier Calcutta), India, is used for the purpose of irrigation during the winter/summer crop. The results show that plots using wastewater containing organic nutrients earn lower profits than those using groundwater. We also find the profitability of plots using wastewater is negatively affected by the presence of heavy metals such as Lead and Mercury that are carried through untreated sewage-water canals and deposited in the soil. Of the two opposing effects of wastewater irrigation, the negative effect of heavy metal toxicity outweighs the positive effects of organic nutrients. The results support regulation of the discharge of the heavy metals like Lead and Mercury into the water from households and industries: this would lead to conservation of the Wetlands generating a number of ecological and environmental benefits to the society.

Keywords: Profitability; Rice cultivation; Waste-water irrigation; Toxicity; Heavy metal pollution.

JEL Classification: Q13, Q15, Q53

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Toxicity and Profitability of Rice Cultivation under Waste-Water Irrigation: The Case of the East Calcutta Wetlands

1. Introduction

Use of wastewater in agriculture undoubtedly helps to recycle useful nutrients through the food chain. But it also poses risks simultaneously for human health and for the profitability of the cultivated crop because of the possible presence of toxic elements in the irrigation water. The East Calcutta Wetlands in India present a somewhat unique case where untreated sewage water from the city of Kolkata (Calcutta) located upstream has been used for decades in downstream agriculture and fisheries. This paper presents the results of an empirical study on the profitability of rice cultivated using such untreated wastewater for irrigation purposes during the dry season.

Since the inception of the plan in 1930 of diverting sewage from the city to the Wetlands through a chain of canals, the sewage water has provided the farmers not only with a cheap irrigation option in the dry season of the year but also an inexpensive substitute for costly fertilizers because the water is full of nutrients. The plan has enabled the East Calcutta Wetlands, spreading over an area of approximately 7500 hectares[1] towards the south eastern fringe of the Kolkata metropolis, to provide important eco-system services to the city as well as livelihood support to a large number of people living in the region. Ghosh (2005) reports that this area is home to the largest wastewater-based non-saline fishery in the world. He also points out that the cumulative efficiency in reducing the Biochemical Oxygen Demand (BOD) of the wastewater in this region is above 80 percent and that of reducing coliform bacteria 99.99 percent on average. Not only does the plan save the city the cost of construction of a Sewage Treatment Plants (STP), it also contributes to flood control in the city and serves the cause of carbon sequestration. The area supports a wide variety of flora and fauna and is a storehouse of biodiversity. For these reasons, the East Calcutta Wetlands (ECW) is hailed as a great success story that is both ecologically sound and cost effective when it comes to dealing with urban sewage. Sarkar (2002) measures

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[1] The estimate is given in Chattopadhyay (2002).

the value of livelihood support and sewage water treatment services of the Wetlands at Indian Rupees 1656 million per annum (or USD 36.8 million per annum[2]). In 2002, the Wetlands were admitted into the list of Ramsar sites and are now preserved by law against conversion to other usages. Itsprotected status therefore restricts the expansion of the city towards the south east.

The reliance of the city of Kolkata on the Wetlands for waste disposal is underscored by the fact that despite the manifold expansions in the city over the decades and the corresponding increase in bio-degradable and non-bio-degradable contents in its sewage water, the city has not constructed a treatment plant for sewage, depending solely on the East Calcutta Wetlands for waste water disposal. However, the appearance, with time, of more industrial plants in and around the city and the use by households of more manufactured chemical products, such as detergents and other household chemicals, have increased the presence of toxic industrial effluents in the sewage water. The question therefore is whether the increase in toxicity of sewage water negatively impacts on the profitability of the fisheries and agricultural practices in the region. An answer in the affirmative points invariably to reduced livelihood support for people in this region and reduced value addition from the existence of the Wetlands.

Such a conclusion also, indirectly, supports the growing demand to convert the wetlands to real estate and industry. An answer in the negative on the other hand supports the cause of conservation. Appropriate policy interventions are therefore necessary, including the proper treatment of the sewage water flowing into this region, from those who wish to hold at bay the ever-increasing pressure in favor of conversion and to preserve the wetlands for the valuable ecosystem services it provides for the city.[3]

In this paper, we study whether the presence of heavy metal toxicity in wastewater and soil negatively impacts on the profitability of rice cultivated in the East Calcutta Wetlands region.

Although vegetables, jute and oilseeds too are produced in the region, we restrict ourselves to the study of rice cultivation for the following two reasons: (i) rice occupies a majority of the cultivated land in this area during the winter/summer crop when wastewater is used for irrigation; (ii) the crop uses substantial amounts of water at different stages of its production and

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[2] Assumed US$1 = Indian Rupees 45.

[3] See Mukherjee (2010) for a discussion

is therefore the most likely to be vulnerable to toxicity in the water and, through the water, in the soil. The results indicate that in this region rice cultivation through wastewater irrigation is less profitable than rice cultivated using groundwater-based irrigation. This is explained by the presence of Mercury and Lead in the soil. The results of our study are interesting because they help clarify popular perceptions regarding the profitability of wastewater irrigated plots and adds new insight to the ongoing policy debate.

The paper is organized as follows. Section 2 discusses the available literature on the subject of our research and lays out the scope of the present study. Sections 3 and 4 describe the methodology and the sampling strategy respectively. Section 5 discusses the data while section 6 presents the results. The last section concludes with a brief outline of the policy implications and recommendations of our study.

2. Literature Survey and Scope of the Study

How does the toxicity of irrigation water affect plant growth? According to experts, the heavy metals carried through the irrigation water accumulate in the soil over time. Though the presence of heavy metals in small quantities is 'natural' in the water and soil, their elevated concentrations kill micro-organisms that are beneficial to plant growth. As Alloway (1995) points out, Chromium (Cr), Zinc (Zn), Cobalt (Co), Copper (Cu) and Manganese (Mn) in small quantities are good for plant growth but the presence of metals like Lead (Pb), Cadmium (Cd) and Mercury (Hg) are always a cause for concern above a certain level. Of these, Pb and Cd, being heavier metals, work at the root and stem of the plant to destroy them while Hg being lighter gets easily transported to the grains. The metal mobilization and plant uptake would be restricted by the alkaline pH of the soil.

A recent study by Nawaz *et al.* (2006) studied the effect of water containing heavy metals on yield, yield components and heavy metal contents in paddy and straw. They looked at three varieties of rice and soil at three different sites in the district of Sheikhupura near the bank of Nallah Daik where the crop is irrigated with water from Nallah Daik in Pakistan. This study showed contamination by the two heavy metals Cu and Cd to be within safe limits in the soil.

Moreover, although they observed a minor accumulation of these metals in the plant parts, they found it to remain within the permissible limit. A study by Fazeli *et al.* (1998), who investigated the degree of accumulation of seven heavy metals (Cu, Zn, Pb, Co, Cd, Cr and Ni) in the soil and in different plant parts of paddy irrigated by paper mill effluents near Nanjangud, Mysore district, Karnataka in India, also found remarkably low concentrations of heavy metals (except Zn) in the seeds of paddy although this was not the case for the roots and leaves. Further, the crop seemed able to tolerate the presence of the heavy metals in the polluted water without suffering much damage.

