EVALUATION OF GROUNDWATER ARSENIC CONTAMINATION AND REMEDIAL INTERVENTIONS

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Sanjana Chakraborty

Department of Economics
Jadavpur University
Kolkata-700032, India

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<u>Certified that the Thesis Entitled</u>

Evaluation of Groundwater Arsenic Contamination and Remedial Interventions submitted by me for the award of the degree of Doctor of Philosophy in Arts at Jadavpur University is based upon my own work carried out under the supervision of Dr. Vivekananda Mukherjee, Professor, Department of Economics, Jadavpur University. Neither this thesis nor any part of it has been submitted before for any degree or diploma anywhere/elsewhere.

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Candidate:

Dated:

....

Countersigned by the Supervisor

Prof. Vivekananda Mukherjee

Department of Economics

Jadavpur University

Dated:

"Statement of Originality"

I, ***Sanjana Chakraborty***, registered on 11th ***July, 2014*** do hereby declare that this thesis entitled ***"Evaluation of Groundwater Arsenic Contamination and Remedial Interventions"*** contains literature survey and original research work done by the undersigned candidate as part of Doctoral studies.

All information in this thesis have been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

I also declare that I have checked this thesis as per the "Policy on Anti Plagiarism, Jadavpur University, 2019", and the level of similarity as checked by iThenticate software is **9.0 %**.

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1.

Dedicated To

My beloved father Late Dr. Dipankar Chakraborti who instilled in me his lifelong motto and belief:

"Nothing is difficult, if you want to do it.

You have the power within you, you can do it."

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Sanjana Chakraborty
Department of Economics
Jadavpur University
Kolkata

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CHAPTER 1

INTRODUCTION

1.1. Motivation

Access to safe drinking water being a basic human need as well as a right. During the later half of the twentieth century millions of hand tubewells were installed by the governments for providing drinking water. For overcoming the problem of drinking microbiologically unsafe and untreated surface water, more emphasis was given on groundwater use and the use of treated surface water was ignored. The accessibility of hand-pumps / tubewells to the households had increased substantially, whereas the use of the dugwells or any surface water source declined significantly. With increasing population, the demand for drinking, cooking and irrigation water had increased, which was fulfilled by increasing withdrawal of groundwater by tube-wells. Besides domestic use, to meet the food demands of the growing population, agriculture too had shifted to use of groundwater to supplement the rainwater supplies for the purpose of irrigation. As a result, groundwater exploitation was rampant. The absence of regulation on the part of the government intensified the use. This was more of a feature of the rural areas than of the urban areas. Over the years, this limitless and reckless human attack on the nature's sub-soil water-table eventually caused so far dormant geogenic poison arsenic to erupt and being leached out, to exert finally its chronic toxic impact via groundwater contamination. Consumption of arsenic contaminated water beyond permissible limit (WHO guideline value of 10 μg / L) has very serious health implications. The arsenicosis is a health hazard, caused by direct consumption of contaminated drinking water and indirect consumption of such water through the food chain as it is used in agricultural production. The people affected by arsenic poisoning suffer from skin lesions, gradual loss of energy, physical weakness, loss of appetite, lethargy, sleeplessness, diminishing work ability, uneasiness in the stomach, burning sensation over the body and gradually progressive debilitation etc. which lead to loss in the working hours and their income. It also creates unhealthy and strained within-family relations and stress at the social front. With the symptoms of arsenicosis becoming evident more often various agonizing social issues arise, such as, affected persons are often sacked from their jobs, arsenic affected children are sometimes debarred from their schools, the affected girls are denied of marriage and often married women face problems in their marital life and even divorce ensues. Affected people are quite often ostracized from social functions. The arsenic affected persons are often boycotted socially as they are mistakenly considered as the patients infected with contagious diseases. The social barriers create economic barriers as well (Becker, 1971). It may create inequality in the rural society and may perpetuate poverty. The World Health Organization (WHO) points out that social problems arising from groundwater arsenic contamination create pressure on the economy of the affected areas (WHO, 2000). The present thesis draws its motivation in measurement of economic loss both contemporaneous and over the time of the arsenic affected households vis-à-vis the arsenic unaffected households. It also studies adoption of piped drinking water by the households in an arsenic affected area as a mitigation strategy against the arsenic-related hazards.

'Arsenic' is a shiny metalloid which is the 20^{th} element in the nature. It is found throughout the Earth's crust, soil, sediments, water, air and living organisms. In different countries, arsenic has been used as a drug as well as a poison**.** The estimated global average level of arsenic in soil is 5μg / kg (microgram per kilogram), but the concentrations may vary considerably in different geological regions. The variation can be in the range of 0.1 to 4000 μg / kg. While arsenic contamination has been reported from 38 countries in the world (Chakraborti et al. 2009), Asian countries seem to be more affected than the others. The magnitude of arsenic contamination is considered as the highest in the following four Asian countries: India, Bangladesh, China and Taiwan; India having the highest and Taiwan having the lowest incidence. The Ganga-Meghna-Brahmaputra (GMB) plain (shown in Figure 1.1 below) of India and Bangladesh is the worst affected among the world arsenic scenario raising a severely alarming note. More than 500 million people of the GMB plain may be potentially at risk from groundwater arsenic contamination (Nahar et al. 2008, BGS; DPHE, 2001).

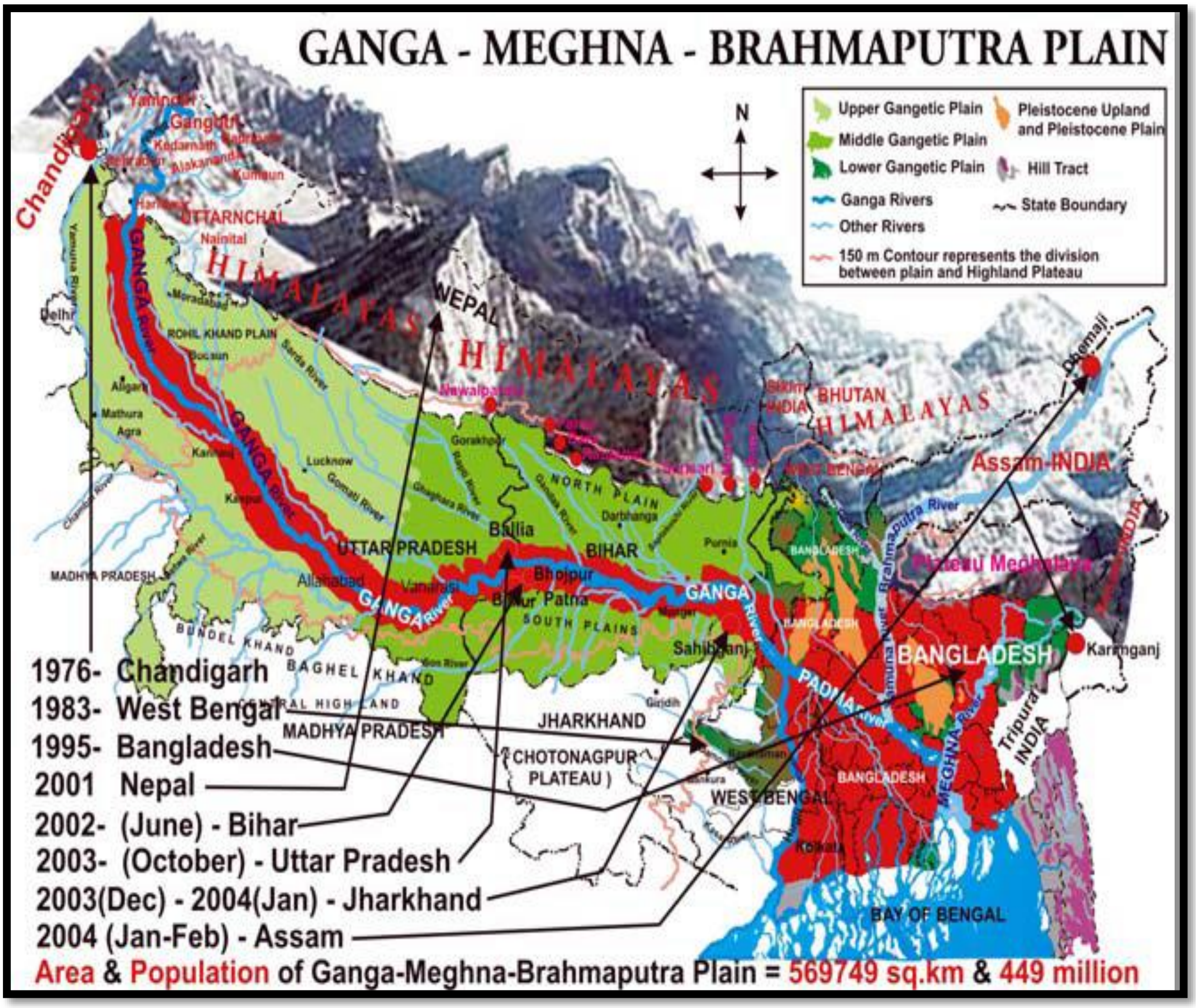

Figure 1.1: Groundwater arsenic contamination status in different countries and different states of India in GMB Plain

“Arseno Pyrites” ore found in the Himalayan Mountains and Tibet Plateau is considered to be the source of arsenic in the Gangetic plain. The flood plains of many rivers originating from Himalayan mountains and Tibet Plateau are contaminated with arsenic. Geologically arsenic is being washed down from the Himalayas and Tibetan Plateau to the Ganga-Meghna-Brahmaputra (GMB) plain which stretches across and shelters in some states of India especially in most of the districts of West Bengal, some parts of Uttar Pradesh, Bihar, Jharkhand, Assam and Manipur. These six arsenic affected states of India are in the GMB plain formed by the second largest river system in the world. The present thesis studies households from West Bengal, one of the most affected states of India. Based on the arsenic concentrations, 19 districts of West Bengal have been classified into three categories:

(i) Severely affected: The nine districts (Maldah, Murshidabad, Nadia, North-24-Parganas, South-24-Parganas, Bardhaman, Howrah, Hooghly and Kolkata), where more than 300 µg / L arsenic concentrations were found in some tubewells (3.3%) are categorized as severely affected, (ii) Mildly affected: The five districts (Koch Bihar, Jalpaiguri, Darjiling, North Dinajpur and South Dinajpur) where the contaminated tubewells showed arsenic concentrations mostly below 50 µg / L (only a few above 50 µg / L but none above 100 µg / L), are considered as mildly affected and (iii) Arsenic safe: The rest five districts (Bankura, Birbhum, Purulia, Medinipur East and Medinipur West), where all the recorded concentrations were below 10 µg / L are termed as unaffected or arsenic safe. The categorization has been shown in Figure 1.2 below.

