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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 the profitability of rice cultivation in the East Calcutta Wetlands region where untreated sewage water from the city of 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 higher profits than those using groundwater. However, we also find the profitability of plots using wastewater negatively affected by the presence of heavy metals such as Chromium, Lead and Mercury that are found in the water and soil. Of the two opposing effects of wastewater irrigation, the positive effects of organic nutrients outweigh the negative effects of heavy metal toxicity. These results support both efforts to conserve the Wetlands, which will generate a number of ecological benefits, as well as to regulate the discharge of heavy metals into the water from households and industries that are located upstream in the city of Kolkata.

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

JEL Classification: Q13, Q15, Q53

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 project in 1930 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 project has enabled the East Calcutta Wetlands, spreading over an area of approximately 7,500 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 project save the city the cost of construction of Sewage Treatment Plants (STP), it also contributes to flood control in the city and 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 the value of livelihood support and sewage water treatment services of the Wetlands at INR 1,656 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. Its protected status therefore restricts the expansion of the city towards the south east.

The reliance of the city of Calcutta 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 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]

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

[2] Assumed USD1 = INR 45.

[3] See Mukherjee (2010) for a discussion.

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 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 more profitable than rice cultivated using groundwater-based irrigation. However, the profitability of rice cultivated using wastewater is on the decline due to the presence of heavy metals like Chromium, Lead and Mercury in the water and soil. The results of our study are interesting because they help clarify popular perceptions regarding the decreasing 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 points out (1995), 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 of 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, 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 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 noteworthy is that none of the above-cited studies was 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) which has a system of output and inputs to study allocative efficiency in Russian agriculture.

3. The Study Area, Sample Design and Data

The East Calcutta Wetlands located on the south-eastern fringe of the city of Kolkata 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).

Moreover, as the water flows 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

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

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 bio-degradable content of the waste water.

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 is lifted from the Storm Water Flow (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 Dry Water Flow (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 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): (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.

In order to collect pollution data, we first conducted a pilot survey to identify the most significant heavy metals, 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. We gathered the samples in March-April, 2010, during the summer crop. 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.

Figure 1 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 area. It is noteworthy that while Cr has a rising trend from the upstream to the downstream, Pb has a declining trend. 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 shows the acidity/alkalinity of the soil. The value of pH below 7 implies acidic soil quality. The value of pH above 7 implies alkaline soil quality. The pH is exactly 7 at the control (i.e., ground water irrigated) area of Padmapukur while showing an overall declining trend from upstream to downstream areas. Figure 3, like Figure 1, shows the presence of Lead, Mercury and Chromium in the canal wastewater along the sampling points where they are again arranged upstream to downstream. The toxicity levels are more or less constant along the canal with a sharp rise at Narayanpur for Chromium and Mercury although the Chromium presence sharply drops again at the next point which is Ghoshpur.

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 lands at all the sampling points. Our data however did not indicate clearly the ownership of the lands in many of the areas although all of the respondents claimed that they had been cultivating these lands 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, tractors 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. Figure 3 shows the average profitability of the nine sampling areas arranged from upstream to downstream. It is noteworthy that there is a dip in average profitability at the Padmapukur region, which is the control area in our sampling strategy using only groundwater for cultivation having never used canal water for irrigation. On the other hand, among the canal water using regions (present and past), the average profitability increases even downstream of the Leather Complex.

Table 1 summarizes the collected data and defines the variables. It is noteworthy that there is wide variability in the profitability data. 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. It is possible that the output price also depends on the quality of the grain, which in turn depends on the presence of toxicity. In order to check if this is the case, we ran a pair-wise correlation with output price on the one hand and toxicity levels measured for each of the three heavy metals in water and soil. The test suggested the correlation to be quite low with CrCW (0.119), PbCW (0.113), HgCW (0.164), CrS (0.055), PbS (0.035), and HgS (0.037). Only the first three metals were significant at 1 percent level.

The price of seed shows more variability compared to the price of rice. We found the farmers in each of the plots to use combinations of fertilizers. PFERTI represents the *simple* average of the respective prices of fertilizers in these baskets. This was not the case with pesticides where farmers use branded products. We considered two types of fertiliser prices in this study, one for the main fertiliser used and one for a supplementary fertiliser.[5] In the case of pesticides too, we used the price of two types of pesticide.

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[5] Farmers purchase N, P and K and mix these in some proportion judged suitable for their own particular seed and soil. This is the main fertiliser. Farmers also purchase a supplementary fertiliser such as urea or compost.

The variability in the Hg(S) is smaller than the variability of either Cr(S) or Pb(S), which have a roughly similar pattern of variation across the plots. In canal water, the variability in Pb(CW) is the lowest. The price of fertilizer shows very little variability although the use of fertilizer varies relatively more. The opposite pattern manifests itself in the case of the pesticides.

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 the rice producing farms in this area to be small landholdings (see Table 1), in addition to 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,[6] we assume the farmers to be competitive sellers in the market for rice.