In another study, Yap *et al.* (2009) investigated the accumulation of seven heavy metals (Cd, Cr, Cu, Fe, Mn, Pb and Zn) in the soil and in different parts of the paddy plant at Kota Marudu, in Sabah, Malaysia. Although the results showed Fe to be the most predominant metal ion in the rice grains and roots, the concentrations of heavy metals in the rice grains were still below the maximum levels as stipulated by the Malaysian Food Act (1983) and Food Regulations (1985). In 2007, Zeng *et al.* studied the effect of Pb treatment on soil enzymatic activities, soil microbial biomass, rice physiological indices and rice biomass in a greenhouse pot experiment. Their experiment showed that when the Pb treatment was raised to the level of 500 mg/Kg, there was an ecological risk both to soil microorganisms and plants. The results also revealed a consistent increase in chlorophyll contents and rice biomass initially, peaking at a certain level of Pb treatment, and then a gradual decrease with a continued increase in Pb concentration. Studies have shown that Pb is effective in inducing proline accumulation and that its toxicity causes oxidative stress in rice plants. A study by Wang *et al.* (2003), on the other hand, has estimated the status of trace elements in paddy soil and sediments in the Taihu Lake region in China. It showed Zn, Cu and Pb to be the main pollutants in the experiment sites and the rapid development of village/township industries to be the primary cause of severe environmental pollution in the Taihu Lake region, especially of irrigation river sediments. Markandya and Murthy (2000), in their study of the Kanpur-Varanasi region in India, found that though the mean levels of Cd, Cr, Nickel (Ni) and Pb in the soils were above their respective tolerable limits for agricultural crops, since the pH of the receiving soil was alkaline, their effects were less harmful than expected. They also noted the positive effect on agricultural yield of nutrients present in partially treated wastewater when compared with crops grown using groundwater.

In contrast with the studies discussed above, the primary objective of our study, taking the East Calcutta Wetlands as its study site, is to investigate the effect of wastewater toxicity on the livelihood options of farmers involved in rice cultivation in the region. Therefore, we study whether wastewater cultivation has had a negative impact on the profitability of rice cultivation in this region rather than the impact of heavy metals on yield and the plant body. We consider this important as farmers may adopt a number of measures like pollutant resistant varieties of seeds, fertilizers and pesticides in order to cope with the negative externality posed by toxicity so that higher yield is achieved at lower profits. But if this indeed happens, the livelihood support provided by the Wetlands will be reduced and the pressure for its conversion into more economically beneficial projects will build up. In the case of the East Calcutta Wetlands, some studies have already noted the presence of heavy metals in the body of fish and vegetables produced in the region. A study by Chatterjee, Dutta and Mukherjee (2004), for instance, has found high Cu concentrations in fish liver.

The team of researchers also found Zn, Pb and Calcium (Ca) concentrations to be above the maximum permissible levels in edible muscles. On the other hand, although recent studies by Raychaudhuri *et al.* (2007, and 2008) observed the presence of toxic elements in both the vegetables and fish produced in the region, they also found the elements to be within the safe limit and not substantially higher than in the case of produce coming from the control region.

What is important to note is that none of the above-cited studies were carried out in the context of the cultivation of rice; nor did they look at the profitability issue. To that extent, ours is a pioneering study into the effects of the toxicity of wastewater on the profitability of rice cultivated in the region.

The paper will therefore attempt to estimate a profit function. Since there are standard econometric methods for such estimations, our study too adopts them. It particularly adheres to the estimation technique of a quadratic profit function used by Arnade and Trueblood (2002) and Vincent (2008).

3. The Study Area, Sample Design and Data

The East Calcutta Wetlands located on the south-eastern fringe of the city of Kolkata, India is spread across an area of approximately 7500 hectares. Since British colonial times, the area has been used for the purpose of sewage water disposal from the city of Kolkata. From 1930 onwards, people living in the area have used this untreated sewage water in fisheries and agriculture.

The quality of the untreated sewage water used by farmers in the East Calcutta Wetlands area has however changed over time with the change in population and industry profile of the city of Kolkata. On the one hand, the growth in population and the expansion in industry have led to an increase in the toxicity of the sewage. On the other hand, the new concern with environmental pollution has led to the relocation of some polluting industries like the tanneries out of city limits and to the adoption of effluent treatment practices by some industries. The rehabilitation of cowsheds outside the city has, at the same time, led to a drop in the biodegradable content of the wastewater although there is no systematically maintained time series data available to evaluate its impact.[4] We have therefore substituted time series data with carefully collected cross-section data collected through a field survey. The substitution of time series data with cross-section data is possible in our study because of a unique feature of the study area. Rice cultivation in this area uses wastewater from more than one canal flowing through the East Calcutta Wetlands (including fishery feeder canals) with apparently different levels of toxicities in them (see Map 1 in the Appendix 1).

The Storm Water Flow (SWF) canal, which was constructed to flush out the flood water of the city during the heavy rains, is the main canal in this region. The Dry Water Flow (DWF) canal, which is not as deep and as wide as the SWF, runs parallel to SWF canal through the heart of this region. The DWF being richer in nutrients compared to SWF is primarily used to feed the fisheries located in the region. There are other fishery feeder canals too in this region which originate from the SWF and ends up in the SWF itself. The most of the other canals located in the region eventually merge with SWF with exceptions like Krishnapur and Bagjola/Bhangar canals.

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[4] The West Bengal Pollution Control Board has some data for the recent years

Apart from the different levels of toxicity in them, which is apparent, as the water flows down through the canal system described above into the tidal river of the Sunderbans at Ghusighata in its nearly 40-kilometre journey from the city limits, its toxicity keeps changing from the upstream to the downstream regions. In fact, even as leather factories were moved beyond the city limits by order of the Green Bench of the Calcutta High Court, the West Bengal Government has established a new leather complex at Bantala towards the southern boundary of the Wetlands. Some cowsheds too have been rehabilitated on the southern fringe of the Wetlands at Paglahata downstream of the leather complex. Though the leather complex has its own Effluent Treatment Plant (ETP), the respondents in the field survey from the downstream agricultural lands reported increased toxicity after the establishment of the complex. The increased toxicity can also be attributed to the growth in illegal tanneries on the southern boundary of the complex, which do not have treatment facilities. The cowsheds on the other hand were expected to increase the nutrient content of the waste water. The West Bengal Pollution Control Board has some data for the recent years.

In addition to the impact of the tanneries and cowsheds on the quality of the wastewater at different locations in this region, the study also factored in the wide variation in the degree to which farmers resort to wastewater irrigation in the region, which means that not all land in the area is under wastewater cultivation. While there are lands that have never been under wastewater cultivation being cultivated only through ground water irrigation, there are lands that were under canal irrigation in the past but are now under groundwater irrigation. The area is also host to a paint factory at Narayanpur discharging its effluents into the canal water.