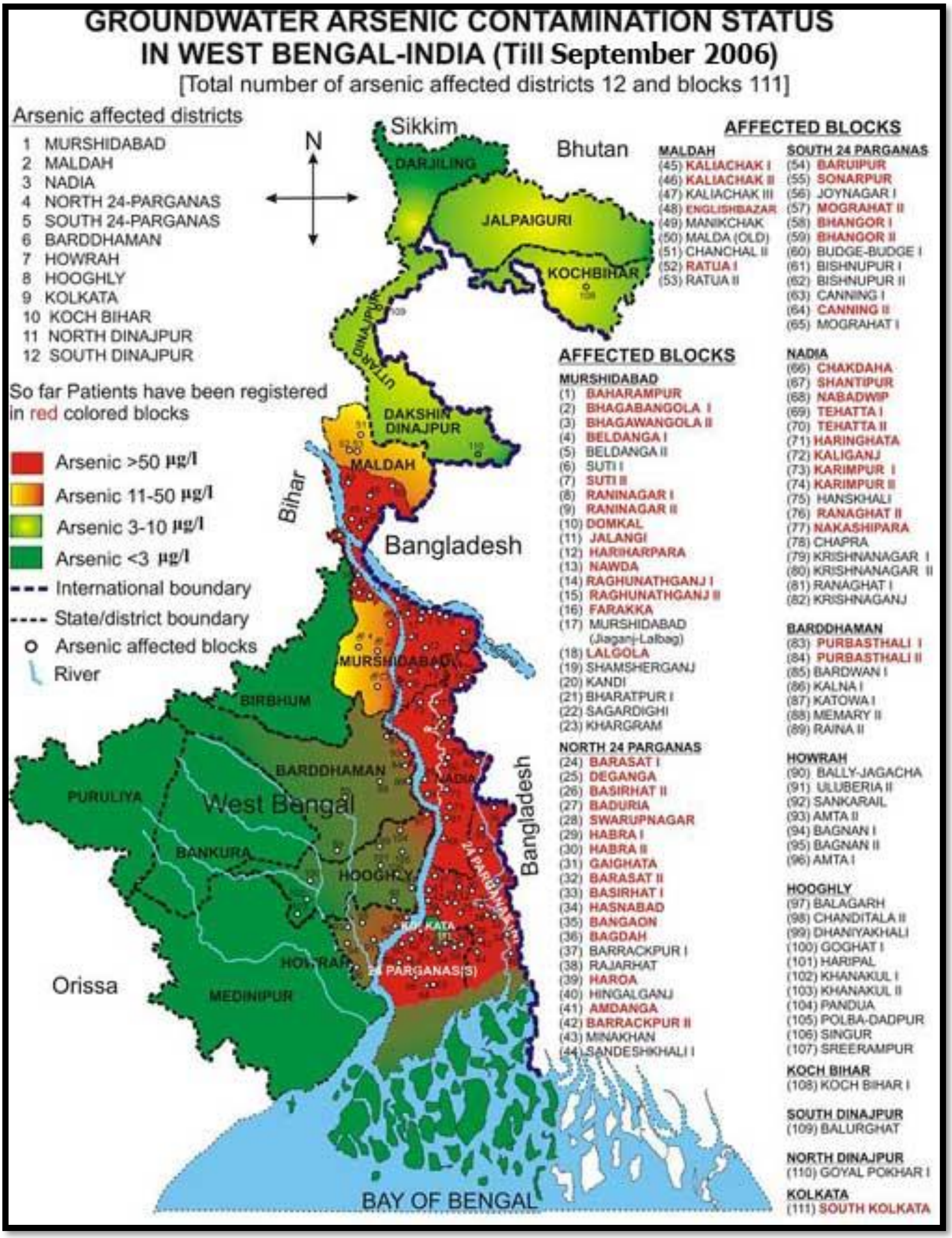

Figure 1.2: Groundwater arsenic contamination status in all 19 districts of West Bengal

The thesis draws its sample households from the severely affected North 24 Parganas district.

Among the strategies for fighting the arsenic menace / hazards, the use of arsenic-safe water sources like treated dugwell, arsenic-safe deep-tubewells (often coloured green for easy identification while unsafe are coloured red), treated piped water etc. and improvement of nutritional status are considered as the most important strategies[1]. The spread of awareness complements such strategies. Since dugwells and tubewells are more vulnerable to contamination, the piped water supply is considered as the safest source of arsenic-free water. The provision of piped water being costly as it is network dependent, in developing countries like India, the government in recent times has arranged for free-access, intermittent-supply of piped water at some locations at the arsenic affected villages lived mainly by the poor. Apart from the behavioural trait and bounded rationality, the adoption decision of piped water source can also be affected by the costs of adoption and economic-demographic characteristics like education, religion, percentage of female at the household and the household income. The present thesis studies the adoption of this source of safe-water among arsenic affected and unaffected households in an arsenic affected village of West Bengal, India.

While several studies have investigated the issue of arsenic contamination before, most of them have explored its geological aspects, health problems related to arsenic and technologies for arsenic removal. Though studies evaluating the economic cost of arsenic contamination are few, designing of any arsenic mitigation program would require such a cost estimate. The present thesis investigates the economic cost of arsenicosis on the per capita monthly household income of the arsenic affected households at a particular time period as well as over the years by applying two different kinds of impact evaluation methods: (i) PSM [for Chapter 2] and (ii) DID [for Chapter 4]. This thesis also studies the

[1]People having poor nutrition were found to be affected more from arsenic toxicity than the people having an adequate nutrition rich food. Intake of nutritious diet especially with vitamins such as A, C and E is essential for arsenic mitigation (Quamruzzaman et al. 2003; Milton, 2003).

probability of adoption of arsenic-safe piped water supply projects as mitigation strategy among the households when piped water supply project was freely provided by the government during 2011-2012 [for Chapter 3]. Chapter 2 shows that the loss from labor market participation is not the only source from which an arsenic affected household suffers but the additional loss comes from the social discrimination it faces. The ‘social discrimination’ being an unobserved factor, has been captured indirectly and found out to lead to significant income loss. To refine our estimation of relative economic loss of the arsenic affected households over the years, in chapter 4, we derive the income loss due to arsenicosis that arises purely from the time-dependent unobserved factors that differentiates the treatment (arsenic-affected) and control (arsenic-unaffected) group households. It shows that the arsenic affected households adapt to their situation over time to reduce their income gap vis-à-vis the arsenic unaffected households. In chapter 3, to check the nature of adoption decision among the households we empirically seek answer to the following research questions: (a) Whether the arsenic-affected households show higher probability of adoption of arsenic-safe piped water source than the arsenic-unaffected households? (b) How the spread, intensity and years of experience with arsenicosis in the households matter in adoption decision? We found affirmative to the first question and for the second, we found the years of illness matters the most in the adoption decision.

In the next section we review the relevant literature.

1.2. Survey of the Literature

The papers like Mandal et al. (1996), Chowdhury et al. (1999), Chowdhury et al. (2000), Chakraborti et al. (2002, 2003, 2009), Ahmed et al. (2006) mapped spatial pattern of arsenic risk zones of West Bengal in India and in Bangladesh. These studies also evaluated the scale or magnitude of the problem in terms of at-risk population coverage. The geological aspects of arsenic contamination in groundwater have been studied by Harvey et al. (2002, 2005), Akai et al. (2004), Acharyya and Shah (2007), Biswas et al. (2012), Planer-Friedrich et al. (2012). The studies in the epidemiological issues and adverse health effects related to chronic arsenic toxicity include Datta (1976), Milton (2003), Chakraborti et al. (2004), Kapaj (2006), Ghosh (2008), Vahter (2009) and Rahman et al. (2009). A substantial literature is also available in mitigation strategies and technologies for arsenic removal (Das et al. (2001), Misbahuddin and Fariduddin (2010), Hossain et al. (2006)). During the last decade, a number of studies, mostly in Bangladesh, have highlighted the social, socio-cultural, socio-economic, psycho-social and mental health effects as a consequence of arsenic poisoning (WHO (2000), Barkat (2004), Hadi and Parveen (2004), Hanchett (2004), Hassan et al. (2005), Ahmad et al. (2007), Nahar et al. (2008), Brinkel et al. (2009), Sarker (2010), Mahmood and Halder (2011), Sultana et al. (2012), Syed et al. (2012) etc.). However, there is a dearth of such valuable socio dimensional studies in Indian context. The papers like Khan (2007), Roy (2008), Mahanta et al. (2016) and Thakur et al. (2019) measure willingness-to-pay of the arsenic affected households towards mitigation projects by estimating their loss from labor market participation and the remedial medical expenditure for this loss. Khan (2007), Roy (2008), Mahanta et al. (2016) and Thakur et al. (2019) estimate the income loss of arsenic-affected households from their reduced labour market participation due to illness. However, it does not provide any measure of income loss such households face from the discrimination they face either at the labour market or at everyday life at their social neighbourhood. The methodologies adopted by Khan (2007), Roy (2008), Mahanta et al. (2016) and Thakur et al. (2019) elude this dimension of cost. Chapter 2 of the present thesis attempts to fill this gap. Chapter 2 contributes to the literature by providing a broader measure of the economic costs due to arsenicosis which includes the costs of social discrimination faced by the arsenic affected households.

The studies about issues related to adoption of arsenic-safe sources of water are scarce in the literature. There are studies like Ahmad et al. (2003, 2005), Aftab et al. (2006), Inauen et al. (2013), Larsen (2016) and Singh (2017) which analyse the technological aspects of adoption i.e. they study the cost effectiveness of alternative feasible technologies. On the other hand, there are studies in economics which discuss adoption of safe-water sources and its benefits in the case of water-borne diseases like diarrhoea. While Jalan and Ravallion (2003), Nandi et al. (2016) focus on health benefit of piped-water adoption in such cases, the papers like Suzuki and Sakamoto (2018), Balasubramaniam et al. (2014) respectively show that the social network and religious segregation play an important role in piped water adoption in rural India. Although, in Morocco, Devoto et al. (2012) shows that the ensuing health benefit is not the cause adoption of piped water, in Uganda Onjala et al. (2013) shows, the risk perception of drinking unsafe water matters in adoption decision. Both these papers, however, agree on that the cost of adoption deters adoption. In case of Bhutan, Rahut et al. (2016) highlights the role of household income in adoption decision. According to their finding, the higher income households adopt more. In a closely related paper, Delaire et al. (2017) analyses the household drinking water practices in two villages in arsenic-affected Murshidabad district of West Bengal, India in year 2014. The labour market and non-labour market costs of the arsenic affected households turn out to be substantial, estimated in papers such as Khan (2007), Roy (2008), Mahanta et al. (2016), Chakraborty and Mukherjee (2020). But, the arsenic-affected areas in India also being the areas affected with wide-spread microbial contamination, it is not clear whether the adoption decision is guided by arsenic contamination or microbial contamination (Delaire et al. (2017)). The prevention of arsenicosis occurs as a co-benefit in Delaire et al. (2017) and the supply of piped water plays a non-significant role. In contrast, chapter 3 focuses exclusively on piped water adoption behaviour of households, who has suffered from arsenicosis. Although the adoption of piped water sources as a response to microbial contamination has been studied in details in the existing literature, not much is known about the adoption of it as a response to arsenic contamination (Amrose, Burt and Ray (2015)). Chapter 3 attempts to fill the gap.

In chapter 4 we derive the income loss due to arsenicosis that arises purely from the time-dependent unobserved factors that differentiates the treatment (arsenic-affected) and control (arsenic-unaffected) group households. Earlier the papers like Ahamed et al. (2006), Chakraborti et al. (2009), Shewale et al. (2017), and Jamil et al. (2019) evaluated the impact of arsenic contamination over the years, but with objectives different from chapter 4. Ahamed et al. (2006) focuses on several surveys of the arsenic contamination situation and consequent clinical manifestations of arsenicosis among the villagers of Eruani village, Lakshamupazila, Comilla district, Bangladesh during 1997-2005. It shows that due to lack of proper awareness among the villagers about different aspects of arsenic toxicity, even after eight years of known exposure, village children were still drinking arsenic-contaminated water, and many of them had arsenical skin lesions and also there were social problems due to the symptoms of arsenicosis. Jamil et al. (2019) analyses the effectiveness of different approaches to arsenic mitigation over 18 Years (during 2000-2001 to 2018-2019) in Araihazar, Bangladesh. However, none of the papers studied the dimension of income loss as we do it in the chapter 4.

1.3. Outline of the Chapters

The thesis contains three core chapters. This section provides a brief description of the chapters in the thesis.

Chapter 2 uses Propensity Score Matching (PSM) method in calculation of economic loss due to arsenicosis. In contrast to the existing studies that estimate the loss only from labor market sources, the PSM method used in this chapter controls for all labor market and other possible sources of income, the demographic and educational factors and calculates the loss from factors like social discrimination. The method compares monthly household income of arsenic affected and arsenic unaffected households which are similar on large number of observed parameters / characteristics. The matched pairs between the two types of households i.e. arsenic affected households (treatment group) and arsenic unaffected households (comparison group / counterfactuals) would be constructed based on the maximum closeness of their Propensity Score (PS) values. Herein, the nearest neighbor (NN) matching without replacement within a caliper would be applied. By adopting this method, finally, a subsample of control participants as well as treated participants whose propensity scores have been matched would be obtained. After the matched treatment and control groups are formed, the averages of the outcome variable for the two groups are compared i.e. the difference between the mean of the monthly household income of the treatment and the control groups is calculated and whether the obtained value is significant or not is checked.

Chapter 2 proves two points. It shows, first, that the social discrimination exists against the arsenicosis affected households which leads to significant economic loss both in terms of per capita income and per capita consumption of expenditure; second, the existence of social discrimination leads to underestimation of income loss when calculated only from labor-market sources. We construct a theoretical model of income determination to substantiate our point. To test the theory empirically, we use the survey data collected from the arsenic affected and arsenic unaffected households of Kolsur village in North 24 Parganas District of the State of West Bengal in India during 2005-2006 and find support for the theory. The results have important implications both for understanding plight of arsenic-affected households and for cost-benefit calculation towards adoption of policies for fighting the problem of arsenic-contamination. It argues that the method of propensity score matching, when applied properly, solves the problem of estimation of loss from the non-labor-market sources like social discrimination.