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. The realized profit of the farm depends on these prices. Since the farmers are competitive buyers in the input markets, they have no control over input prices. Thus, we can consider the realized value of profit as a function of the output and input prices. We call this function the profit function following standard microeconomics theory. In the case under consideration, the heavy metals present in the wastewater and soil act as indicators of the impact of metal pollution. Since our study area is too small for climatological variations from one observation unit to the other, we do not consider the climate as an attribute in the argument of the profit function. Therefore, the study primarily estimates the profit function specified as:

Profit per kg of rice = *f* (Plot size, price of output and its square, Dummy 1 for use of local varieties of rice seed, prices of seed, tractor, main and supplementary fertiliser, main and supplementary pesticide, labor and the squares of each of these, Dummy 2 for use of canal water, levels of Chromium, Lead and Mercury in canal water and soil and the squares of each of these) .... (1)

Land area is included as an explanatory variable as are output and input prices. The quadratic terms are included so that the supply function, a derivative of the profit function, remains a function of these prices (Arnade and Trueblood, 2002). Also included are levels of metal pollution in water and soil, which we expect to negatively impact on profits. The inclusion of the square terms of pollution levels is justified for the purpose of capturing the non-linearity of the impact of metal pollution on profits, the implication being that the marginal impact of these pollutants is not constant at all levels of these variables.

Some of the variables in the argument of the profit function are beyond the control of the farmer such as pollution levels. Similarly, the use of canal water is a matter of compulsion due to lack of a viable alternative source. Other variables such as price of output, price of tractor or labor and other inputs are also market determined. Thus, the specification partially avoids the endogeneity problem which is supposed to arise when variables on both sides of an equation are a function of the same factors and, therefore, are correlated.[7] In such instances the results may be interpreted to imply association rather than causation.

Ideally, our study should have been able to estimate a production function. However, one problem of land fragmentation and the resultant small size of holdings in this region is that farmers often cultivate several plots of land. Furthermore, they buy inputs in bulk at the beginning of the agricultural season and keep them in storage for use in small doses from the beginning of the season to the end. It is therefore impossible to collect reliable data on the quantity of each input such as seed, fertilizer or pesticide used on each plot of land. There is also likely to be some multi-collinearity between inputs which would result in some input quantities being dropped from the possible production function being estimated. Taking these problems into consideration, we opted to estimate a profit function.

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[6] See http://www.indiastat.com for the data.

[7] See Vincent (2008) for details.

5. Results and Discussion

We discuss in this section the results of our investigation into the impacts of environmental (heavy metals) pollution on profit per unit of output. Table 2 reports the results.

We run the regression using three alternative specifications. The dependent variable is profit per unit of output rather than profit per unit of land. In Model I, profit per unit of output is regressed on plot size (area in *katha*[8]), price of output per Kg and its square, price of seed and its square, price of labor and its square, price of tractor and its square, price of two types of fertilizers and their squares, and the price of two types of pesticides and their squares. For each plot of cultivated land, the fertilizer used the most, a combination of N, P, and K, is classified as type one fertilizer, the supplementary fertilizer being termed type two. Similarly, we term the main rice pesticide such as Folidol pesticide type one and the supplementary pesticide used to repel flying insects type two. The justification for using the square terms is that it allows us to capture any non-linear impact of price while the supply function, which is a derivative of the profit function, remains a function of price of that input. We have also included two dummy variables, D1 for the use of local varieties of rice seed (= 1) as opposed to miniket (= 0), which is the most widely used rice seed, and another dummy (D2) for farmers who have systematically used canal wastewater for the last 4 years (= 1) as opposed to those who did not (= 0). We summarize the regression results in Table 2.

The adjusted R^2 value in Model I is 0.2297. Area, price of seed and its square, price of tractor, square of price of supplementary fertiliser, price of supplementary pesticide and its square, and the dummy for use of canal water turn out to be variables that are significant at 1 percent level. The price of supplementary fertiliser and price of main pesticide are significant at 10 percent level.

Plot size has a positive impact on profits, a sign of scale economies. While we can see from the signs that the more expensive seeds yield more profit, the marginal rate is declining. The sign of the price of tractor is positive, with a rising marginal rate. Although this is unexpected as is the sign of the price of supplementary fertiliser, which is also positive with a falling marginal rate, there may be an unexplained quality such as “suitability to soil” issues here that we have not been able to single out. The price of the main pesticide shows the expected negative sign. But the sign of the supplementary pesticide shows an unexpected positive sign with the declining marginal rate indicating similar uncaptured quality factors. The sign of the dummy for use of canal water is positive showing that waste canal water does contain bio-nutrients that enrich the fertility of the soil, this being the original rationale behind using urban wastewater from the canal in farms adjacent to the wetlands. However, with the more recent flow of hazardous metals in the waste water, this relationship can change when pollution variables are included in the regression. This is in fact investigated in the next two models.