We therefore designed the sampling strategy in such a way as to pick up this wide variation in the toxicity of the water used in the paddy fields for the purpose of relating it to their profitability. Toxicity was measured through a chemical analysis of both the canal water as well as the soil since toxic chemicals are deposited in the soil over the years and works on the plant through it. We collected the profitability data through a household survey. A map created by the Canal Drainage Outfall Division (Department of Irrigation, Government of West Bengal, 2000) provide details of all the irrigation canals of the region. Several trips made to the study site revealed that the irrigation canals carrying sewage water from the city also supplied nutrients to all the non-saline fisheries in the region. We also found that lands located reasonably close to the canals have the opportunity to use the sewage water in agriculture. There was only one area called Babupara located upstream of the leather complex where the same canal supplying wastewater to the fisheries was used to supply irrigation water to the agricultural land. We were also informed by local farmers about other areas that used wastewater for agriculture from a government-sponsored cooperative scheme that lifted water from the canals through electric pumps for distribution. We were however unable to locate these schemes because they had stopped functioning either due to bad governance or the increased toxicity of the water, except in the case of Karaidanga, Vatipota, Narayanpur and Ghoshpara which are located downstream of the leather complex.

The present study relies on data from nine sampling points including Karaidanga, Vatipota, Narayanpur and Ghoshpara mentioned above. Of these, Vatipota, Narayanpur and Ghoshpara use wastewater lifted from the SWF canal. With regard to location, while Vatipota is located just next to the boundary of the leather complex and upstream of the cowshed area in Paglahata, Narayanpur is located downstream of Paglahata. Ghoshpara however is located further downstream. In Karaidanga on the other hand, the scheme distributes water from a different canal called Krishnapur Canal.

The other sampling points of our study do not rely on the government scheme. In Kantatala, which is located upstream of the leather complex, farmers therefore use wastewater directly from both the DWF and SWF canals using pumps installed through private arrangements to lift water. An arrangement similar to that in Kantatala prevails in Ghojer Math too where farmers mix up canal water from the wastewater carrying DWF with water from the clean Bagjola/Bhangar Canal. The shared feature among all these areas is that everywhere farmers depend mainly on canal waste water for the winter and summer crop of the dry season. During the monsoons, they use either rain water or mix the canal water with rain water. On the other hand, there are lands located away from the canals that never use canal water, substituting for it groundwater. Padmapukur is one such area which has never been under canal water irrigation. In order to estimate the functions, we therefore use this area as the control site.

The sampling area in summary form is as follows (see Map 2 in Appendix 1): (i) Babupara: Located upstream of the Leather Complex, farmers in this area use fishery water from the fishery feeder canal originating from SWF; (ii) Kantatala: Located upstream of the Leather Complex, farmers in this area use fishery water from DWF and SWF; (iii) Vatipota: Located downstream of the Leather Complex and upstream of the Paglahata cowsheds, farmers in this area used water from SWF until recently, but have shifted to groundwater for irrigation in the last four years; (iv) Narayanpur: Located downstream of both the Leather Complex and the Paglahata cowsheds, farmers in the area use water directly from the SWF; (v) Ghoshpara: Located further downstream of both the Leather Complex and the Paglahata cowsheds, farmers in this area use water directly from the SWF; (vi) Ghojer Math: Located downstream of the leather complex, farmers in this area mix water from DWF and Bagjola/Bhangar canal; (vii) Karaidanga: Farmers in this area collect water from Krishnapur Canal; (viii) Padmapukur: Located between Ghojermath and Narayanpur, farmers in the area use ground water only, farms in the area having never been under canal water irrigation; (ix) Kulberia: Located upstream of the leather complex, farmers in the area use water from DWF for irrigation. Table 1 below describes the sampling areas in a nutshell.

<Table 1 about here>

In order to collect pollution data, in March-April, 2010, during the summer crop we first conducted a pilot survey to identify the most prominent heavy metals present in the soil, which vary in their presence across the designated sample points. Of the seven heavy metals (Co, Ni, Cr, Pb, Zn, Cd and Hg) tested for, we found only three (Pb, Hg and Cr) to fit our criteria. We collected two samples of soil from each of these sampling areas and took the average. For profit data, we surveyed 360 households in total with 40 from each of the 9 sampling points. These households provided us with profitability information for 565 plots in all located in the 9 sampling points taken together. The profit data was collected in the harvesting season November, 2010. The distribution of the surveyed plots in the nine sampling areas is described in figure 1 below.

<Figure 1 about here>

Figure 2 shows the variations in Lead (Pb), Mercury (Hg) and Chromium (Cr) in the soil across the nine sampling points. It arranges the sampling points from upstream to the downstream locations. It is noteworthy that while Cr has a rising trend from the upstream to the downstream, Pb has a declining trend. The presence of Pb suddenly jumps up at Naryanpur which has a paint factory. The presence of Hg on the other hand rises by a small amount at Vatipota immediately after the leather complex while declining further downstream.

<Figure 2 about here>

We checked the variation of Pb, Hg and Cr in soil has significant positive correlation with the variation of them in canal water across the sampling points.

For the purpose of collecting profitability data we prepared a questionnaire and gathered data on revenue and cost separately from the people who work in these plot of lands at all the sampling areas. Our data however did not indicate clearly the ownership of the plots in many of the areas although all of the respondents claimed that they had been cultivating these plots for decades while being residents of adjoining villages. The data on all the components of costs were collected separately. These include the cost of seeds, fertilizers, pesticides, tractor hire and labor. On the basis of the collected data, we calculated the value of profit. After checking the data, we were able to use only 549 of the 565 observations for the estimation of equation (1). The rest had to be dropped either due to incomplete information or for being outliers.

Table 2 summarizes the collected data and defines the variables.

<Table 2 about here>

A wide variability in the profitability data is observed. The farmers in fact made loss in some of the plots. In terms of plot size, the average size of the plot is small. The variation in output price for rice is the result of different varieties produced in different plots with the area being home to around 12 different varieties of rice. The price of seed shows more variability compared to the price of rice. We found the farmers in each of the plots were using combinations of fertilizers and pesticides. We divide both of the entire fertilizer basket and the entire pesticide basket used by the farmers in two separate baskets: main and supplementary. In the case of fertilizers farmers purchased N, P and K and mixed these in some proportion judged suitable for their own particular seed and soil. This is the main fertiliser. Farmers also purchased supplementary fertilisers such as urea and compost. In the case of pesticides, Furadon, Metacidi, Foratox were used a main pesticides while Hildon, Foret, Endosulfan were used as supplementary pesticides. We take the average price of the main and supplementary fertilizers used by the farmers in a particular plot as $PF1$ and $PF2$ respectively. Similarly, the average price of the main and supplementary pesticides used by the farmers in a particular plot has been taken as $PP1$ and $PP2$ respectively. Note the price of both main and supplementary fertilizer shows very little variability although the use of them varies relatively more across plots. The opposite is the case for the pesticides. The other inputs like services of tractors and the labor show no variability in the sampling areas, therefore we drop them from the scope of regression analysis. In our analysis we include a dummy variables D1. D1 = 1 represents a plot using canal water irrigation for last four years while D1 = 0 represents a plot using the ground water irrigation.

4. Methodology

Our hypothesis tests the impact of heavy metal toxicity found in wastewater and soil on the profitability of rice cultivation in the East Calcutta Wetlands region. Since our data reveals that the rice producing farms in this area have small landholdings, in addition to this area being a very small constituent of the large market for paddy that exists in the state of West Bengal which is one of the major rice-producing states of India,5 we assume the farmers to be competitive sellers in the market for rice. Similar logic allows us to assume that the farmers behave competitively in the input markets too.