Chapter 3 studies adoption of piped water source, where it is freely provided, as mitigation strategy against arsenic contamination in an arsenic affected village of West Bengal, India. Applying probit regressions that control for co-variates like adoption costs and demographic variables like religion, literacy, percentage of female members at the household and per capita monthly household income, we find that the probability of adoption of piped water source is higher among the arsenic affected households vis-à-vis the unaffected households i.e. it finds that the households affected by arsenicosis are more likely to adopt an arsenic-safe source than the unaffected households. The study also analyses the role of factors like the extensiveness of arsenicosis, intensity of symptoms and the years of experience about the health and social hazards associated with it at the household level on the adoption decision of the households. Here, we use the survey data collected from the arsenic affected and arsenic unaffected households and the households that have adopted piped water and that have not done so from Kolsur village in North 24 Parganas District of the State of West Bengal in India during 2015-2016.

In chapter 4 we estimate relative economic loss of the arsenic affected households over a time period by using Difference in Difference (DID) regression method. The DID method is able to control the unobserved heterogeneity among either type of households if it does not vary over time. It also controls for the common time trend faced by both types of households. Therefore, the income loss due to arsenicosis that we estimate in this chapter arises purely from the time-dependent unobserved factors that differentiates the treatment (arsenic-affected) and control (arsenic-unaffected) group households. For our purpose we use the survey data collected from Kolsur village in North 24 Parganas District of the State of West

Bengal in India during 2005-2006 and 2015-2016 on the households who did not change their treatment-control identity in 2015-2016 vis-à-vis 2005-2006. We apply the Kernel Propensity Score DID regression model with common support which matches them in 2005-2006 to justify random allotment of treatment status and the common trend assumption and then study the difference of per capita household income over time.

1.4. Results

In this section, we summarize the results derived in the three core chapters of the thesis.

Chapter 2 shows empirically that the social discrimination exists against the arsenicosis affected households and consequently these households suffer from significant economic loss both in terms of per capita income and per capita consumption i.e. the existence of social discrimination leads to underestimation of income loss when calculated only from the labor-market sources. Chapter 2 argues that the method of propensity score matching, when applied properly, solves the problem of estimation of loss from the non-labor-market sources like social discrimination. It applies the method on a dataset collected from a household survey in an arsenic affected Kolsur village in West Bengal, India during 2005-2006 to estimate the income and consumption loss due to social discrimination and compares the estimates with a previous study by Roy (2008) during similar time period to show the extent of possible underestimation. According to chapter 2, the figure $13.76 measures the welfare loss per capita due to arsenicosis on account of social discrimination. This figure is more than the income-loss figure calculated by Roy (2008) which stands at $7. The difference arises because while Roy (2008) calculates the income loss which arises only due to adverse labor market outcome, whereas, our figure captures the income-loss from the non-labor sources like social discrimination. Therefore, the empirical finding of the study confirms that the figure provided by Roy (2008) underestimates the economic loss due to arsenicosis.

Similarly, we obtain the mean of the household expenditure per month per capita of the arsenic affected group is lower than that of the arsenic unaffected group by $8.86 per month per capita. Since we have controlled for the labor-market effects (and other kinds of wealth effects like land holding) in our empirical study, this can happen if and only if social discrimination against arsenic affected households exists.

Chapter 3 empirically analyses the role of piped water adoption as mitigation strategy against arsenic contamination in an arsenic affected village of West Bengal, India. The results show that the households affected by arsenicosis are more likely to adopt an arsenic-safe source than the unaffected households. Chapter 3 also analyses the role of factors like the extensiveness of arsenicosis, intensity of symptoms and the years of experience about the health and social hazards associated with it at the household level on the adoption decision of the households. It finds that although the marginal impact of these factors on the adoption decision is small, the effect of years of suffering is stronger than the other two factors. The results derived in Chapter 3 suggest that greater adoption of piped water sources in arsenic affected villages can be facilitated if the awareness is spread through the households, who suffered from arsenicosis for a long time. Interestingly, the data finds that the Muslim households in the sample adopt piped water source more compared to the Hindu households as the village had majority of the Muslim households. The results also show, even if the piped water was provided free of cost, the time cost associated with intermittent supply of water created a bias in adoption in favour of the high per capita income households, as these households could possibly employ someone to negotiate the cost. The empirical analysis suggests that the piped water sources must be located more evenly in the clustered villages for greater adoption. Also, it suggests that a more continuous supply of piped water may remove the high-income bias from adoption of piped water in arsenic affected villages, where it is provided free of cost.

Chapter 4 empirically analyses the impact of arsenicosis on households' monthly per capita income over the years 2005-2006 and 2015-2016 evaluated at the common base of 2004-05. The analysis shows that although the average per capita monthly incomes of both the arsenic-affected and arsenic-unaffected group of households show a declining trend over the years, the arsenic affected households lose less than the arsenic unaffected households. So, the arsenic affected households adapt better to their situation compared to the arsenic unaffected households. The result is surprising as it was expected that the arsenic affected group would have more income loss over time than the control group households. However, it turns out that when we eliminate the household specific fixed factors and the common time trend, the arsenic affected households do significantly better than the unaffected households to improve their income. This happens due to their adjustment towards the adversities they faced because of arsenicosis. Perhaps, the factors like piped water adoption, social awareness related to arsenicosis acted in their favour.

In the next section we present a plan of the thesis.

1.5. Plan of the Thesis

The rest of the thesis is organized as follows. Chapter 2 analyses whether the social discrimination exists against the arsenicosis affected households and consequently these households suffer from a significant economic loss both in terms of per capita income and per capita consumption. Chapter 3 analyses the mitigation behaviour of the households in an arsenic affected village of West Bengal, India by adoption of arsenic safe piped water sources. Chapter 4 analyses the impact of arsenicosis on households' per capita monthly income calculated with respect to the base year 2004-2005 over the years 2005-2006 and 2015-2016 by elimination of the common time trend and household specific factors. Chapter 5 concludes the thesis.

CHAPTER 2

REVISITING ECONOMIC COSTS OF ARSENICOSIS: A PSM APPROACH

*This chapter is based on:

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2.1. Introduction

'Arsenic' is a shiny metalloid which is the 20th element in the nature. It is found throughout the Earth's crust, soil, sediments, water, air and living organisms. In different countries, arsenic has been used as a drug as well as a poison**.** The estimated global average level of arsenic in soil is 5μg / kg (microgram per kilogram), but the concentrations may vary considerably in different geological regions. The variation can be in the range of 0.1 to 4000 μg / kg.

Arsenic enters human body directly through consumption of contaminated drinking water and indirectly through food chain as arsenic contaminated groundwater is used in agricultural production. It creates health hazards. Due to regular intake, the arsenic gets absorbed in blood and may cause skin, lung, liver, bladder and kidney cancer. Arsenic can harm the central and peripheral nervous systems as well as heart and blood vessels. It may also cause birth defects and problems in the reproductive system. Arsenic related health hazards may be classified into two types: (i) Acute: include gastrointestinal discomfort, vomiting, diarrhea, convulsions, coma and ultimately death (Acute toxicity, however, is quite infrequent); (ii) Chronic: include skin lesions (arsenicosis or arsenical dermatitis), which are characterized by hyper-pigmentation, hyperkeratosis and hypo-pigmentation. The toll of arsenic on the victim is not immediate. Gradual arsenic poisoning from tainted drinking water can take years to ravage the body, producing pigment patches and scaly skin; limbs and joints swollen like balloons and tumorous growths on limbs and feet. By the time even early symptoms are visible, the person is often riddled with cancer. Thus, arsenic has a cumulative toxic effect that shatters the human body all the way to ultimate death. Since rural areas, especially in developing countries, are seldomly supplied with treated surface water, the threat is much higher in such areas.

While arsenic contamination has been reported from 38 countries in the world (Chakraborti et al. 2009), Asian countries seem to be more affected than the others. The magnitude of arsenic contamination is considered as the highest in the following four Asian countries: India, Bangladesh, China and Taiwan; India having the highest and Taiwan having the lowest incidence. The Ganga-Meghna-Brahmaputra (GMB) plain of India and Bangladesh is the worst affected among the world arsenic scenario raising a severely alarming note. More than 500 million people of the GMB plain may be potentially at risk from groundwater arsenic contamination (Nahar et al. 2008, BGS; DPHE, 2001).

Arsenicosis has an economic impact that feeds back through the health and the human well-being of both the individual and the family (Hanchett, 2004; Roy, 2008). The people affected by arsenic poisoning suffer from the health hazards like gradual loss of energy, physical weakness, loss of appetite, lethargy, sleeplessness, diminishing work ability, uneasiness in the stomach, burning sensation over the body and gradually progressive debilitation etc. which lead to loss in the working hours and their income. It also creates unhealthy and strained within-family relations and stress at the social front. With the symptoms of arsenicosis becoming evident more often various agonizing social issues arise, such as, affected persons are often sacked from their jobs, arsenic affected children are sometimes debarred from their schools, the affected girls are denied of marriage and often married women face problems in their marital life and even divorce ensues. Affected people are quite often ostracized from social functions. The arsenic affected persons are often boycotted socially as they are mistakenly considered as the patients infected with contagious diseases. The social barriers create economic barriers as well (Becker, 1971)[2].

[2] The World Health Organization (WHO) points out that social problems arising from groundwater arsenic contamination create pressure on the economy of the affected areas (WHO, 2000).

Although arsenicosis cannot be cured, it can be adapted and mitigated. The medical expenditure undertaken by the affected households for reducing arsenic related hazards is an example of adaptation. There are a few mitigation approaches as well: (i) Use of alternative arsenic-safe water sources like dugwells, deep tubewells that are regularly monitored for arsenic level, piped water projects etc.; (ii) Improving nutritional status by ensuring intake of nutritious diet especially with vitamins such as A, C and E (Quamruzzaman et al. 2003; Milton, 2003)[3]. The government may undertake policies to promote and to complement the mitigation effort. For example, it may spread awareness about the arsenic-safe sources of drinking water and the nutrition-requirement for combating arsenicosis. It may also undertake piped water project as well as may identify the arsenic safe tube-wells.[4] The economic incidence of arsenicosis on a household therefore depends not only on the adaptation and mitigation behavior of the concerned household, but also on the various social and policy parameters.

While several studies have investigated the issue of arsenic contamination, most of them have explored its geological aspects, health problems related to arsenic and technologies for arsenic removal. The papers like Mandal et al. (1996), Chowdhury et al. (1999), Chowdhury et al. (2000), Chakraborti et al. (2002, 2003, 2009), Ahmed et al. (2006) mapped spatial pattern of arsenic risk zones of West Bengal in India and in Bangladesh. These studies also evaluated the scale or magnitude of the problem in terms of at-risk population coverage. The geological aspects of arsenic contamination in groundwater have been studied by Harvey et al. (2002, 2005), Akai et al. (2004), Acharyya and Shah (2007), Biswas et al. (2012), Planer-Friedrich et al. (2012). The studies in the epidemiological issues and adverse health effects related to chronic arsenic toxicity include Datta (1976), Milton (2003), Chakraborti et al. (2004), Kapaj (2006), Ghosh (2008), Vahter (2009) and Rahman et al. (2009). A substantial

[3] Malnutrition slows down the elimination of toxic arsenic from the body, aggravates arsenicosis.
[4] Arsenic-safe tube-wells are colored as green whereas the unsafe tube-wells are colored red.

literature is also available in mitigation strategies and technologies for arsenic removal (Das et al. (2001), Misbahuddin and Fariduddin (2010), Hossain et al. (2006)). As mentioned before, besides its chronic toxicity groundwater arsenic contamination creates widespread social and psychological problems for victims and their families. During the last decade, a number of studies, mostly in Bangladesh, have highlighted the social, socio-cultural, socio-economic, psycho-social and mental health effects as a consequence of arsenic poisoning (WHO (2000), Barkat (2004), Hadi and Parveen (2004), Hanchett (2004), Hassan et al. (2005), Ahmad et al. (2007), Nahar et al. (2008), Brinkel et al. (2009), Sarker (2010), Mahmood and Halder (2011), Sultana et al. (2012), Syed et al. (2012) etc.). However, there is a dearth of such valuable socio dimensional studies in Indian context.