Treating Model I as a benchmark, we next modify the model specification for Model II. In addition to the variables included in Model I, we therefore add three measures of heavy metals present in canal wastewater and their squares as explanatory variables. As discussed earlier, a unique feature of agriculture in the neighbourhood of the East Calcutta Wetlands is the use of urban wastewater from the city of Kolkata for rice cultivation. The original logic behind the use of the canal water was that this wastewater rich in bio-nutrients and would thereby help retain the fertility of soil and improve agricultural productivity. However, two things have changed with the passage of time. First, the chemical content of the wastewater from urban use has changed over time with the water now containing more chemicals and metals of the detergent-type waste chemicals and toxic substances than before. Second, the mushroom growth of many small and medium scale industries immediately outside the wetlands pose the hazard of industrial pollution, especially pollution from heavy metals. The location of the Calcutta Leather Complex at Bantala near the Wetlands is a case in point. We therefore measure for the presence of three major heavy metals, namely Chromium, Lead and Mercury, as these are the most toxic of the heavy metals found in the water. We have included these concentration measures (mg/litre) and their squares as explanatory variables. The rationale behind including the square of the pollutant measures is to ensure that we do not force the regression to assume the impact of the presence of heavy metals on profitability to be constant at all levels. In the present model, the heavy metal concentration measures are taken from water samples collected from the point nearest to the agricultural plot. We discuss these results below.

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[8] *Katha* is a popular local unit of measurement in the area. 1 *Katha* = 720 square feet. 20 *Kathas* = 1 *Bigha* and 3 *Bighas* = 1 Acre.

In Model II, there is considerable improvement in the goodness of fit measured by adjusted R2 value. It increases from 0.23 in Model I to 0.35 in Model II, mainly because of the addition of more explanatory variables. When compared with Model I, variables now found significant at 1 percent level are price of seed and its square, price of tractor, price of supplementary pesticide and its square, price of labor and its square, and dummy for use of canal water. Among the heavy metals, the concentration of Mercury in canal water is significant at 1 percent level. At 5 percent level, the significant variables are plot size and price of supplementary pesticide and its square. At 10 percent level, the square of Hg concentration is significant.

In Model II, the sign of plot size is positive and this is to be expected. The sign of seed prices shows that more expensive seeds yield more profit but the marginal impact is declining. The problem with the sign of tractor prices seen earlier remains although here too the sign is positive and unexpected with a declining marginal rate. The prices of supplementary fertilizer and supplementary pesticides too show positive, unexpected signs with declining marginal rates. Hence, we have to assume that there may be an undetected quality or "suitability to the soil" issues that have not been captured in the data. The impact of the price of labor and its square on profitability falls at a rising rate and this is expected. Concentrations of Mercury have a negative sign, with a rising marginal rate, clearly demonstrating the negative impact of the presence of heavy metals on crop and its profitability. This clearly shows the impact of heavy metals present in canal water. Thus, among the heavy metals present in the canal water, Mercury seems to be the metal that is damaging to crop production and consequently negatively affecting profitability the most. Further, the decline in profitability happens at a rising rate with increasing levels of Mercury indicating that at some level of Mercury pollution in canal water, agriculture is likely to become unprofitable altogether. The seriousness of such non-linearities in the impact of metal pollution on profits is a matter for concern. The dummy variable for use of canal water is positive indicating that the wastewater is rich in bio-nutrients, which helps increase profitability.

In general, the impact of prices of inputs and their squares show a significant impact on profitability. In addition, pollutants like heavy metals show a negative impact on profitability although their impact is non-linear.

In the above regression, the concentration of heavy metals was measured in the nearest canal bearing urban wastewater. There was some concern about its lasting impact when such contaminants reach the soil via the canal water. Since rice cultivation requires water to remain stagnant at the base of the plant for quite some time, we felt that contaminants can therefore enter the soil and remain there for longer periods. Thus, instead of measuring the contaminants in the canal water, we need to measure these directly in the soil. Thus, we now replace all values measured in canal water by corresponding values measured in soil. Model III presents the results.

Model III has an adjusted R squared of 0.35 which is nearly the same as in Model II. Most of the variables whose coefficients were significant at 1 percent level in Model II remain significant at the same level in this model with the square of price of tractor coming significant at 5 percent level. The signs of the major input prices and their squares behave exactly the same as they do in Model II and the problem of uncaptured quality issues remains here too.

The concentrations of metal pollutants behave now in an interesting way. Concentration of Chromium, Lead and Mercury and their squares come out significant at 1 percent level with a negative sign on the first order term and a positive sign for the marginal rate for Chromium and Mercury, indicating that profits fall at a rising rate with higher levels of concentration of Chromium and Mercury in the soil. It is noteworthy that Mercury is the lightest heavy metal and has a tendency to climb up the plant to the grain affecting profitability negatively. As to Lead, the sign of the first order term is positive and unexpected, but the sign of the square term is negative indicating a declining marginal rate.

According to these results, toxic metals like Chromium and Mercury in the soil do play a major role in reducing the profitability of rice cultivation. Further, since the marginal rate of impact for these metals is increasing, one could conclude that the negative impact on profits increases with rising levels of metal pollution and that at some further higher level of metal pollution rice cultivation may become unprofitable altogether. However, the impact of metal pollution through soil is higher than in instances where the same contaminants are absorbed via irrigation from canal water.