A competitive farm maximizes its profit by the choice of its output given the price of rice and the price of relevant inputs prevailing in the market and physical conditions like the climate and the quality of the soil. Thus, we can consider the realized value of profit as a function of the output and input prices and certain non-price inputs. We call this function the profit function following standard microeconomics theory. In the case under consideration, we are interested to estimate the impact of the non-price inputs like the presence of heavy metals in soil, the use of nutrient-rich wastewater on the amount on the profit earned by the farms. For this purpose following (Arnade and Trueblood, 2002) and Vincent (2008) we estimate a flexible form of the profit function by using Seemingly Unrelated Regression (SURE) method so that we are able to track the way the non-price inputs influence the output supply and the priced-input use decisions of the farms as well eventually to have the estimated impact on profit. The flexible form profit function has been specified as:

$$\pi = \alpha_\pi + \beta_0 P_0 + \beta_{P_s} P_s + \beta_{P_{F_1}} P_{F1} + \beta_{P_{F_2}} P_{F2} + \beta_{P_{P_1}} P_{P1} + \beta_{P_{P_2}} P_{P2} + \beta_{00} P_0^2 + \beta_{P_{ss}} P_s^2 + \beta_{F1F1} P_{F1}^2 + \beta_{F2F2} P_{F2}^2 + \beta_{P1P1} P_{P1}^2 + \beta_{P2P2} P_{P2}^2 + \beta_{P_0A}(P_0 \times A) + \beta_{P_0Cr}(P_0 \times Cr) + \beta_{P_0Pb}(P_0 \times Pb) + \beta_{P_0Hg}(P_0 \times Hg) + \beta_{P_0D1}(P_0 \times D1) + \beta_{P_sA}(P_s \times A) + \beta_{P_sCr}(P_s \times Cr) + \beta_{P_sPb}(P_s \times Pb) + \beta_{P_sHg}(P_s \times Hg) + \beta_{P_sD1}(P_s \times D1) + \beta_{P_{F_1}A}(P_{F1} \times A) + \beta_{P_{F_1}Cr}(P_{F1} \times Cr) + \beta_{P_{F_1}Pb}(P_{F1} \times Pb) + \beta_{P_{F_1}Hg}(P_{F1} \times Hg) + \beta_{P_{F_1}D1}(P_{F1} \times D1) + \beta_{P_{F_2}A}(P_{F2} \times A) + \beta_{P_{F_2}Cr}(P_{F2} \times Cr) + \beta_{P_{F_2}Pb}(P_{F2} \times Pb) + \beta_{P_{F_2}Hg}(P_{F2} \times Hg) + \beta_{P_{F_2}D1}(P_{F2} \times D1) + \beta_{P_{F_1}A}(P_{P1} \times A) + \beta_{P_{P_1}Cr}(P_{P1} \times Cr) + \beta_{P_{P_1}Pb}(P_{F1} \times Pb) + \beta_{P_{P_1}Hg}(P_{P1} \times Hg) + \beta_{P_{P_1}D1}(P_{P1} \times D1) + \beta_{P_{P_2}A}(P_{P2} \times A) + \beta_{P_{P_2}Cr}(P_{P2} \times Cr) + \beta_{P_{P_2}Pb}(P_{P2} \times Pb) + \beta_{P_{P_2}Hg}(P_{P2} \times Hg) + \beta_{P_{P_2}D1}(P_{P2} \times D1) \tag{1}$$

So that from equation (1) the *output supply* function $(\frac{\partial \pi}{\partial P_0})$ is derived as:

$$Y = \beta_0 + \beta_{P_0A} A + \beta_{P_0Cr} Cr + \beta_{P_0Pb} Pb + \beta_{P_0Hg} Hg + \beta_{P_0D1} D1 + \beta_{00} 2P_0 \tag{2}$$

Similarly, the *input demand* function of ith priced-input is derived as $(-\frac{\partial \pi}{\partial P_i})$ for $i = S, F1, F2, P1, P2$. The respective input demand functions of seed, main fertilizer, supplementary fertilizer, main pesticide and supplementary pesticide are specified as:

$$S = -\beta_{P_s} - \beta_{P_{ss}} 2A - \beta_{P_sA} A - \beta_{P_sCr} Cr - \beta_{P_sPb} Pb - \beta_{P_sHg} Hg - \beta_{P_sD1} D1 - \beta_{ss} 2P_s \tag{3}$$

$$F1 = -\beta_{P_{F_1}} - \beta_{F1F1} 2P_{F1} - \beta_{P_{F_1}A} A - \beta_{P_{F_1}Cr} Cr - \beta_{P_{F_1}Pb} Pb - \beta_{P_{F_1}Hg} Hg - \beta_{P_{F_1}D1} D1 - \beta_{F1F1} 2P_{F1} \tag{4}$$

$$F2 = -\beta_{P_{F_2}} - \beta_{F2F2} 2P_{F2} - \beta_{P_{F_2}A} A - \beta_{P_{F_2}Cr} Cr - \beta_{P_{F_2}Pb} Pb - \beta_{P_{F_2}Hg} Hg - \beta_{P_{F_2}D1} D1 - \beta_{F2F2} 2P_{F2} \tag{5}$$

$$P1 = -\beta_{P_{P_1}} - \beta_{P1P1} 2P_{P1} - \beta_{P_{P_1}A} A - \beta_{P_{P_1}Cr} Cr - \beta_{P_{P_1}Pb} Pb - \beta_{P_{P_1}Hg} Hg - \beta_{P_{P_1}D1} D1 - \beta_{P1P1} 2P_{P1} \tag{6}$$

$$P2 = -\beta_{P_{P_2}} - \beta_{P2P2} 2P_{F2} - \beta_{P_{P_2}A} A - \beta_{P_{P_2}Cr} Cr - \beta_{P_{P_2}Pb} Pb - \beta_{P_{P_2}Hg} Hg - \beta_{P_{P_2}D1} D1 - \beta_{P2P2} 2P_{P2} \tag{7}$$

The equation system (1) – (7) has been estimated together using the restrictions on the coefficients described in Appendix 2.

As we estimate (1) – (7) notice from microeconomics theory we know the expected signs of certain coefficients. In particular we know, since the profit function is convex in output and input prices, it must be true from equation (1) that $\hat{\beta}_{00} = \frac{\partial^2 \pi}{\partial^2 P_0^2} > 0$ and $\hat{\beta}_{ii} = \frac{\partial^2 \pi}{\partial^2 P_i^2} > 0$ for $i = S, F1, F2, P1, P2$. On the other hand the intercept of the input demand functions $-\hat{\beta}_{ii} = -\frac{\partial \pi}{\partial x}$ must be positive for $x = P_S, P_{F1}, P_{F2}, P_{P1}, P_{P2}$. Note from (2) that $\hat{\beta}_{00}$ also estimates the slope of the output supply function. Similarly $\hat{\beta}_{ii}$ estimates the slope of the input demand function for the ith input from equations (3) – (7).