Though studies evaluating the economic cost of arsenic contamination are few, designing of any arsenic mitigation program would require such a cost estimate. This study attempts to derive such an estimate of cost. The papers like Khan (2007), Roy (2008), Mahanta et al. (2016) and Thakur et al. (2019) measure willingness-to-pay of the arsenic affected households towards mitigation projects by estimating their loss from labor market participation and the remedial medical expenditure for this loss. However, the loss from labor market participation is not the only dimension of loss from which an arsenic affected household suffers. The additional loss comes from the social discrimination it faces. The methodologies adopted by Khan (2007), Roy (2008), Mahanta et al. (2016) and Thakur et al. (2019) elude this dimension of cost. The present study attempts to fill this gap.

The present study accounts for the income loss of the arsenic affected households both from non-labor market sources like social discrimination. First, it shows theoretically that in presence of social discrimination, economic-cost calculation based on the labor market effect alone suffers from underestimation. Then, it predicts the pattern of labor supply behavior and expenditure behavior of the households that face social discrimination and shows in presence of sufficiently strong social discrimination the households may work more; when the labor market effects are controlled, such households definitely spend less than the other households. We test the theory by use of survey data collected from the arsenic affected and unaffected households of Kolsur village in North 24 Parganas District of the State of West Bengal in India during 2005-06 and find support for the theory. Our estimation strategy of the economic cost compares the income of observationally similar households who differ only in terms of the presence of arsenicosis in their households. The observational match has been found by use of the Propensity Score Matching (PSM) method pioneered by Rosenbaum and Rubin (1985)[5]. In PSM we control for the labor market and other sources of earning considering the variables like the household's income earned by working on own land or on land owned by others, the household's other source of income, the household's per capita working days per month in different seasons (summer, winter and monsoon), the adaptive expenditure for avoiding labor market loss and the host of demographic and educational factors. We show that social discrimination exists, and we estimate the income-loss due to social discrimination. The results show that the measure of income loss per capita derived by Roy (2008) based on the labor market outcome alone, in similar geographical region and during similar time-period is an underestimation[6].

The chapter contributes to the literature by providing a broader measure of the economic costs due to arsenicosis which includes the costs of social discrimination faced by the arsenic affected households. It argues that the economic costs are more than any estimate generated from the labor market outcome alone. The result of the study is important from the policy point of view as the use of suggested method of economic cost calculation in our study may make several arsenic removal programs viable which are stalled on the ground of cost-benefit

[5] See Caliendo and Kopeinig (2008), Imbens and Wooldridge (2009), Heinrich et al. (2010) and Kassie et al. (2010) for recent reviews of the literature.
[6] Our result is not directly comparable to either Mahanta et al. (2016) and Thakur et al. (2019) due to location and time dissimilarity.

calculation. The chapter also highlights importance of policies which would eliminate social discrimination against arsenic affected households as it leads to significant economic loss of such households.

The chapter is organized as follows. Section 2.2 presents a theoretical model to illustrate the way arsenicosis affects a household's labor supply, income and expenditure. It also shows that consideration of only labor market effects underestimates the welfare loss of an arsenic affected household and why a technique like PSM is required for this purpose. Section 2.3 and 2.4 describe the methodology and the data collection respectively. Section 2.5 analyzes the data and discusses the results. Section 2.6 draws the conclusions.

2.2. Theoretical Foundation

Consider a representative arsenic affected household that derives its utility from the consumption of commodities and leisure. The expenditure on the commodities is represented by x. The time endowment of the household is represented by $T(A)$ hours out of which L hours is consumed as leisure. The utility function of the household is:

$U = U(x, L)$

which is maximized by the choice of $\{x, L\}$ subject to the budget constraint:

$$x = w(T(A) - L) + M(A). \qquad (1)$$

In equation (1), w stands for the market wage rate and $M(A)$ stands for the non-labor income of the household. In our model, $A > 0$ stands as an index of the severity of arsenicosis in the household. Higher value of A implies, more severity of arsenicosis. We assume, $T'(A) < 0$ i.e. more severely a household is affected with arsenicosis; lower the time endowment it has both for the work as well as for leisure. We also assume $M'(A) < 0$ i.e. severity of arsenicosis in a household implies lower non-labor income of the household. We treat $M(A)$

as an indicator of social capital enjoyed by the household. The lower non-labor income of the more severely affected household reflects social discrimination faced by such a household.

Assuming existence of an interior solution$\{x^* > 0, T(A) > L^* > 0\}$to the household's utility maximization problem, the equilibrium amount of the labor supply and the equilibrium expenditure of the household are written as:

$$l^* = T(A) - L^*\big(w, T(A),\ M(A)\big) \tag{2}$$

and

$$x^* = wl^* + M(A) \tag{3}$$

respectively. Since leisure is a normal good, by income effect it follows that $\frac{\partial L^*}{\partial T} > 0,\ \frac{\partial L^*}{\partial M} > 0$ and $\frac{\partial L^*}{\partial A} = \frac{\partial L^*}{\partial T} T'(A) < 0$.

Substituting $\{x^* > 0, T(A) > L^* > 0\}$ in the utility function above, the indirect utility function of the household is defined as:

$$v(A) = U\big(x^*(A), L^*(A)\big). \tag{4}$$

Proposition 1: *The welfare loss to the households due to arsenicosis calculated only from the labor market outcome leads to underestimation.*

Proof: Applying the first order conditions of the household's utility maximization problem, from equations (3) and (4) we derive as:

$$\frac{\partial v}{\partial A} = \frac{\partial U}{\partial x}[wT'(A) + M'(A)]. \tag{5}$$

The first term of the RHS of equation (5) captures the loss in welfare due to labor market effect and the second term captures the loss due to lack of social capital which is due to the presence of social discrimination.

From the assumptions of the model we know$\frac{\partial U}{\partial x} > 0$, $w > 0$, $T'(A) < 0$ and $M'(A) < 0$. Therefore, the RHS of equation (5) is negative. Hence the statement of the proposition follows. □

Proposition 1 justifies the use of PSM method for estimating the welfare loss of a representative arsenic affected household. The method also captures the loss of income that arises due to the erosion of social capital of such households on top of the loss due to reduced labor market participation, which the previous studies in the literature failed to capture.

Proposition 2: (a) $\frac{\partial l^*}{\partial A} \gtreqless 0$ *if and only if* $T^{'}(A) \lesseqgtr \left[T^{'}(A)\frac{\partial L^*}{\partial T} + M^{'}(A)\frac{\partial L^*}{\partial M}\right]$;

(b) (i) *if* $T^{'}(A) \geq \left[T^{'}(A)\frac{\partial L^*}{\partial T} + M^{'}(A)\frac{\partial L^*}{\partial M}\right]$, $\frac{\partial x^*}{\partial A} < 0$;

(ii) *if* $T^{'}(A) < \left[T^{'}(A)\frac{\partial L^*}{\partial T} + M^{'}(A)\frac{\partial L^*}{\partial M}\right]$,

$\frac{\partial x^*}{\partial A} \gtreqless 0$ *if and only if* $w\frac{\partial l^*}{\partial A} \gtreqless -[M^{'}(A)]$.

Proof: From (2) we obtain:

$\frac{\partial l^*}{\partial A} = T^{'}(A) - \left[T^{'}(A)\frac{\partial L^*}{\partial T} + M^{'}(A)\frac{\partial L^*}{\partial M}\right]$;

and from (3) we obtain:

$$\frac{\partial x^*}{\partial A} = w\frac{\partial l^*}{\partial A} + M^{'}(A).$$

The statement of the proposition follows. □

As the incidence of arsenicosis escalates in a household, the endowment of time and social capital of the household shrink. In terms of labor supply, it generates two different kinds of reactions from the household. First, a direct effect of reduction of time endowment $T^{'}(A)$ through which its supply of labor falls. Second, an indirect effect $\left[T^{'}(A)\frac{\partial L^*}{\partial T} + M^{'}(A)\frac{\partial L^*}{\partial M}\right]$ through which because of income effect consumption of leisure falls and labor supply rises. The household's supply of labor falls if the direct effect dominates the indirect effect. For such households, consumption expenditure falls as well. However, if the indirect effect dominates the direct effect, the labor supply rises i.e. it works more. If the social discrimination is strong i.e. $M^{'}(A)$ has a large magnitude, indirect effect would also be strong. If it is strong enough, proposition 2 suggests, it is perfectly possible that an arsenic affected household works more than an arsenic unaffected household and its consumption expenditure is more than that of an arsenic unaffected household. However, if the labor supply remains unchanged or rises, social discrimination would imply a fall in the consumption expenditure of arsenic affected households.

The earlier papers in the literature like Khan (2007), Roy (2008), Mahanta et al. (2016) and Thakur et al. (2019) which do not consider the theoretical possibility of social discrimination and do not apply the PSM method like the present study as their empirical methodology, find labor supply and consequently welfare of the households fall due to arsenicosis. The data and the methodology applied in this chapter yield a different result that we explain at the end of section 2.4 below.

2.3. Empirics: Methodology

The statistical tradition of studying an impact evaluation (causal inference) is fundamentally based on the randomized experiment. By making successful randomization, the participant or treated (affected) and the nonparticipant or untreated (unaffected) groups become identical with respect to all observed and unobserved characteristics except the treatment status. The two groups are thus totally exchangeable. Although the randomized experiment is considered as theoretically ideal, in practice randomization is mostly an infeasible specifically in social science experiments or social behavioral research studies. Under such circumstances non-experimental methods are used. But the nonrandom observational studies or non-experimental methods usually suffer from the selection bias (a bias in sample selection). The techniques like multi-variate regression analysis, instrumental variable method, quasi-experimental method and propensity score matching method (PSM) are used to minimize the selection bias. We use the PSM method in our case.

The propensity score {P(X)} is defined as the probability of participation in a program given the observed set of variables X. Unlike randomization, in PSM the two groups are identical only on the observed characteristics. Dealing with multiple covariates/confounding background covariates/observed background characteristics was too troublesome due to both computational and data problems. So, Rosenbaum and Rubin (1985) suggested the use of the propensity score which is actually a balancing score. When the set of variables to match is large, the applied matching procedure based on this unidimensional balancing score is known as the propensity score matching. In a simple language, it may be said that propensity score matching refers to the pairing of the treatment and the control or comparison units with similar values on the propensity score, and possibly discarding off all unmatched units (Rubin, 2001).

2.3.1 *Evaluation Framework and Matching basics*

Inference about the impact of the treatment on the outcome of an individual involves speculation about how this individual would have performed had he/she not received the treatment. The standard framework to discuss this problem is the potential outcome approach or Roy-Rubin model (or Rubin causal model). In the case of a dichotomous/binary treatment, the treatment indicator $D_i = 1$ if an individual i receives the treatment or affected and zero otherwise. The framework assumes that there are two potential outcomes Y_1 and Y_0 corresponding to with ($D_i = 1$)or without ($D_i = 0$) treatment. Importantly, a unit i can only be in one state (either $D = 1$ or $D = 0$) at the same point of time, so only one of the two outcomes of Y_1 and Y_0 is observed. If Y_1 is observed (say) the unobserved outcome Y_0 is taken as the "missing link". The unobservable outcome of this framework is termed as 'counterfactual' since it is counter to fact (Winship and Morgan, 1999) i.e. what would the outcome be without the program at the same point of time. Hence, we need a comparison group that will allow us to attribute any change in the treatment group to the program to reflect causality properly. The PSM method matches the treatment and the comparison/control group on their observed characteristics and finds out the impact of the treatment.

In the present study, we consider the incident of arsenic related illness in the arsenic affected households as the treatment. The outcome variables are per capita monthly household income and per capita monthly household expenditure. The use of PSM method ensures that the selection bias is minimized on the observable characteristics.

In applying PSM we adopt the three-step analytic process described in Guo and Fraser (2010). The steps are as follows:

Step 1: Selection of Background Covariates

The first and foremost step is to search for and select the best background covariates that are speculated to be causing an imbalance between the treated and the control groups. The treatment group / arsenic affected group and the control group / arsenic unaffected group are compulsorily made to share similar set of various background covariates.

Step 2: Calculation of Propensity Scores

The propensity scores are calculated for each household by the use of binary logistic regression or binary discrete choice model (Gujarati and Sangeetha, 2007). Denoting the binary treatment condition as D_i, we define $D_i = 1$ if a household is in the treatment condition, here arsenic affected and $D_i = 0$ if a household is in the control condition i.e. here the household is arsenic unaffected.