Of the three models, Model III performs the best in terms of adjusted R squared. We also used Akaike Information Criteria [or AIC] for the purpose of comparing the models. Table 2 reports the results which makes it again evident that on this count too Model III performs the best. This is further substantiated by the number of variables found significant at 1 and 5 percent levels in Model III and its ability to capture the impact of non-linearity and the effect of heavy metal contaminants on profitability.

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 more 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. We find that the average profit per unit of output (Rs/Kg) from all sample plots using urban sewage water is 3.09 while it is only 0.40 for all plots under irrigation with ground water. However, the local farmers were of the opinion that the profitability of rice cultivation has been decreasing due to toxicity of the irrigation water and soil. The present study confirms this view. While our study establishes that the profitability of canal water irrigated plots are higher than that of ground water irrigated plots due to the positive nutrient effect, it is entirely possible that the profitability of sewage-water-irrigated land has been falling over the years due to the presence of heavy metals like Chromium and Mercury. Interestingly, though Chromium and Mercury still hover around the legally permissible levels in the canal water and soil of this region, it has a significantly negative impact on the profitability of rice cultivation. Of the two metals, while the presence of Mercury in the water and soil may be the result of discharges from industries producing paint and glass, 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 which leaves a negative impact on the soil. Instead, our results would support regulations to control the discharge of Lead and Mercury from other industries such as batteries, paint and glass located in the city and from private households using products with high Lead content such as enamel 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.

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 framework point of view, evidence from studies that conjoin economic with health benefits would therefore strengthen the voice of those supporting the conservation of the East Calcutta Wetlands against others who are demanding its conversion into more economically productive uses.

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Tables

Table 1 : Descriptive Statistics

Variables	Description	Maximum	Minimum	Mean	Std. Deviation
Profit	Profit per kg	16.74	0.016	11.23	2.86
Poutput	Output Price	13.33	10	11.84	0.84
Area	Plot Size (Katha/Hh)	140	2.5	21.23	4.35
PSEED	Price of Seed	35	14	26.41712	4.352086
PTRAC	Price of Tractor	520	56	234.561	120.3871
PFERTI1	Price of Main Fertilizer	65	3	9.563352	6.548568
PFERTI2	Price of Supplementary Fertilizer	18	3	6.505373	1.882891
PPEST1	Price of Main Pesticide	900	10	140.4786	141.238
PPEST2	Price of Supplementary Pesticide	600	20	122.7779	102.3962
PLAB	Price of Labor	180	100	112.8233	9.487204
Cr(CW)	Amount of Chromium present in the canal water (mg/Lit)	0.39	0.002	0.072438	0.134079
Pb(CW)	Amount of Lead present in the canal water (mg/Lit)	0.01	0.004	0.008295	0.002334
Hg(CW)	Amount of Mercury present in the canal water (mg/Lit)	0.098	0.002	0.036465	0.038491
Cr(S)	Amount of Chromium present in the soil (mg/Kg)	99.9	48.6	78.81494	17.68263
Pb(S)	Amount of Lead present in the soil (mg/Kg)	57.85	5.9	27.40018	16.92186
Hg(S)	Amount of Mercury present in the soil (mg/Kg)	8.74	0.49	3.409617	2.75002

Note: All the monetary values are in INR. Other variables used are:

D1: Dummy for seed variety, 1=Local Varieties, 0 = Otherwise

D2: Dummy for using canal water for last 4 years, 1= Yes, 0=Otherwise

Table 2: Results from Regression Analysis (Dependent Variable: Profit per Kg)

	Model I	**Model II**	**Model III**
	0.23	0.35	0.34
AIC	4.743	4.590	4.588
Constant	-22.39 (-1.308)	30.08 (1.762)	104.07** (2.422)
Area (*Katha*)	0.0035*** (4.243)	0.0177** (2.226)	0.0167** (2.100)
(Output Price/kg)	2.5785 (.996)	-1.2088 (-.489)	-1.3021 (-.527)
(*Output price/kg*)^2	-0.0756 (-.690)	0.0901 (.862)	0.0943 (.903)
D1, Miniket=0, Otherwise=1	0.0002 (.064)	0.0001 (.055)	0.0003 (.123)
Price of Seed	1.0735*** (4.245)	0.6337*** (2.603)	0.6978*** (2.827)
(Price of Seed)^2	-0.0218*** (-4.233)	-0.0138*** (-2.774)	-0.0154*** (-3.031)
Price of Tractor	0.0033*** (2.665)	0.0042*** (3.180)	0.0048*** (3.799)
(Price of tractor)^2	0.0087 (-1.572)	-0.000013 (-1.485)	-0.000016** (-1.792)
Price of Fertilizer #1	0.0087 (.133)	0.0417 (.572)	0.0961 (1.457
(Price of Fertilizer #1)^2	0.000098 (.010)	-0.0007 (-.631)	-0.0014 (-1.498)
Price of Fertilizer #2	0.2348* (1.794)	0.2499** (2.001)	0.2567** (2.066)
(Price of Fertilizer #2)^2	-0.0190*** (-2.474)	-0.0159** (-2.189)	-0.0158** (-2.189)
Price of Pesticide #1	-0.0048* (-1.775)	0.0012 (.461)	0.0020 (.718)
(Price of Pesticide #1)^2	0.00001 (.245)	-0.00006 (-1.525)	-0.000068* (-1.659)
Price of Pesticide #2	0.0173*** (3.559)	0.0130*** (2.771)	0.0127*** (2.742)
(Price of Pesticide #2)^2	-0.00044*** (-3.666)	-0.00034*** (-3.011)	-0.00033*** (-2.940)
Labor price	-0.0468 (-.356)	-0.4167*** (-3.092)	-0.3716*** (-2.790)
(Price of PLabour)^2	0.0002 (.392)	0.0016*** (2.808)	0.0014*** (2.547)
D2, using canal water last 4 year y=1, n=0	1.1386*** (3.832)	1.5914*** (2.688)	0.8088 (.662)
Cr(CW)		236.38 (1.017)	
(Cr(CW))^2		-.0.00034 (-1.021)	
Pb(CW)		-4970.8881 (-.927)	
(Cb(CW))^2		480372.2 (.901)	
Hg(CW)		-208.4472*** (-2.681)	
(Hg(CW))^2		2960.4913* (1.702)	
Cr(S)			-1.8050*** (-2.077)
(Cr(S))^2			0.0104*** (2.069)