However, in this study our main focus had been the estimation of marginal effect of non-price inputs likeCr, Pb, Hg, A and $D1$ on π. These are estimated from equation (1) as:

$$\frac{\partial \pi}{\partial z} = \hat{\beta}_{P_0 z} P_0 + \hat{\beta}_{P_S z} P_S + \hat{\beta}_{P_{F1} z} P_{F1} + \hat{\beta}_{P_{F2} z} P_{F2} + \hat{\beta}_{P1z} P_{P1} + \hat{\beta}_{P2z} P_{P2}$$

Where $\beta_{xz} = \frac{\partial y}{\partial (x \times z)}$ for $x = P_0, P_S, P_{F1}, P_{F2}, P_{P1}, P_{P2}$ and $z =$ like $Cr, Pb, Hg, A, D1$ (8)

For the purpose of the calculation of $\frac{\partial \pi}{\partial z}$ from equation (8) we take only the statistically significant coefficients in consideration and discard all other coefficients.

The estimation of the marginal effect of like Cr, Pb, Hg, A and $D1$ on output supply and the demand for each of the inputs is relatively straightforward. For the output supply the estimates are derived from equation (2) as $\hat{\beta}_{P_0 z} = \frac{\partial Y}{\partial z}$ for $= Cr, Pb, Hg, A, D1$. For the input i, the estimates are derived from equations (3) – (7) as $\hat{\beta}_{P_i z} = -\frac{\partial i}{\partial z}$ for $i = \mathrm{S, F1, F2, P1, P2}$ and $z = \mathrm{Cr, Pb, Hg, A, D1}$.

5. Results

We discuss in this section the results of our investigation. Table 3 and 4 report the regression results for equations (1) and (2) – (7) separately.

<Table 3 and 4 about here>

From table 3 note that the coefficients of square of all the input prices and square of the output price are positive and significant at 1% level confirming the convexity of the profit function in prices. Table 3 also confirms that all the input prices except the main pesticide have negative coefficients (significant at 1% level) implying positive intercepts of their respective input demand functions. The coefficient of main pesticide price has unexpected positive sign, but turns out to be insignificant. However the output price has a significant negative coefficient implying negative intercept for the output supply function: it appears that positive amount of output is not produced unless the price of the output is sufficiently high at the market.

From table 4 it is clear that the output supply function and all the input demand functions have their slope coefficients having expected signs (positive for output supply function and negative for input demand functions) significant at 1% level, except the supplementary pesticide. Though the input demand function of supplementary pesticide has slope coefficient of expected sign (negative), but it turns out to be insignificant.

Table 4 also notes the impact of the non-price inputs on the output supply and input demand decisions made by the farms on individual plots. First, the use of canal water is observed to have insignificant impact on output supply, but it has significant positive impact on demand for seeds and significant negative impact on the demand for the supplementary pesticides. Marginal increase in Cr in soil raises output of a plot and reduces demands for both main and supplementary fertilizers. However, it increases demand for the main pesticide. The marginal increase in Pb in soil reduces output (almost 5 times more than the increase in the case of Cr), increases the demand for supplementary fertilizer, but reduces demand for both the pesticides. The marginal increase in Hg is found to have positive impact on output (in slightly lower extent compared to Cr), but reduces demand for both the fertilizers and increases demand for both the pesticides.

The net impact of the non-price inputs on the profitability of rice cultivation has been calculated following the method described in the previous section and the outcome is described in table 5 below.

<Table 5 about here>

The most interesting observation is: on average the canal water using plots is found to have lower profit from rice cultivation compared to the plots using groundwater. The accumulated Pb in soil explains the major fall in profitability of such plots. The presence of Hg in soil also has a small negative impact. Though the accumulated Cr in soil raises profitability of the plots its effect is far outweighed by the combined negative impact of Pb and Hg. Our results also show that while large plots can withstand the fall in profitability up to a certain level, the small plots really bears the burn.

6. Conclusions and Policy Recommendations

Our objective in this study was to empirically test the profitability of rice cultivated on lands irrigated using untreated wastewater from the city of Kolkata. The results reported above indicate that rice cultivation is less profitable in plots of land that are under untreated-sewage water irrigation compared to lands that have never been under such irrigation and/or use ground water only. Thus, the local farmers‟ complaint about the fall in profitability of rice cultivation due to toxicity of the irrigation water and soil receives credence through our study. Our study establishes that the positive nutrient effect of the sewage water fails to outweigh the negative effects due to accumulation of heavy metals like Lead and Mercury in the soil. Interestingly, though Lead and Mercury still hover around the legally permissible levels in the canal water and soil of this region, our study finds Lead to have a large negative impact and Mercury to have a small negative impact on the profitability of rice cultivation. Though Chromium has a positive impact on profitability, it is nearly five times smaller than the negative impact due to Lead. So it is clear from figure 2 that as we move in sequence from the sampling area of Babupara in the upstream to Ghoshpara in the downstream, though the presence of chromium increases in soil and the presence of lead falls, the profitability still takes a beating. We also observe the wisdom of the farmers of Vatipota area in switching from the canal irrigation to the ground water irrigation. Of these three metals mentioned above, while the presence of Lead and Mercury in the water and soil may be the result of discharges from industries producing paint and glass, batteries and from the disposed medical equipments, that of Chromium can be attributed to the tanneries.

Our study also found that the construction of the leather complex on the fringe of the East Calcutta Wetlands, contrary to popular perceptions, may not have been all that harmful to rice cultivation in this region although it uses Chromium. Instead, our results would support regulations to control the discharge of Lead and Mercury from other industries such as batteries, paint and glass, disposal of medical equipments from the health facilities located in the city and from the private households using products with high Lead content such as paints. An alternative to such stringent regulations which are always difficult to implement would be to construct an effluent treatment plant which removes these metals from the sewage before discharging it into the outflow canals. It is evident that the survival of the wetlands with all its ecological and environmental benefits crucially hinges on the controlled use of these metals by the household sector and industry. Such measures would enable the continuation of the long-established practice of using sewage water in rice cultivation in the East Calcutta Wetlands region. Otherwise the voice for conversion of the Wetlands gets strengthened.

The results we obtain in the paper glosses over the differences among varieties of rice produced in the region. The study would therefore have been more useful had it been conducted for specific varieties of rice. Moreover, since the rice grown is ultimately for human consumption, the conclusions drawn from this research on the profitability of rice cultivated using untreated sewage water would not be complete without a parallel study investigating the health impacts of rice produced using such water. From a policy point of view, since the non-saline fishery present in this region is the other major user of the wastewater and provider of livelihood support for the local population, a similar study in fisheries is also due. If the impact of wastewater is positive in fisheries and outweighs the loss in agriculture, the voice of those supporting the conservation of the Wetlands is strengthened. Otherwise unless the appropriate corrective steps are taken it appears that conversion of the Wetlands in economically more productive use is imminent.