The vector of the conditioning variables is denoted as X_i and the vector of the regression parameters is denoted as β_i. The binary logistic regression depicts the conditional probability of receiving the treatment as follows:

$$P\,(D_i|\,X_i) \;=\; E\,(D_i) \;=\; \frac{e^{X_i\beta_i}}{1+e^{X_i\beta_i}} \;=\; \frac{1}{1+\,e^{-X_i\beta_i}} \qquad (6)$$

Note this is a nonlinear model as D_i is not a linear function of the vector of conditioning variables X_i. But the transformed equation through the logit function (i.e. the natural logarithm of odds or $\log\,[\frac{P\,(D_i)}{1-P\,(D_i)}]$ becomes a linear function of X_i).The logit model being estimated is specified as[7]:

$$L_i = \log_e(\frac{P}{1-P}) \;=\; X_i\beta_i \qquad (7)$$

Where, P denotes $P(D_i)$. The propensity score is the estimated value of P_i= $P(D_i)$. As PSM is applied for comparison of outcome of the two groups, the two assumptions mentioned below are required to be satisfied.

Assumption 1: D_i's are independent over all i.

The non-randomized data of this study ensures that assumption 1 holds.

Assumption 2: Conditional Independence Assumption (CIA): $Y\,(0),\; Y\,(1) \sqcup D \mid X$.

Assumption 2 implies, given a set of observable covariates X which are not affected by the treatment, potential outcomes are independent of the treatment status. That is, it is assumed that the outcomes $Y\,(0),\; Y\,(1)$ are independent of the treatment status conditional on X. In this study we assume CIA to hold.

As we have considered several background covariates subsequently, there is a multidimensional problem. Therefore, to reduce the multidimensionality of background covariates, the propensity scores were estimated. The set of the background covariates are described in section 2.4 below. The questionnaire based on which the data on the selected

[7] Alternatively, a probit model or a discriminating analysis could be used for the same purpose.

background or confounding covariates were collected is given in Appendix 1. After the propensity scores are calculated we use them for the purpose of matching of the two groups.

Step 3: Matching

After PS estimation, in the third step PSM is implemented. We construct the matched pairs between the two types of households i.e. the arsenic affected households (treatment group) and the arsenic unaffected households (comparison group/counterfactuals) based on the maximum closeness of their PS values. Before matching it is required that we satisfy the following assumption:

Assumption 3: Common Support or Overlap Condition: $0 < P(D = 1 | X) < 1$.

We adopt the approach of "minima and maxima criterion" that deletes all observations whose propensity scores are smaller than the minimum and are larger than the maximum in the opposite groups, to identify the common support region. Observations which lie outside this described region are discarded from analysis.

In the present study we apply the most straightforward, traditional pairwise matching method (Rubin, 1973) i.e. the nearest neighbor (NN) matching, where the households from the comparison group are chosen as a matching partner for a treated household that is closest in terms of the propensity score. Nearest Neighbor matching is of two types-'with replacement' and 'without replacement'. In the former case, an untreated / control household can be used more than once as a match, whereas in the latter case it is considered only once i.e. once a treated case is matched to one non-treated case, both cases are removed from the pool. In the present study, the sample size of the control group (i.e. households unaffected by arsenic) is large, so we use a "NN matching without replacement".

Formally, if P_i and P_j represent the respective propensity score for the treated and control participants and if I_1 and I_0 represent the respective set of the treated and control participants, a neighborhood $C(P_i)$ contains a control participant j (i.e. $j \in I_0$) as a match for the treated participant i (i.e. $i \in I_1$), if the absolute difference of propensity scores is the smallest among all possible pairs of propensity scores between i and j as:

$$C(P_i) = \min \|P_i - P_j\|, \; j \in I_0$$

If once we get j matches to i, then j is removed from I_0 without replacement. If for each i there is only a single j found to fall into $C(P_i)$ then the nearest neighbor matching is 1-to-1 matching. If for each i there are n participants found to fall into $C(P_i)$ then the nearest neighbor matching is 1-to-n matching. Note, here we are not imposing any kind of restriction on the distance between P_i and P_j as long as j is a nearest neighbor of i in terms of the estimated propensity score. Even if $\|P_i - P_j\|$ is large (i.e. j is very different from i on the estimated propensity score), j is still considered as a match to i. So, to overcome the problem the following condition is derived where the absolute distance of the propensity scores between the two participants is less than the pre-specified tolerance for matching or a caliper (ε) satisfying:

$$\left\|P_i - P_j\right\| < \varepsilon \,, j \epsilon I_0. \tag{8}$$

Rosenbaum and Rubin (1985) suggested that the size of the caliper to be 0.25 of standard deviation of the sample estimated propensity scores (σ_P) (i.e. $\varepsilon \leq 0.25\, \sigma_P$). This variety of NN matching, which has been adopted in the present study, is known as caliper matching. Here, we are using NN matching without replacement within a caliper. By adopting this method, finally, we get a subsample of the control participants as well as the treated participants whose propensity scores have been matched.

Step 4: Post-matching analysis

After the matched treatment and control groups are formed, we compare the average of the outcome variables for the two groups and check if they are significantly different or not. The questionnaire about the outcome variables is also presented in Appendix 1.

2.4. Data

The data used in the empirical analysis is drawn from a household database created by School of Environmental Studies, Jadavpur University (SOES, JU) using a primary survey during 2005-2006 at arsenic affected village of Kolsur located at block Deganga in the district North 24-Parganas (West Bengal, India). It was a complete enumeration of 1000 households living in the village. Out of 1,000 households 374 households were arsenic affected and rest of the households (i.e. 626 households) were arsenic unaffected. In our study we have included all the 374 arsenicosis affected households in the treatment group. The control group is constituted by taking arsenicosis-unaffected households living within a radius of 6-9 meters from each of the affected households. In this way we have 392 households in the control group. Both the treatment and the control groups were purposively drawn from the same geographical area so that they do not differ much in terms of the socioeconomic and demographic characteristics and we have some control over the unobserved heterogeneity of the households. All the households in both the groups had the same source of drinking water which was arsenic affected. We have collected household data on two outcome variables: per capita monthly income [in Indian National Rupee (INR[8])] and per capita monthly expenditure (INR).

The descriptive statistics and the comparison of the outcome variables are presented in the Table 2.1 below.

[8] 1 INR = $ 0.02 on 04.05.2005. See https://www.poundsterlinglive.com/bank-of-england-spot/historical-spot-exchange-rates/usd/USD-to-INR-2005. Roy (2008) also uses the same exchange rate.

TABLE 2.1

DESCRIPTIVE STATISTICS AND COMPARISON OF THE OUTCOME VARIABLES OF ARSENIC AFFECTED HOUSEHOLDS AND ARSENIC UNAFFECTED HOUSEHOLDS

Outcome Variables	Arsenic affected (no. of observations = 374)			Arsenic unaffected (no. of observations = 392)			Mean difference
	Mean	Min	Max	Mean	Min	Max	
Per Capita Monthly household income (Rs.)	1475.52 (495.15)	500	4000	2187.11 (832.20)	833	6000	-711.59***
Per Capita Monthly household expenditure (Rs.)	1300.81 (277.97)	677	3725	1730.33 (555.28)	677	5033	-429.52***

(Note: Standard deviations are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

In all the two outcome variables on average the control group performs better than the treatment group. They earn more and spend more. They differ significantly in terms of their per capita monthly income and per capita monthly expenditure. The arsenic affected households and the arsenic unaffected households on average earn INR 1475.52 and INR 2187.11 per month per capita respectively. They on average spend INR 1300.81 and INR 1730.33 per month per capita respectively. Both the standard deviations of the income and expenditure variables are high in nature, income showing more variation than the expenditure.

We consider three different sets of background covariates for our study. The first set relates to the demographic characteristics of the households and contains variables like religion of the household, percentage of male and female members in the household and the percentage of household members of working age (within 15-64 years bracket) in the household. The second set relates to the income as well as medical expenditure of the households. The variables include whether the household earns farm income or non-farm income. For the farm income, whether the income is earned by working on own land or on land owned by others. The variables also include the household’s per capita working days per month in different seasons (summer, winter and monsoon) and the household’s per capita monthly medical expenditure (INR) which we expect to approximate the adaptative measures taken by the household to avoid the possible labor market loss. The third set includes the variables on extent of education of the households. The variables include percentage of the households having middle school education (passed class 8), percentage of the households having higher secondary education (passed class 12), percentage of graduates and percentage of the household members who are literate. Land being the major asset held in the rural areas, we also include the per capita land ownership of the households in Katha[9] to record the wealth of the households[10]. We describe the data on the background covariates in Table 2.2 below.

TABLE 2.2

DESCRIPTIVE STATISTICS AND COMPARISON OF THE BACKGROUND COVARIATES OF ARSENIC AFFECTED HOUSEHOLDS AND ARSENIC UNAFFECTED HOUSEHOLDS

Background Variables	Arsenic affected (no. of observations = 374)			Arsenic unaffected (no. of observations = 392)			Mean difference
	Mean	Min	Max	Mean	Min	Max	
Religion dummy (Hindu=1, Muslim=0)	0.40 (0.49)	0	1	0.48 (0.50)	0	1	-0.08
% of Males in the household	36.07 (14.13)	0	75	37.61 (12.83)	0	66.67	-1.54
% of Females in the household	33.70 (12.86)	0	75	36.87 (12.97)	0	66.67	-3.17**
% of household members in working age (15-64 years)	74.75 (20.55)	33.33	100	75.73 (22.37)	0	100	-0.98
Working in own land (Yes=1, No=0)	0.47 (0.50)	0	1	0.48 (0.50)	0	1	-0.01***
Working on others land (Yes=1, No=0)	0.23 (0.42)	0	1	0.19 (0.39)	0	1	0.04*
Other source of income (Non-farm income) (Yes=1, No=0)	0.60 (0.49)	0	1	0.53 (0.50)	0	1	0.07

[9] 1 Katha = 0.017 Acre.

[10] We have not included the source of drinking water as background covariate since in our sample, arsenic contaminated ground water is consumed both by the treatment (arsenic affected households) and the control (arsenic unaffected households) groups and therefore, this parameter/factor is not a source of variation in explaining observed incidence of arsenicosis. We thank one of the referees for bringing up this issue.

Per Capita working days per month in summer	9.70 (3.42)	3.33	30	9.76 (3.20)	4.33	15	-0.06
Per Capita working days per month in winter	9.71 (3.44)	3.33	30	9.76 (3.20)	4.33	15	-0.05
Per Capita working days per month in monsoon	9.53 (3.51)	0	30	9.66 (3.21)	3.75	15	-0.13
Per Capita Monthly household medical expenditure (Rs.)	24.02 (21.16)	10	225	13.56 (6.54)	4	50	10.46***
Middle school (upto class 8) (in %)	75.64 (24.39)	0	100	77.44 (24.42)	0	100	-1.8
Higher secondary (in %)	1.85 (7.34)	0	50	1.90 (7.80)	0	50	-0.05
Graduate (in %)	1.01 (5.32)	0	50	0.76 (4.70)	0	50	0.25
% of literate persons	72.96 (23.55)	0	100	75.24 (24.19)	0	100	-2.28
Per capita land ownership (Katha)	6.87 (7.36)	0.5	55.5	5.78 (5.73)	0.67	40	1.09***

(Note: Standard deviations are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

Among the demographic variables, there are more female members among the arsenic unaffected households compared to the arsenic affected households (significant at 5% level). Among the income as well as medical expenditure related variables the treatment group and the control group are significantly different on three counts. There are households in the control group who work more in own land compared to the treatment group (significant at 1% level). But there are households in the treatment group who work more on others land compared to the control group (significant at 10% level). Again, the per capita monthly medical expenditure (INR) among the arsenic affected households is more compared to the arsenic unaffected households (significant at 1% level), which shows the correctness of our apprehension that the per capita monthly medical expenditure essentially reflects the adaptive expenditure of the arsenic-affected households from possible labor-market loss. The two groups are not significantly different in any other aspect except that the treatment group has more per capita ownership of land than the control group (significant at 1% level). The similarity of per capita working days between the groups shows (by proposition 1) that the direct and indirect effect of arsenicosis almost balance each other, which indicates existence of social discrimination for the arsenic affected group.