Pb(S)			0.3511*** (2.100)
$(Pb(S))^2$			-0.0114*** (-2.411)
Hg(S)			-1.2857*** (-3.037)
$(Hg(S))^2$			0.1228*** (3.746)

t- values in parenthesis; ***, ** and * indicate significance at 1 percent, 5 percent and 10 percent levels, respectively.

Figures

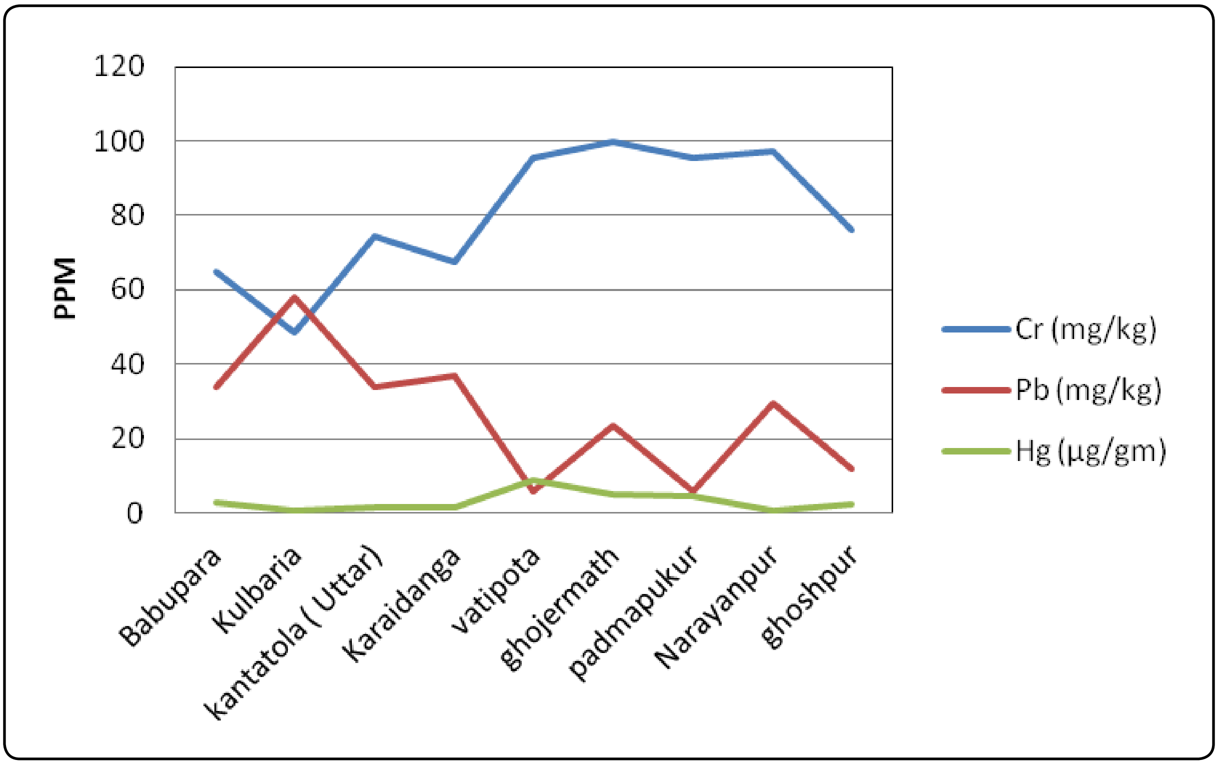


Figure 1: Presence of Heavy Metals in Soil

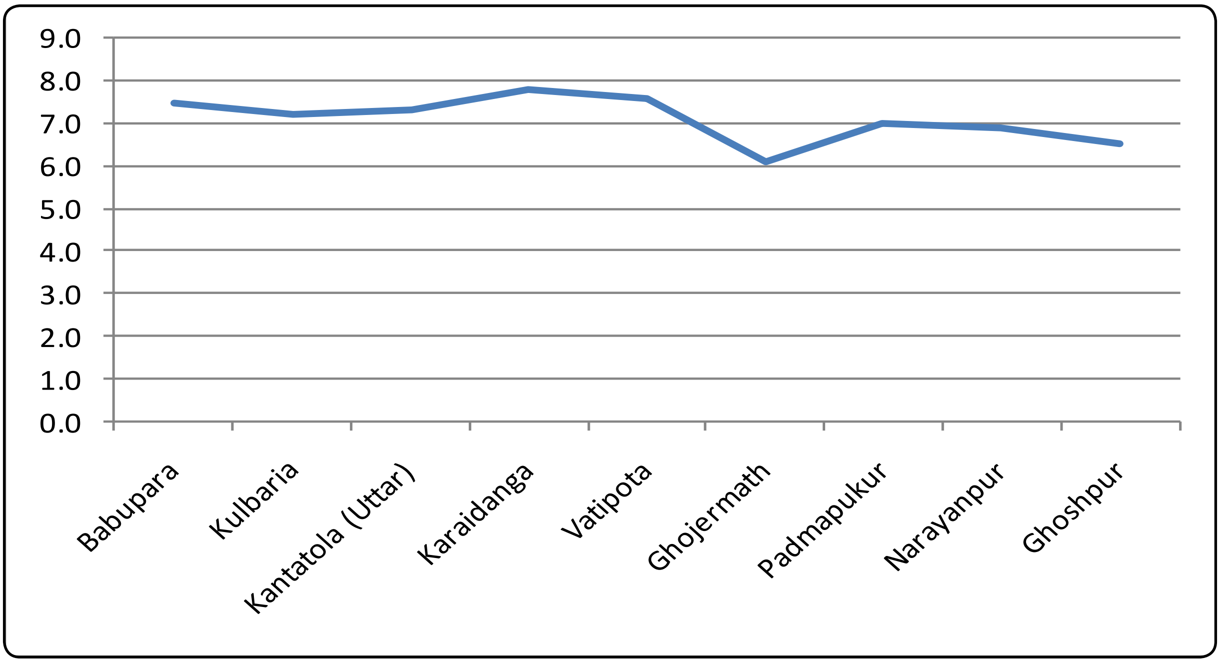


Figure 2: pH in Soil