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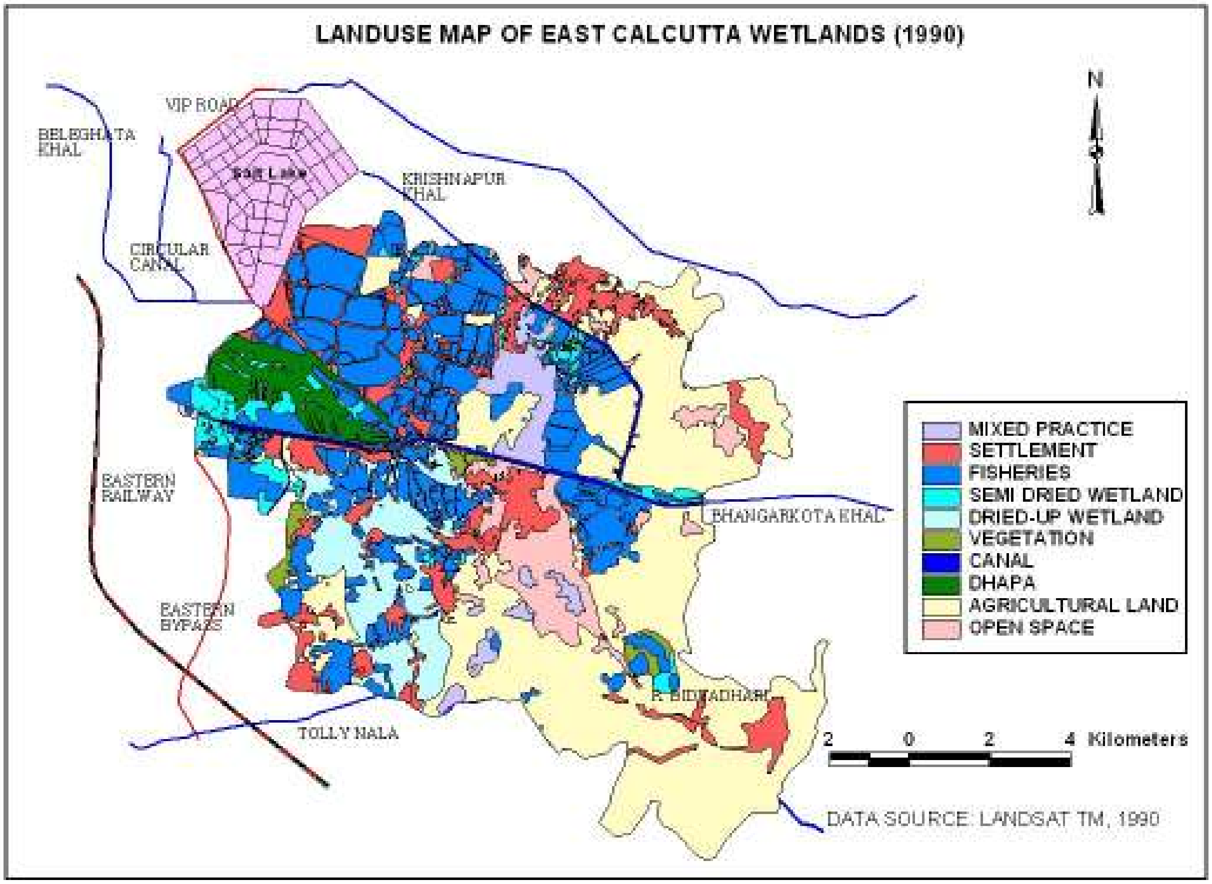
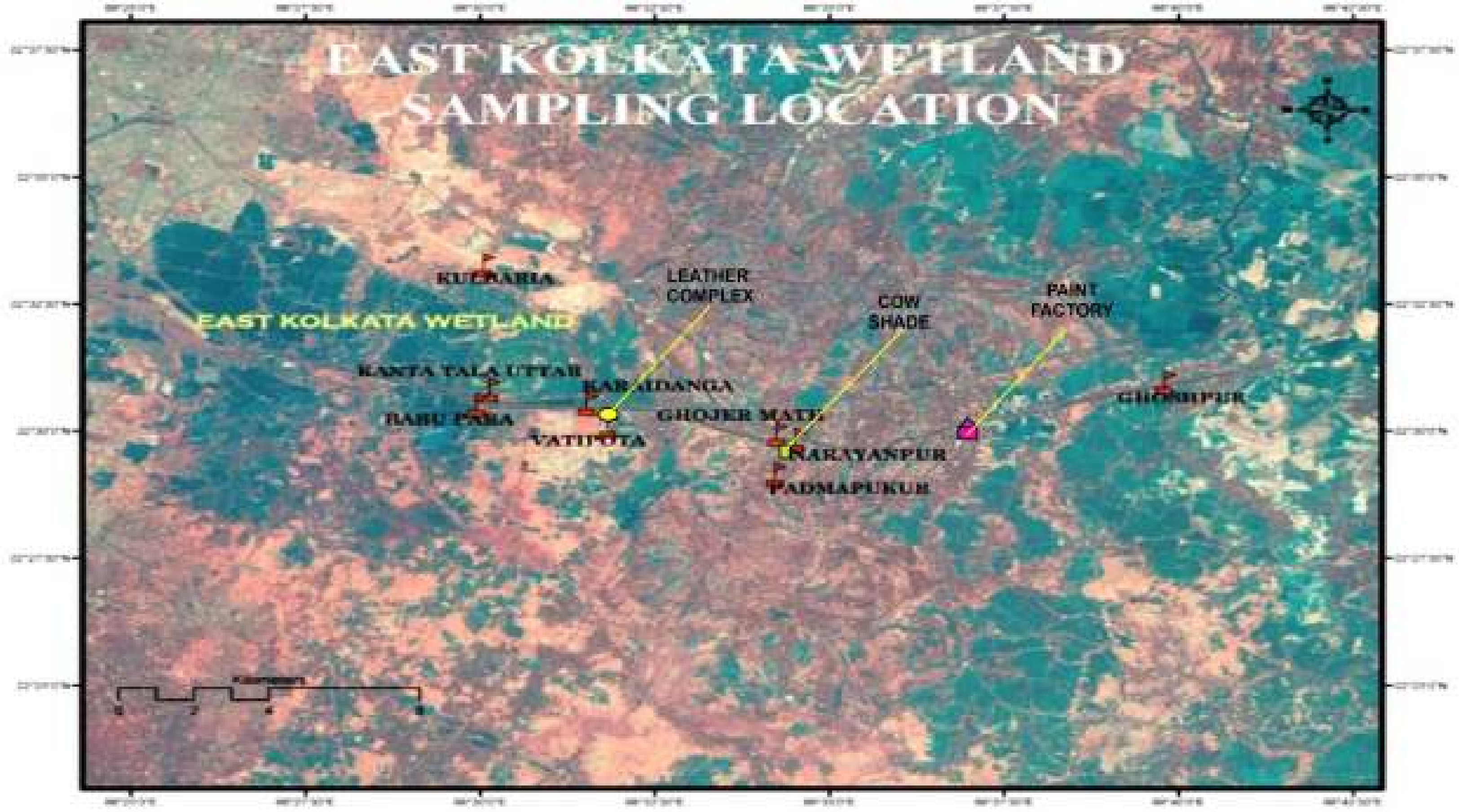
Appendix 1

Map 1: Landuse Map of East Calcutta Wetlands (2001)



DATA SOURCE: LANDSAT TM, 1990

Map 2: Sampling Areas



Appendix 2

Restrictions on coefficients used in estimation of equations (1) – (7)