2.5. Analysis and Results

We perform PSM using STATA 12. Through PSM we first pair the households in the treatment group (i.e. arsenic affected group) with the households in the control group (i.e. arsenic unaffected group) who observationally possess similar characteristics. For doing this we identify the common support between the treatment and the control groups in terms of their PS. Note that PSM can be performed only on the observations in the common support between the two groups. From PS calculations, we find 329 households of the treatment group (i.e. arsenic affected group) and 392 households of the control group (i.e. arsenic unaffected group) in the common support region. The rest 45 households of the treatment group are off the common support region. The 329 households (on support) of the treatment (arsenic affected) group are matched with exactly 329 households (on support) of the control (arsenic unaffected) group. According to the methodology described above, we use the standard deviation of the propensity scores (estimated as 0.26) to calculate the value of the caliper as 0.0656.

The differences in the mean outcomes of the matched pairs are interpreted as the impact of the treatment i.e. the economic loss suffered by per household due to arsenicosis. Table 2.3 describes the results of the comparison of the outcome variables of the two groups.

TABLE 2.3

COMPARISON OF THE OUTCOME VARIABLES OF MATCHED HOUSEHOLDS (no. of observations =329)

Outcome Variables	Arsenic affected			Arsenic unaffected			Mean difference	S.E.	T-stat
	Mean	Min	Max	Mean	Min	Max			
Per Capita Monthly household income (Rs.)	1485.98 (515.64)	640	4000	2174.17 (888.33)	1000	6000	-688.20***	70.38	-9.78
Per Capita Monthly household expenditure (Rs.)	1309.06 (309.42)	677	3725	1751.85 (596.65)	765	5033	-442.78***	46.05	-9.61

(Note: Standard deviations are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

Observe from Table 2.3 that the mean of the monthly household per capita income of the 329 households (on support) of the treatment (arsenic affected) group is obtained as INR 1485.98 per month per capita while the mean of the monthly household per capita income of the 329 households (on support) of the control (arsenic unaffected) group is INR 2174.17 per month per capita. The former is lower than the latter by INR 688.20 (equivalent to $13.76) per month per capita, which turns out to be significant at 1% level. We can take this figure as a measure of welfare loss per capita due to arsenicosis on account of social discrimination[11]. Notice that this figure is more than the income-loss figure calculated by Roy (2008) which stands at $7. The difference arises because while Roy (2008)[12] calculates the income loss which arises only due to adverse labor market outcome, whereas, our figure captures the income-loss from the non-labor sources like social discrimination. Therefore, the empirical finding of the study confirms that the figure provided by Roy (2008) underestimates the economic loss due to arsenicosis as claimed theoretically in Proposition 1 stated in section 2.2 above.

[11] The treatment and control groups of our study are matched in terms of their hours of labor-supply in different seasons of the year and their adaptive medical expenditure as well. It controls for the labor-market effects on the household income.

[12] Also Mahanta et al. (2016) and Thakur et al. (2019) more recently depicted the same.

We have also compared the per capita average monthly household expenditure for both the treatment and the control groups. While the mean of per capita monthly household expenditure of the matched households of the treatment (arsenic affected) group is obtained as INR 1309.06, the mean of the per capita monthly household expenditure of the matched households of the control (arsenic unaffected) group is obtained as INR 1751.85. The mean of the household expenditure per month per capita of the treatment group is lower than that of the control group by INR 442.78 (equivalent to $8.86) per month per capita, which is significant at 1% level. Since we have controlled for the labor-market effects (and other kinds of wealth effects like land holding) in our empirical study, according to Proposition 2 derived in section 2.2 above, this can happen if and only if social discrimination against arsenic affected households exists[13].

2.6. Conclusions

The present chapter proves two points. First, social discrimination exists against the arsenicosis affected households and consequently these households suffer from significant economic loss both in terms of per capita income and per capita consumption; second, the existence of social discrimination leads to underestimation of income loss when calculated only from the labor-market sources. The results have important implications for cost-benefit calculation in adoption of policies for fighting the problem of arsenicosis.

While the existing works in the literature that estimate economic loss due to arsenicosis concentrate only on the estimation of loss of labour income due to illness, the present study constructs a theoretical model to argue that such a method underestimates the true economic

[13] This argument follows from the fact that from table 2.2 the labor supply by the arsenic affected households and arsenic-unaffected households at all seasons of the year not significantly different (statistically) from zero and there is no evidence in our survey that there exists more than one wage rate at the market (the labor supply at own land also fetches the market wage rate (in the sense of opportunity cost)). Moreover, a PSM study with per capita working days per month in the three seasons as outcome variable showed that the arsenic affected households supplied significantly more labor compared to the matched arsenic unaffected households in the sample. We report the result in Appendix 2 of the paper.

loss of these households as they also face social discrimination. It argues that the method of propensity score matching, when applied properly, solves the problem of estimation of loss from the non-labor-market sources like social discrimination. It applies the method on a dataset collected from a household survey in an arsenic affected village in West Bengal, India to estimate the income and consumption loss due to social discrimination and compares the estimates with a previous study by Roy (2008) during similar time period to show the extent of possible underestimation. On policy front, the chapter highlights on two aspects. First, since the study shows that social discrimination against arsenic-affected households exists and they face significant loss in income and expenditure due to such discrimination, there should be policies to build awareness against social discrimination faced by such households; Second, the cost-benefit analysis conducted for projects aimed to solve arsenic problem should take into account the estimate of loss from social discrimination, which seems to be significantly high as we show in this chapter, so that more of such kind of projects become viable.

The study suffers from an important limitation. The 'social discrimination' is an unobserved factor in this study which under control makes significant per capita income and expenditure difference between the treatment and control group households. A direct measure of social discrimination would have made the results robust. The present study faces data-limitation on this count. This work can be updated in a more recent and a more complete data base. The impact of various policy interventions on the arsenic affected households can also be studied. These remain as future research agenda.

Appendix 1

NAME OF THE HEAD OF THE FAMILY	

FAMILY SIZE	MALE	FEMALE	TOTAL

RELIGION DUMMY	HINDU (1)	MUSLIM (0)

NO. OF LITERATE PERSONS	

PERCENTAGE OF LITERATE PERSONS	

PERCENTAGE OF MALES IN THE HOUSEHOLD	

PERCENTAGE OF FEMALES IN THE HOUSEHOLD	

WORKING IN OWN LAND	YES (1)	NO (0)

WORKING ON OTHERS LAND	YES (1)	NO (0)

OTHER SOURCE OF INCOME (Non-farm income)	YES (1)	NO (0)

HOUSEHOLD MEMBERS DATA SURVEY

HOUSEHOLD MEMBERS	EDUCATION LEVEL			EDUCATION LEVEL (in %)			AGE	PERCENTAGE OF AGE RANGE [15-64 Years (working age group)]
	Middle school (upto class 8) (1)	Higher secondary (2)	Graduate (3)	(1)	(2)	(3)	(Years)	
1.								
2.								
3.								
4.								
5.								
6.								
7.								

TOTAL LAND OWNERSHIP OF THE HOUSEHOLD(KATHA)	

PER CAPITA LAND OWNERSHIP OF THE HOUSEHOLD (KATHA)	

TOTAL MONTHLY HOUSEHOLD INCOME (Rs.)	

PER CAPITA MONTHLY HOUSEHOLD INCOME (Rs.)	

HOUSEHOLD WORKING DAYS PER MONTH IN DIFFERENT SEASONS

SUMMER		WINTER		MONSOON	

HOUSEHOLD PER CAPITA WORKING DAYS PER MONTH IN DIFFERENT SEASONS

SUMMER		WINTER		MONSOON	

TOTAL MONTHLY HOUSEHOLD EXPENDITURE (Rs.)	

PER CAPITA MONTHLY HOUSEHOLD EXPENDITURE (Rs.)	

TOTAL MONTHLY HOUSEHOLD MEDICAL EXPENDITURE (Rs.)	

PER CAPITA MONTHLY HOUSEHOLD MEDICAL EXPENDITURE (Rs.)	

Appendix 2

COMPARISON OF LABOUR SUPPLY OF MATCHED HOUSEHOLDS
(no. of observations =329)

Outcome Variables	Arsenic affected			Arsenic unaffected			Mean difference	S.E.	T-stat
	Mean	Min	Max	Mean	Min	Max			
Per Capita working days per month in summer	9.76 (3.49)	3.33	30	9.21 (2.95)	4.33	15	0.55**	0.25	2.19
Per Capita working days per month in winter	9.77 (3.50)	3.33	30	9.21 (2.94)	4.33	15	0.57**	0.25	2.24
Per Capita working days per month in monsoon	9.59 (3.58)	0	30	9.10 (2.94)	3.75	15	0.49	0.26	1.94

(Note: Standard deviations are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

CHAPTER 3

ADOPTION OF PIPED WATER SOURCE IN AN ARSENIC AFFECTED AREA

*This chapter is based on:

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3.1. Introduction

Although the adoption of piped water sources as a response to microbial contamination has been studied in details in the existing literature, not much is known about the adoption of it as a response to arsenic contamination (Amrose, Burt and Ray (2015)). The present study attempts to fill the gap.

Groundwater Arsenic contamination in the Ganga-Meghna-Brahmaputra (GMB) plain of India and Bangladesh and its consequences on human health have been reported as one of the World's biggest natural groundwater calamities to the mankind. More than 500 million people of the GMB plain may be potentially at risk from groundwater arsenic contamination (Nahar et al. 2008, BGS; DPHE, 2001). In India, seven states namely - West Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur and Chattisgarh have so far been reported as affected by arsenic contamination in groundwater much above the World Health Organisation (WHO) permissible limit of 10µg / Litre (Mandal et al. 1996). People in these states have chronically been affected by arsenic poisoning directly due to consumption of arsenic contaminated hand-tube-wells water and indirectly through the food chain since arsenic contaminated groundwater is used in agricultural productions. Arsenic related health hazards may be classified into two types: (i) Acute: include bone marrow depression, gastrointestinal discomfort, vomiting, diarrhoea, convulsions, coma and ultimately death (Acute toxicity however is quite infrequent) and (ii) Chronic: include skin lesions (arsenicosis or arsenical dermatitis), which are characterized by keratosis (hardening of skin), melanosis, hyper-pigmentation (dark spots like rain drops), hyperkeratosis and hypo-pigmentation (white spots) [14] . The arsenic affected individuals, due to their illness, are not only in a disadvantageous position at the labour market, their households are also socially discriminated against. They are often dismissed from their jobs. The arsenic affected children

[14] See papers such as Chakraborti et al. (2018), Kapaj et al. (2006).

are sometimes restrained from their schools. The affected girls are refused and rejected of marriage and often married women face problems in their marital life and even divorce ensues. Affected people are quite often ignored and avoided from social functions. The arsenic affected persons are often prohibited socially as they are mistakenly considered as the patients infected with contagious diseases. The labour market and non-labour market costs of the arsenic affected households turn out to be substantial, estimated in papers such as Khan (2007), Roy (2008), Mahanta et al. (2016), Chakraborty and Mukherjee (2020). Therefore, it is imperative that the rational households in the arsenic affected areas would adopt the arsenic-safe sources of water as mitigation strategy. But, the arsenic-affected areas in India also being the areas affected with wide-spread microbial contamination, it is not clear whether the adoption decision is guided by arsenic contamination or microbial contamination (Delaire et al. (2017)). However, it is more likely that the households respond to the microbial contamination only, as it has immediate perceptible health outcome, which the arsenic contamination does not have since it takes nearly seven years to show up its symptoms. Among the available alternative safe water sources, treated piped water adoption seems to be the best strategy against both types of contamination mentioned above[15]. The provision of piped water being costly as it is network dependent, in developing countries like India, the government in recent times has arranged for free-access, intermittent-supply of piped water at some locations at the arsenic affected villages lived mainly by the poor. Our chapter studies the adoption of this source of safe-water among arsenic affected and unaffected households in an arsenic affected village of West Bengal, India.

Although we cannot be sure about motivation of arsenic-unaffected households whether they have adopted piped water as a response against microbial contamination or

[15]Although household water treatment and safe storage is proved to be somewhat effective against microbial contamination, it is not very effective against arsenic contamination. See Amrose, Burt and Ray (2015) for details.

arsenic contamination in water, it can safely be hypothesized that the households which have already suffered from more severe incidence of arsenicosis would adopt piped water sources with higher probability. Apart from the behavioural trait and bounded rationality, their adoption decision can also be affected by the costs of adoption and economic-demographic characteristics like education, religion, percentage of female at the household and the household income. This chapter takes all these costs and socio-economic factors into account and empirically seeks answer to the following research question: do the households with more severe incidence of arsenicosis show higher probability of adopting arsenic-safe water sources? It investigates the question by using a primary-survey data collected from village Kolsur (block Deganga) in the district North 24-Parganas (West Bengal, India), one of the severely affected areas, during 2015-16, and finds an affirmative answer to the question.