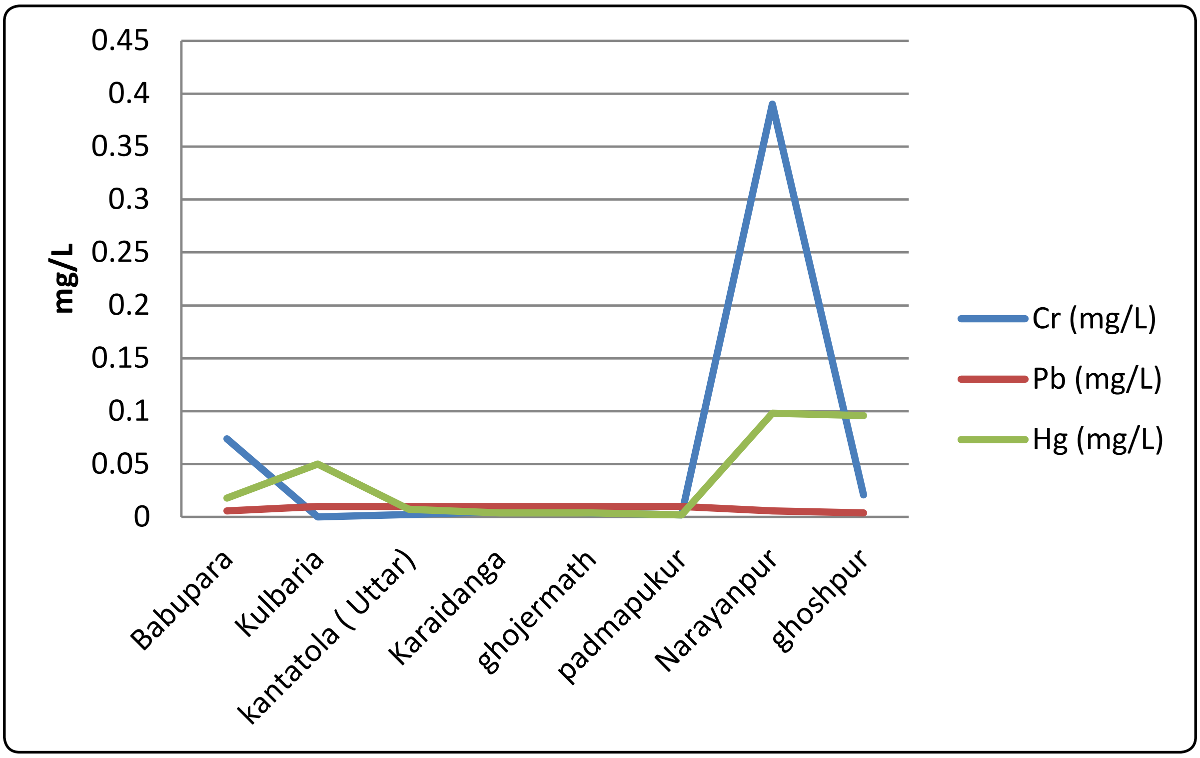


Figure 3: Presence of Heavy Metals in Canal Water

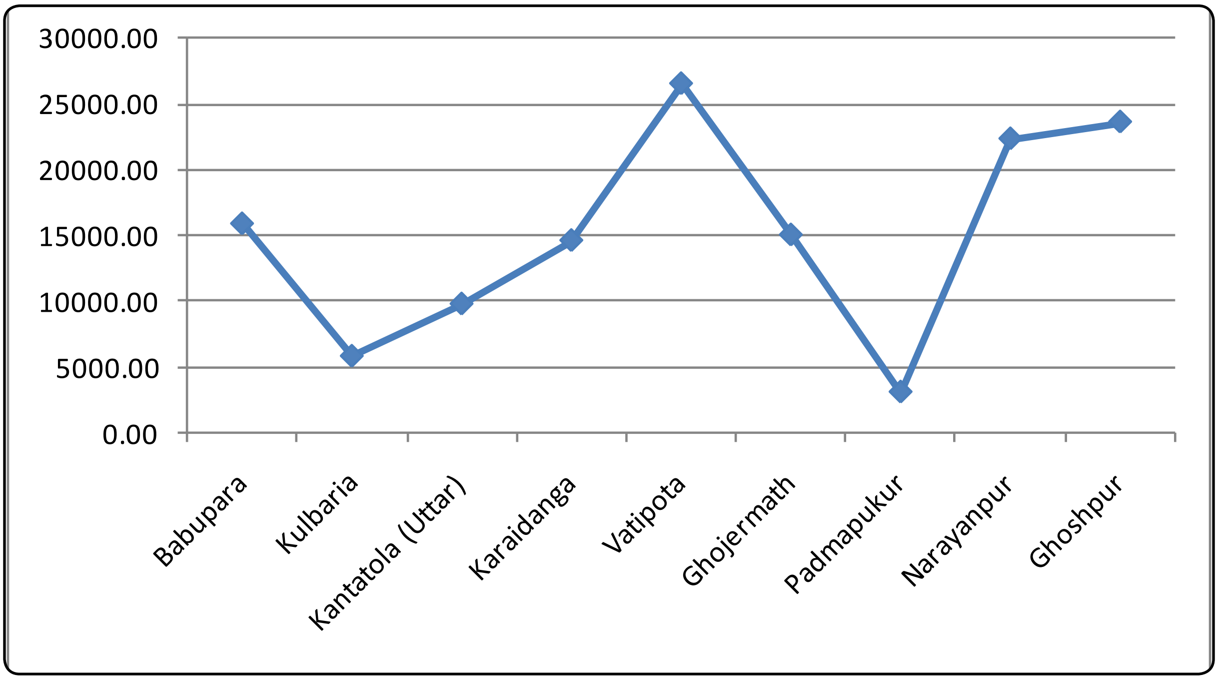
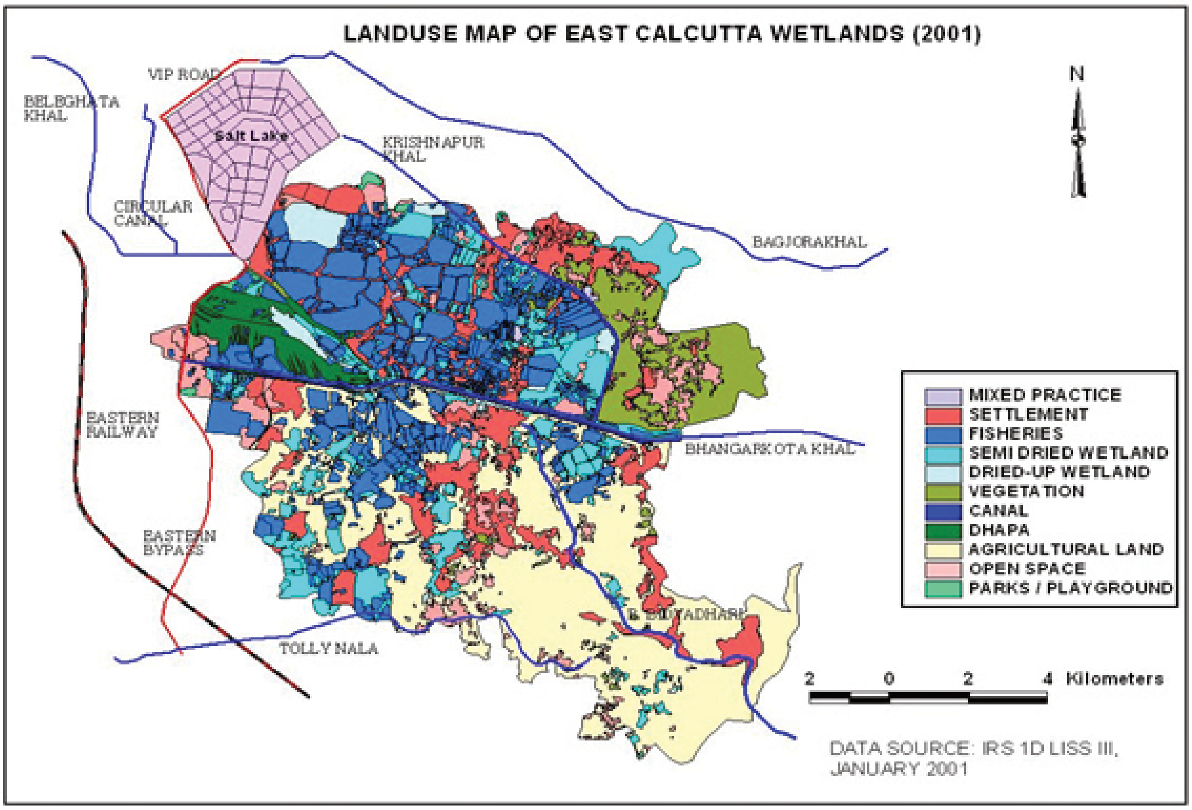
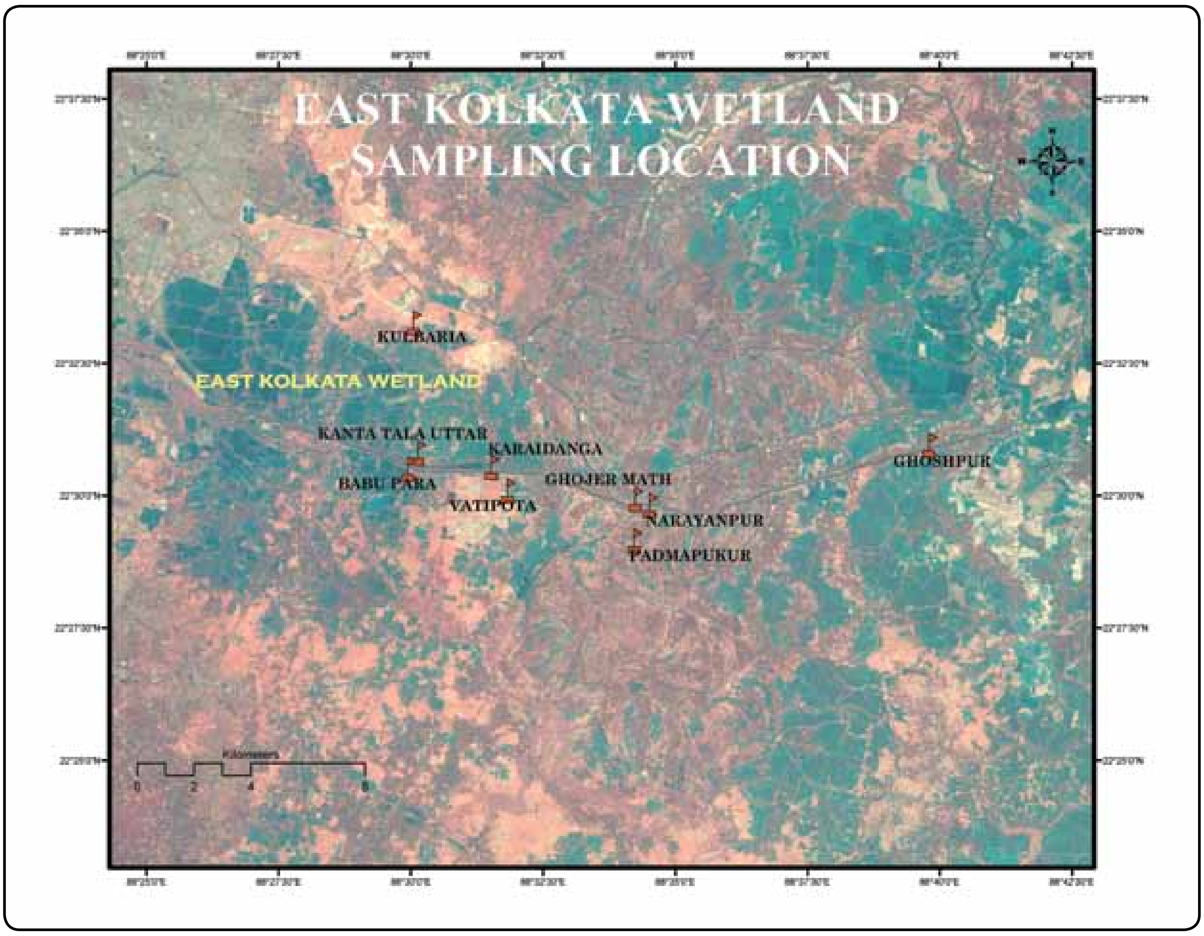


Figure 4: Average Profit (INR)/hectare

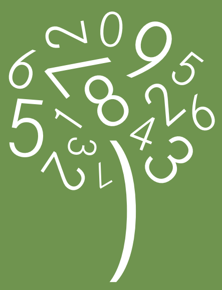
Appendix: Maps



Map 1: Land Use Map of the Study Area in 2001



Map 2: Sampling Areas



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