R1	$[\pi]P_0 = [Y]Cons$	R15	$[\pi]P_S Hg = [S]Hg$	R29	$[\pi]P_{P1}Pb = -[P1]Pb$
R2	$[\pi]P_S = -[S]Cons$	R16	$[\pi]P_S D1 = [S]\mathrm{D1}$	R30	$[\pi]P_{P1}Hg = -[P1]Hg$
R3	$[\pi]P_{F1} = -[F1]Cons$	R17	$[\pi]P_{F1}A = -[F1]A$	R31	$[\pi]P_{P1}D1 = -[P1]\mathrm{D1}$
R4	$[\pi]P_{F2} = -[F2]Cons$	R18	$[\pi]P_{F1}Cr = -[F1]Cr$	R32	$[\pi]P_{P2}A = -[P2]A$
R5	$[\pi]P_{P1} = -[P1]Cons$	R19	$[\pi]P_{F1}Pb = -[F1]Pb$	R33	$[\pi]P_{P2}Cr = -[P2]Cr$
R6	$[\pi]P_{P2} = -[P2]Cons$	R20	$[\pi]P_{F1}Hg = -[F1]Hg$	R34	$[\pi]P_{P2}Pb = -[P2]Pb$
R7	$[\pi]P_0 A = [Y]A$	R21	$[\pi]P_{F1}D1 = -[F1]\mathrm{D1}$	R35	$[\pi]P_{P2}Hg = -[P2]Hg$
R8	$[\pi]P_0 Cr = [Y]Cr$	R22	$[\pi]P_{F2}A = -[F2]A$	R36	$[\pi]P_{P2}D1 = -[P2]\mathrm{D1}$
R9	$[\pi]P_0 Pb = [Y]Pb$	R23	$[\pi]P_{F2}Cr = -[F2]Cr$	R37	$[\pi]P_0^2 = [Y]2P_0$
R10	$[\pi]P_0 Hg = [Y]Hg$	R24	$[\pi]P_{F2}Pb = -[F2]Pb$	R38	$[\pi]P_S^2 = -[S]2P_S$
R11	$[\pi]P_0 D1 = [Y]\mathrm{D1}$	R25	$[\pi]P_{F2}Hg = -[F2]Hg$	R39	$[\pi]P_{F1}^2 = -[F1]2P_{F1}$
R12	$[\pi]P_S A = -[S]A$	R26	$[\pi]P_{F2}D1 = -[F2]\mathrm{D1}$	R40	$[\pi]P_{F2}^2 = -[F2]2P_{F2}$
R13	$[\pi]P_S Cr = -[S]Cr$	R27	$[\pi]P_{P1}A = -[P1]A$	R41	$[\pi]P_{P1}^2 = -[P1]2P_{P1}$
R14	$[\pi]P_S Pb = [S]Pb$	R28	$[\pi]P_{P1}Cr = -[P1]Cr$	R42	$[\pi]P_{P2}^2 = -[P2]2P_{P2}$

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Tables

Table 1: Description of Sampling Areas

Location	Type of irrigation used	Location with respect to the Leather Complex	Location with respect to the cow shade	Location with respect to the paint factory
Babupara	Canal water from fishery feeder canal originated from SWF	Upstream	Upstream	Upstream
Kantatala	Canal water from fishery feeder canal originated from DWF and SWF	Upstream	Upstream	Upstream
Kulberia	Directly from DWF	Upstream	Upstream	Upstream
Karaidanga	Directly from Krishnapur Canal	Upstream	Upstream	Upstream
Vatipota	Last four years used ground water but before directly from SWF	Downstream	Upstream	Upstream
Ghojer Math	Mixed water from DWF and Bagjola/Bhangar canal	Downstream	Upstream	Upstream
Padma Pukur	Ground water, never used canal water	-	-	-
Narayanpur	Directly from the SWF	Downstream	Downstream	Upstream
Ghoshpara:	Directly from the SWF	Downstream	Downstream	Downstream

Table 2: Summary of Statistics

Variable	Notation	Number of Observations	Mean	Std. Dev.	Min	Max
Production (Kg)	Y	549	723.1913	597.0537	60	4050
Profit (Rs)	π	549	8688.526	8279.036	-42.6	72289.4
Output price (Rs/Kg)	P_0	549	18.24772	2.708566	10	33
Price of seed (Rs/Kg)	P_s	549	26.41712	4.352086	14	35
Seed used (kg)	S	549	12.526	10.80548	0.533333	105
Price of main fertilizer (Rs/Kg)	P_{F1}	549	9.666266	6.545541	3	65
Main fertilizer used(Kg)	$F1$	549	49.93115	59.5402	0.39375	480
Price of supplementary fertilizer (Rs/Kg)	P_{F2}	549	6.735082	3.735305	3	60
Supplementary fertilizer used(Kg)	$F2$	549	30.10066	40.31052	0.25348	344.9645
Price of main pesticide (Rs/Kg)	P_{P1}	549	140.5423	141.1982	10	900
Main pesticide used(Kg)	$P1$	549	1.052076	1.247441	0.006154	12.17391
Price of supplementary pesticide (Rs/Kg)	P_{P2}	549	122.7961	102.3841	20	600
Supplementary pesticide used(Kg)	$P2$	549	0.732306	1.04883	0.003639	8
Plot size (katha)	A	549	21.56011	16.83258	2.5	140
Pb in Soil (mg/kg)	Pb	549	27.40018	16.92186	5.9	57.85
Hg in soil (µg/gm)	Hg	549	1036.598	1065.397	34.81	3346.623
Cr in soil (mg/kg)	Cr	549	78.81494	17.68263	48.6	99.9

Note: Other variables used are:

D1: Dummy for using canal water for last 4 years, 1= Yes, 0=Otherwise

Table 3: Results from Regression Analysis (Dependent Variable: Profit)

Dependent Variable: Profit ; R Square: 0.7620; Chi Square: 17229.42*							
P_0	-328.789* (98.65311)	P_{P2}^2	0.001919* (0.000223)	P_{F1}X A	-1.71582* (0.111657)	P_{P1}X Cr	-0.01299* (0.004926)
P_s	-16.0668* (3.089029)	P_0X A	26.79301* (0.526225)	P_{F1}X Cr	1.056709* (0.198298)	P_{P1}X Pb	0.030471** (0.014132)
P_{F1}	-128.4* (19.65585)	P_0X Cr	1.855635** (0.930991)	P_{F1}X Pb	-0.60522 (0.689368)	P_{P1}X Hg	-0.00062* (0.000211)
P_{F2}	-37.7706* (14.22172)	P_0X Pb	-8.91988* (3.148434)	P_{F1}X Hg	0.035676* (0.010252)	P_{P1}X D1	0.244718 (0.202051)
P_{P1}	0.297167 (0.488447)	P_0X Hg	0.116635* (0.047616)	P_{F1}X D1	-10.183 (9.38884)	P_{F2}X A	-0.02739* (0.00262)
P_{P2}	-1.4277* (0.456001)	P_0X D1	-31.8684 (43.52191)	P_{F2}X A	-1.64548* (0.079867)	P_{F2}X Cr	0.005794 (0.004574)
P_0^2	12.86551* (1.14423)	P_sX A	-0.60151* (0.014671)	P_{F2}X Cr	0.486716* (0.141481)	P_{F2}X Pb	0.030778** (0.015767)
P_s^2	0.284312* (0.028984)	P_sX Cr	0.014941 (0.025785)	P_{F2}X Pb	-1.35304* (0.48841)	P_{F2}X Hg	-0.00061* (0.000234)
P_{F1}^2	1.017371* (0.131149)	P_sX Pb	0.116545 (0.088545)	P_{F2}X Hg	0.024744* (0.007284)	P_{F2}X D1	0.167663 (0.219767)
P_{F2}^2	0.431819* (0.160281)	P_sX Hg	0.000015 (0.001329)	P_{F2}X D1	13.45667** (6.688426)	Cons	1179.739* (391.7074)
P_{P1}^2	0.00144* (0.000168)	P_sX D1	-3.77258* (1.209699)	P_{P1}X A	-0.05233* (0.00283)		

The standard errors are in parenthesis; *, ** and *** indicate significance at 1 percent, 5 percent and 10 percent levels, respectively.