Among the strategies for fighting the arsenic menace/hazards, the use of arsenic-safe water sources like treated dugwell, arsenic-safe deep-tubewells (often coloured green for easy identification while unsafe are coloured red), treated piped water etc. and improvement of nutritional status are considered as the most important strategies[16]. The spread of awareness complements such strategies. Since dugwells and tubewells are more vulnerable to contamination, the piped water supply is considered as the safest source of arsenic-free water. In the sampled village, during the survey period, purified-surface-water distributed through pipes was the only known source of arsenic-safe drinking water. The piped water project was implemented by the government during 2011-12. It was made accessible freely for public at certain locations of the village at specific times of a day. Therefore, the distance from a household's location to the piped-water source becomes an important factor in the adoption decision. The greater the distance, the adoption turns out to be more costly. The intermittent

[16]People having poor nutrition were found to be affected more from arsenic toxicity than the people having an adequate nutrition rich food. Intake of nutritious diet especially with vitamins such as A, C and E is essential for arsenic mitigation (Quamruzzaman et al. 2003; Milton, 2003).

nature of the piped water supply increases the cost of collection and is also expected to matter in the adoption decision. First, there can be possible mismatch between a household's preferred time for collection of water and the fixed supply-time of piped water. Second, there can be time-consuming queue for collection of water. It is possible that the households with higher per capita income are in a better position to negotiate these problems by paying people for collection of water. If water is supplied free of cost, which was the case in the sampled village, one expects that the per capita income of the households would not affect the adoption decision. But the cost related to intermittent nature of the supply may make adoption easier for the higher per capita income households. Education increases awareness and the households with more literate persons are expected to adopt the piped water sources with higher probability. The percentage of female members in the households may increase adoption rate from two different aspects. First, the female members of the households are more concerned about the health and hygiene of the household. Second, if some of the female members are not gainfully employed, the presence of such members may alleviate the cost of collection for the households. The sampled village had presence of households belonging to Hindu and Muslim religions. They live clustered in segregated locations. The religion as such is not expected to affect the adoption decision. But, if the location of piped water source is nearer to a particular cluster, it may act as a disincentive for the households belonging to the other cluster[17].

Studies about issues related to adoption of arsenic-safe sources of water are scarce in the literature. On the one hand, there are studies like Ahmad et al. (2003, 2005), Aftab et al. (2006), Inauen et al. (2013), Larsen (2016) and Singh (2017) which analyse the technological aspects of adoption. They study the cost effectiveness of alternative feasible technologies. On the other hand, there are studies in economics which discuss adoption of safe-water sources

[17]On practice of untouchability in Indian villages, see Dasgupta and Pal (2021).

and its benefits in the case of water-borne diseases like diarrhoea. While Jalan and Ravallion (2003), Nandi et al. (2016) focus on health benefit of piped-water adoption in such cases, the papers like Suzuki and Sakamoto (2018), Balasubramaniam et al. (2014) respectively show that the social network and religious segregation play an important role in piped water adoption in rural India. Although, in Morocco, Devoto et al. (2012) shows that the ensuing health benefit is not the cause adoption of piped water, in Uganda Onjala et al. (2013) shows, the risk perception of drinking unsafe water matters in adoption decision. Both these papers, however, agree on that the cost of adoption deters adoption. In case of Bhutan, Rahut et al. (2016) highlights the role of household income in adoption decision. According to their finding, the higher income households adopt more. In a closely related paper, Delaire et al. (2017) analyses the household drinking water practices in two villages in arsenic-affected Murshidabad district of West Bengal, India in year 2014. The paper shows that despite low arsenic awareness, 52.9% of the households adopted safe water sources. They find the adoption decision was guided mainly by the fear of microbial contamination, smell and taste of the available water sources, and supported largely by purchase of safe water, produced by small scale firms, operating in the area. Therefore, adoption decision had a bias in favour of the higher per capita income households. However, the prevention of arsenicosis occurs as a co-benefit in Delaire et al. (2017) and the supply of piped water plays a non-significant role. In contrast, this chapter focuses exclusively on piped water adoption behaviour of households, who has suffered from arsenicosis.

In our study out of 707 sampled households although only 51% are arsenic affected, 62% adopted the piped water source. The study shows that the arsenic affected households adopt the piped water source at 35% higher probability than the arsenic unaffected households. It also analyses the role played by the factors such as extensiveness of arsenicosis in a household (measured by percentage of family members arsenic affected), intensity of symptoms of arsenicosis in a household (measured by the percentage of certain arsenic related symptoms appeared in the household) and the years of experience about arsenicosis in a household, in the adoption decision. The chapter finds that of the three factors mentioned above, the years of experience about arsenicosis matters the most in the adoption decision. Therefore, the risk perception of not using an arsenic-safe source is higher among the households that have long experience of suffering from the related ailments, the social and economic loss. The study also finds that in the sampled village the Hindu households, who were in minority, adopted less because of distance of the piped water source from their locational cluster. As expected, the results show, the piped water being freely available, the per capita income of the households does not matter in the adoption decision; but the time cost is alleviated more by the higher per capita income households by showing higher probability of adoption.

The contribution of the chapter in the literature is manifold. First, it shows that the arsenic affected households adopt the piped water source at higher probability than non-affected households. Second, the households with longer history of arsenic-related illness adopt more than the households showing more extensive or intensive spread of the symptoms among the household members. Third, location of the piped water sources in a clustered village matters in adoption decision. Fourth, the intermittent supply of piped-water may bias the adoption in favour of higher per capita income households, even if it is supplied free by the government. For policy-making, the results suggest that greater adoption of piped water sources in arsenic affected villages can be facilitated if the awareness is spread through the households, who suffered from arsenicosis for a long time. The piped water sources must be located more evenly in the clustered villages for greater adoption. A more continuous supply of piped water may remove the high-income bias from adoption of piped water in arsenic affected villages.

This chapter is organized as follows. Section 3.2 describes the methodology, the data collection and the data respectively. Section 3.3 presents the results. Sections 3.4 and 3.5 discuss the policy implications and highlight the conclusions respectively.

3.2. Materials and Method

In an arsenic affected area, the households are expected to adopt an arsenic-safe source of drinking water. It is part of their mitigation strategy against arsenic related health and social hazards. However, the probability of adoption may differ between the households already suffering from arsenicosis and the unaffected households. It may also vary depending on the spread, intensity of arsenicosis in the household, the length of experience about such disease in the household, the costs of adoption of safe-water sources, the economic-demographic factors like religion, the household income and education, the percentage of female members at the household. The study controls for all the other factors to check the way the incidence of arsenic related health hazard affects a household's adoption decision of arsenic-safe piped water source.

For our study we use a discrete-choice probit model where the binary dependent variable denoting the household's choice Y_i takes a value of 1 as the household chooses piped water source and a value of 0 as the household maintains status quo. The probit model is a statistical probability model with two categories in the dependent variable. Let X_i be the vector of regressors or the vector of the explanatory variables, which are assumed to influence the outcome Y_i. In the present study, we arrange the explanatory variables into three categories – a household's arsenic related health variables, cost of the adoption related variables and the variables related to demography of the households (later in Section 3.3 these independent variables are described in details). Specifically, we assume that the probit model takes the form

$$p_i = \Pr(Y_i = 1|X_i) = \Phi(X_i\beta) = \int_{-\infty}^{X_i\beta} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-Z^2}{2}\right) dz$$

where, p_i denotes the probability of finding $Y_i = 1$ given X_i, and Φ is the Cumulative Distribution Function (CDF) of the standard normal distribution. The set of parameters β are typically estimated by maximum likelihood method. The CDF constrains the probability to lie between 0 and 1 (i.e. $0 < \Phi(z) < 1$, for all real numbers z), or $\lim_{z \to +\infty} \Phi(z) = 1$ and $\lim_{z \to -\infty} \Phi(z) = 0$. Since $\Phi(.)$ has the standard normal CDF, $\widehat{\beta}$ is the probit estimator and $\widehat{Y}_i = \Phi(X_i\widehat{\beta})$ is the fitted probability.

For interpreting the coefficients of the probit regression, the marginal effects are needed to be calculated. The marginal effects show the change in probability when the predictor or independent variable increases by one unit. For continuous variables this represents the instantaneous change given that the 'unit' may be very small. For binary variables, the change is from 0 to 1, so one 'unit', as it is usually thought. The relationship between a specific variable and the outcome of the probability is interpreted by means of the marginal effect, which accounts for the partial change in the probability. The marginal effect associated with continuous explanatory variables say, X_{iK} on the probability $\Pr(Y_i = 1|X_i)$, holding the other variables constant, can be derived as: $\frac{\partial p_i}{\partial X_{ik}} = \Phi'(X_i\beta)\beta_K$ where Φ' represents the probability density function of a standard normal variable. Discrete changes in the predicted probabilities constitute an alternative to the marginal effect when evaluating the influence of a dummy variable. Such an effect can be derived from the following:

$\Delta = \Phi(\bar{X}\beta, d = 1) - \Phi(\bar{X}\beta, d = 0)$.

The marginal effects provide insights into how the explanatory variables shift the probability of frequency of arsenic-safe supply sources adoption. In this chapter, the marginal effects are calculated for each variable while holding other variables constant at their sample mean values.

The empirical analysis in this study uses a primary data base created by School of Environmental Studies, Jadavpur University (hereafter SOES, JU). It was collected during 2015-2016 from the village Kolsur of block Deganga in the district North 24-Parganas (West Bengal, India) which is known to be an arsenic affected area. The data set contains data both on arsenic affected households and arsenic unaffected households. The data was obtained by directly interviewing the households of the village. For this study, we surveyed 707 households selecting every alternative household living in the village. During the survey period, piped water was the only source of arsenic-safe drinking water in the village. The piped water project was implemented by the government during 2011-12. It was made accessible freely for public at certain locations of the village at specific times of a day. The sample of households includes both arsenic affected and arsenic unaffected households and the households that have adopted piped water and that have not done so. The survey prepared a detailed questionnaire and asked the households whether they have adopted piped water source or not; whether they have arsenicosis in the household and if so, it asked about the spread, the intensity and the time-duration of suffering from it. The survey also includes questions on cost of the adoption of arsenic safe water supply sources and demographic information of the household. The dependent variable of the regression analysis, the source dummy, is a binary variable that takes the value of 1 if the household adopts piped water source and the value of 0 otherwise. The independent variables are classified into three different groups: the arsenicosis related health variables, the adoption costs related variables and the demographic variables. Let us describe the components of each group of independent variables in details.

(1) Arsenic related health variables: In this group we consider four different types of variables that may act as alternative indicators of arsenic related health hazard of a household. First, a dummy variable which takes the value of 1 if any member of the household has symptoms of arsenicosis and the value of 0 if no one is affected in the household. Second, a variable defined as SPREAD that measures the spread of arsenicosis at a household indicated by the percentage of household-members affected by arsenicosis. For example, if three members of a four member households show symptoms of arsenicosis, SPREAD of the household takes the value of 0.75. Third, a variable defined as INTENSITY that measures the intensity of arsenicosis at a household. For this, we consider six symptoms of arsenicosis *viz.* change in skin colour, white and black spots in skin, diffuse keratosis on palm/sole, spotted keratosis on palm/sole, non-healing ulcer on body, Bowens disease (suspected cancer) on body. If the members of a household show three of the six symptoms, INTENSITY of the household takes the value of 0.5. Fourth, a variable defined as YOI, that measures the average years of illness under arsenicosis at a household as indicator of experience about arsenic related health hazard. All these variables are expected to have positive coefficients in the regression.

(2) Costs of adoption related variables: Since the piped water sources did not have any access fee in the sampled village, the costs of adoption of such sources were measured based on two different attributes. First, the distance to the piped water source in meters from the location of a household; the longer is the distance, the higher is the travel cost either in terms of physical exhaustion or in terms of transport. Second, the total time required for collecting the piped water in minutes that may include the time required for travel to the source and the time required for queuing at the source. Notice that since longer distance also means longer time of travel, the two measures of adoption costs can potentially be correlated with each other. However, we checked the correlation coefficient to be insignificant and include both as explanatory variables in the regression. Both the variables are expected to have negative coefficients in the regression.