Table 4: Results from Regression Analysis (Dependent Variable: Output and inputs)

Dependent Variable : output R Square: 0.8758 Chi Square: 3672.40		Dependent Variable : Seed R Square: 0.7330 Chi Square: 1892.12		Dependent Variable : Main Ferti R Square: 0.4863 Chi Square: 439.76		Dependent Variable : Supp Ferti R Square: 0.4384 Chi Square: 496.05		Dependent Variable : Main Pesti R Square: 0.1882 Chi Square: 452.53		Dependent Variable : Supp Pesti R Square: 0.1264 Chi Square: 207.45	
A	26.79301* (0.526225)	A	0.601505* (0.014671)	A	1.715817* (0.111657)	A	1.645481* (0.079867)	A	0.052335* (0.00283)	A	0.027394* (0.00262)
Cr	1.855635** (0.930991)	Cr	-0.01494 (0.025785)	Cr	-1.05671* (0.198298)	Cr	-0.48672* (0.141481)	Cr	0.012992* (0.004926)	Cr	-0.00579 (0.004574)
Pb	-8.91988** (3.148434)	Pb	-0.11654 (0.088545)	Pb	0.605225 (0.689368)	Pb	1.353041* (0.48841)	Pb	-0.03047** (0.014132)	Pb	-0.03078** (0.015767)
Hg	0.116635* (0.047616)	Hg	-1.5E-05 (0.001329)	Hg	-0.03568* (0.010252)	Hg	-0.02474* (0.007284)	Hg	0.000616* (0.000211)	Hg	0.000606* (0.000234)
2 X P_0	12.86551* (1.14423)	2 X P_S	-0.28431* (0.028984)	2 X $F1$	-1.01737 (0.131149)	2 X $F2$	-0.43182* (0.160281)	2 X $P1$	-0.00144* (0.000168)	2 X $P2$	-0.00192 (0.000223)
D1	-31.8684 (43.52191)	D1	3.772581* (1.209699)	D1	10.18296 (9.38884)	D1	-13.4567** (6.688426)	D1	-0.24472 (0.202051)	D1	-0.16766 (0.219767)
Cons	-328.789* (98.65311)	Cons	16.06681* (3.089029)	Cons	128.3997* (19.65585)	Cons	37.77056* (14.22172)	Cons	-0.29717 (0.488447)	Cons	1.427696* (0.456001)

The standard errors are in parenthesis; *, ** and *** indicate significance at 1 percent, 5 percent and 10 percent levels, respectively.

Table 5: The Impact of Non-price Inputs on Profit

Variable	Observation	Mean	Std. Dev.	Min	Max
Cr	549	46.63075	8.877071	29.95824	106.794
Pb	549	-163.798	25.50592	-290.937	-89.2765
Hg	549	-3.71752	3.991925	-37.3519	0.086244
A	549	436.7915	74.32663	187.5413	818.1508
D1	549	-633.949	120.9338	-1227.63	77.3688

Figures

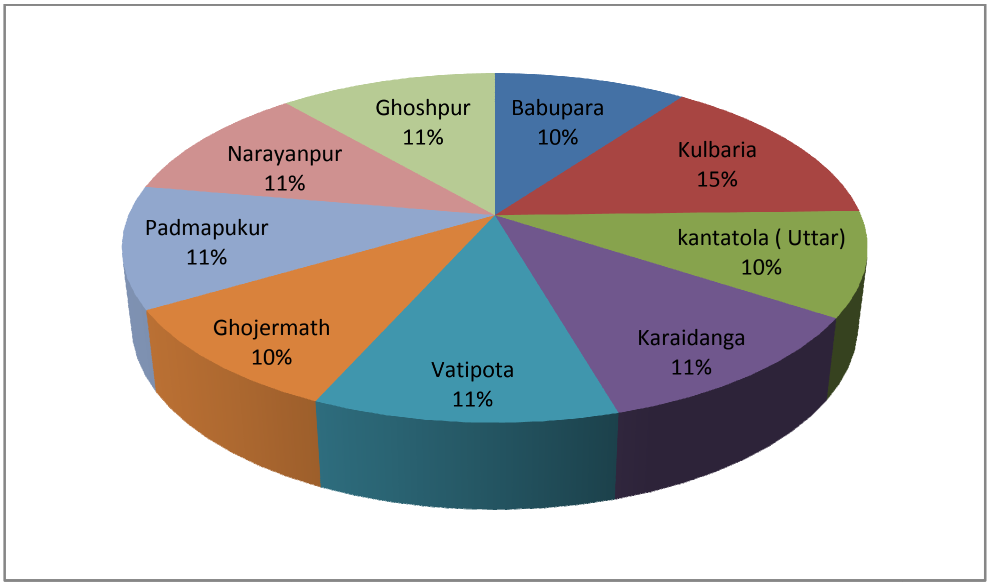

Figure 1: Distribution of Plots in the Sampling Areas

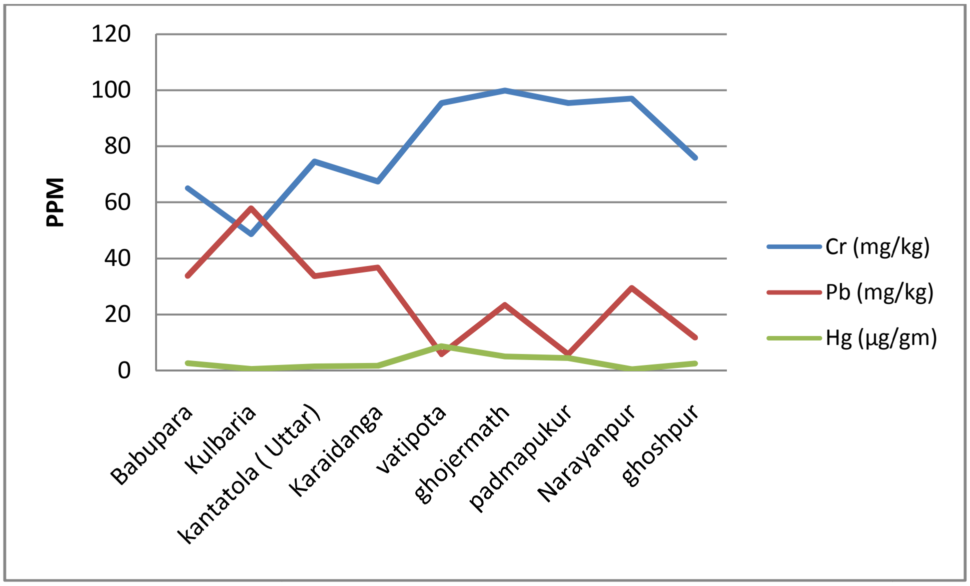

Figure2: Presence of Heavy Metals in Soil