(3) Demographic variables: In this group we include four different variables which may influence a household's adoption decision. First, a dummy variable is introduced that captures the religion of a household. The religion may induce a behavioural variation in sourcing drinking water. In case of deep religious divide, which is widely reported in India[18], households from certain religious communities are not allowed to access certain sources of drinking water. Since the sample had households belonging only to two different religions, Hindu and Muslims, the religion dummy takes a value of 1 if the household is Hindu and the value of 0 if the household is Muslim. Second, since the presence of females in household is thought to bring in a change in the behaviour of a household in terms of health and hygiene[19], the percentage of female members in a household is taken as an explanatory variable. It is expected to have positive coefficient in the regression. Third, since education makes a household assess the risk of drinking from conventional sources in a better way, percentage of literate persons in a household is included as an explanatory variable. The percentage of literate persons in a household is calculated as number of its members of age 18 years or above having at least primary level of education. For example, if three members of a six member-household at their age 18 years or above have studied at least upto the primary level, the percentage of literate persons in the family is calculated as 50%. The percentage of literate persons in a household is expected to have a positive coefficient in the regression. Fourth, since the income strata of a household sometimes influences its behaviour along with affordability of the costs of adoption, the per capita monthly household income in INR has also been included as an explanatory variable. However, in our case since the piped water is

[18]See Dasgupta and Pal (2021).
[19]See papers like Choudhuri and Desai (2020), Duflo (2012).

freely provided to all the households, we do not expect it to significantly affect the adoption decision.

In the regression analysis we also include interaction of some of the explanatory variable described above. Since the time cost of collection can be alleviated by high per capita income households by employing people, we take interaction between time cost of collection and per capita income of the household. We expect the coefficient of it to be positive. We also interact the percentage of female members in a household both with distance to piped water source and collection-time, to check if the presence of higher percentage of female members in the household makes the cost barrier to adoption insignificant. We interact the religion dummy with the distance to piped water sources, to find whether location of the piped water source from clustered location of a particular community, which was the case in the sampled village, explains the adoption behaviour of the households belonging to the two different religious communities living in the village.

The descriptive statistics of the dependent and the main independent variables are presented in the Table 3.1 below.

TABLE – 3.1

DESCRIPTIVE STATISTICS

Variables		Number of observations = 707		
		Mean	Min	Max
Dependent variable				
	Source Dummy (adopted piped water supply =1, did not adopt piped water supply=0)	0.62 (0.49)	0	1
Independent variables				
Arsenic related health variables	Household Dummy (arsenic affected household=1, arsenic unaffected household=0)	0.51 (0.50)	0	1
	% of household members arsenic affected [SPREAD]	16.75 (20.11)	0	100
	% of arsenic affected symptoms (change in skin colour, white and black spots in skin, diffuse keratosis on palm / sole, spotted keratosis on palm / sole, non-healing ulcer on body, Bowens disease (suspected cancer) on body) in households [INTENSITY]	13.98 (15.73)	0	66.67
	Average years of illness (years) [YOI]	9.60 (9.81)	0	25
Costs of the adoption related variables	Distance to the arsenic-safe drinking water source (Meters)	143.88 (147.41)	5	500
	Time required to collect drinking water (Minutes)	15.71 (7.67)	2	40
Demographic variables	Religion dummy (Hindu household=1, Muslim household=0)	0.41 (0.49)	0	1
	% of Females in the household	35.17 (11.90)	16.67	75
	% of Literate persons	63.86 (23.17)	0	100
	Per Capita Monthly household income (Rs.)	1821.06 (592.62)	500	5000

(Note: Standard deviations are in the parentheses)

Table 3.1 shows that out of 707 sampled households although only 51% are arsenic affected, 62% adopted piped water. There are households where all the members show symptoms of arsenicosis. On average 16.75% of the household members show some symptoms of arsenicosis. The variable INTENSITY has a mean of 13.98% in the sampled households. The average years of illness in arsenic related diseases across the households was 9.60 years. The average distance a household from an arsenic-safe piped water source was 143.88 meters and the total time required for collection on average was 15.71 minutes. 41% of the sampled households was Hindu in terms of religion. The average percentage of female members in a household was 35.17 and the percentage of literate persons in the household was 63.86. The average per capita monthly household income was 1821.06 in INR[20]. Therefore, the average per day per capita income of the households living in the village was less than US$1.

3.3. Results

We perform the probit regression using STATA. We run four different sets of the regressions in all of which the source dummy appears (piped water source adopted = 1; 0 otherwise) as the dependent variable. They use the same set of controls, but differ from each other in their use of 'arsenic related health variables' as independent variable. We use arsenicosis dummy (if the household is arsenic affected =1, 0 otherwise), SPREAD, INTENSITY and YOI as alternative measures of 'arsenic related health variables' in the four different sets. For checking the effect of three different groups of independent variables mentioned above, in each set, we run two different specifications of the regression. The first specification considers only the 'arsenic related health variables' as regressor. The second one adds all three groups of independent variables and their interactions, as defined above, as control. Running the alternative specification helps us to check robustness of the results. The results are described in Tables 3.2 and 3.3 below.

[20]1 INR = 0.015 US$ on 31.01.2016.

TABLE-3.2

ADOPTION OF PIPED WATER SOURCE: HOUSEHOLD ARSENICOSIS EFFECT

Independent variables	**(1)**	**(2)**
Household Dummy (i.e. arsenic affected household=1, arsenic unaffected household=0)	0.69** (0.10)	0.65*** (0.10)
Distance to the arsenic-safe drinking water source (Meters)		-0.0007 (0.0016)
Time required to collect drinking water (Minutes)		-0.01 (0.04)
Religion dummy (Hindu household=1, Muslim household=0)		-0.76*** (0.15)
% of Females in the household		0.0041 (0.01)
% of Literate persons		0.0037 (0.0028)
Per Capita Monthly household income (Rs.)		-0.0002 (0.0002)
Religion dummy* Distance to the arsenic-safe drinking water source		0.0023*** (0.0008)
% of Females in the household* Distance to the arsenic-safe drinking water source		-0.00001 (0.00004)
% of Females in the household* Time required to collect drinking water		-0.0001 (0.0008)
Time required to collect drinking water * Per capita Monthly household income		0.00002* (0.00001)
No. of observations	707	707
LR chi 2	**LR chi 2(1)** 50.26	**LR chi 2(11)** 96.89
Prob > chi 2	0.0000	0.0000
Pseudo R2	0.0535	0.1030

(Note: Standard errors are in the parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

Table 3.2 reports the set of regressions with arsenicosis dummy as ‘arsenic related health variables’. In the first specifications run for this regression, the coefficient of the arsenicosis dummy turn out to be positive and significant at 5% level, implying higher rate of adoption of piped water among the households affected by arsenicosis. In the second specification, as the other controls are introduced, the value of the coefficient of the arsenicosis variable remains nearly unchanged with the level of significance going up to 1% level. The coefficients of most of the controls turn out to be insignificant, having their expected sign. The negative significant coefficient of the religion dummy (at 1% level of significance) implies that a Muslim household adopts the piped water with higher probability than a Hindu household. The result is strange because we cannot explain it by standard theory. Therefore, we investigate it further by studying the sign of the interaction term between distance to the piped water sources and the religion dummy, which turned out to be positive and significant at 1% level. The positivity of the interaction term implies that the Hindu households on average live away from the piped water source compared to the Muslim households. Recalling that the descriptive statistics in Table 3.1 shows that the village has Muslim majority, it seems, the piped water sources were provided closer to the location of Muslim households. The clustered location of the communities in the village explains the result. The result adds insight to findings of Balasubramaniam et al. (2014) at district level Indian data that religious segregation affects the piped-water adoption decision. The other interesting result that we derive in the second specification is the sign of the interaction term between collection-time and per capita income of the households, which turns out to be positive at 10% level. Although per capita income of the households does not matter in adoption decision as the provision is free, there is weak evidence that the higher per capita income households alleviates the time cost of collection problem and adopts the piped water source in higher probability. The results also show that higher percentage of female members in a household does not significantly change the adoption behaviour. We also do not find evidence of higher adoption probability in households with higher percentage of literate members.

Similar to the case of set 1, we now describe the results of the regressions involving SPREAD (% of household members arsenic affected), INTENSITY (% of arsenic affected symptoms in households) and YOI [average years of illness (years)] as ‘arsenic health related variable’ separately in Table 3.3 below.

TABLE-3.3

ADOPTION OF PIPED WATER SOURCE: EFFECT OF SPREAD, INTENSITY, YOI

Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
SPREAD	0.01** (0.0026)	0.01*** (0.0027)				
INTENSITY			0.02** (0.0031)	0.02*** (0.0033)		
YOI					0.04** (0.0051)	0.04*** (0.0055)
Distance to the arsenic-safe drinking water source (Meters)		-0.0009 (0.0016)		-0.0010 (0.0016)		-0.0009 (0.0016)
Time required to collect drinking water (Minutes)		-0.01 (0.04)		-0.01 (0.04)		-0.02 (0.04)
Religion dummy (Hindu household=1, Muslim household=0)		-0.78*** (0.15)		-0.78*** (0.15)		-0.79*** (0.15)
% of Females in the household		0.0015 (0.01)		0.0045 (0.01)		0.0025 (0.01)
% of Literate persons		0.0042 (0.0028)		0.0044 (0.0028)		0.0035 (0.0028)
Per Capita Monthly household income (Rs.)		-0.0002 (0.0002)		-0.0002 (0.0002)		-0.0002 (0.0002)
Religion dummy* Distance to the arsenic-safe drinking water source		0.0024*** (0.0007)		0.0025*** (0.0007)		0.0024*** (0.0008)
% of Females in the household* Distance to the arsenic-safe drinking water source		-0.00001 (0.00004)		-0.00001 (0.00004)		-0.000008 (0.00004)
% of Females in the household* Time required to collect drinking water		0.00009 (0.0008)		-0.00005 (0.0008)		-0.0001 (0.0008)
Time required to collect drinking water * Per Capita Monthly household income		0.00002* (0.000013)		0.00002* (0.00001)		0.00002* (0.00001)
No. of observations	707	707	707	707	707	707
LR chi 2	**LR chi 2(1)** 30.22	**LR chi 2(11)** 79.33	**LR chi 2(1)** 28.45	**LR chi 2(11)** 78.82	**LR chi 2(1)** 60.88	**LR chi 2(11)** 108.15
Prob > chi 2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo R2	0.0321	0.0844	0.0303	0.0838	0.0647	0.1150

(Note: Standard errors are in the parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

In Table 3.3, in columns (1) and (2) for both the specifications the coefficient of SPREAD is positive and significant, the level of significance is going up to 1% level on introduction of controls, keeping the value of the coefficient unchanged. The coefficients of controls also show qualitatively similar result as in Table 3.2. As we repeat the regressions with INTENSITY and YOI as main explanatory variables, we find qualitatively similar results, as reported in columns (3)-(4) and (5)-(6) respectively. Therefore, the spread of arsenicosis among the household members, its intensity of occurrence among them and the history of arsenicosis in the household, all have positive significant effect on piped water adoption. But, the comparison of coefficients in Table 3.3, clearly shows that YOI has the strongest impact on adoption, followed by INTENSITY and SPREAD.

Table 3.4 shows calculations of marginal effects (the predicted probabilities) of the 'arsenic health related variables' i.e. the arsenicosis dummy, SPREAD (% of household members arsenic affected), INTENSITY (% of arsenic affected symptoms in households) and YOI (average years of illness (years)) on adoption decision of the households. Since two different specifications have been run in each set of regressions, Table 3.4 reports the average marginal effect.

TABLE-3.4

AVERAGE MARGINAL EFFECTS

Households arsenic related health variables (Independent Variables) (no. of observations =707)	**Average Marginal Effects**	**Standard Errors**	**z-statistic**
Household Dummy (i.e. arsenic affected household=1) adopted arsenic safe piped water supply projects	0.74	0.02	32.38
Household Dummy (i.e. arsenic unaffected household=0) adopted arsenic safe piped water supply projects	0.49	0.03	18.15
SPREAD	0.0051	0.00090	5.66
INTENSITY	0.0061	0.0011	5.58
YOI	0.0139	0.0016	8.85

Notice from Table 3.4, the probability that an arsenic affected household adopts arsenic safe water sources is 35% higher than the probability that an arsenic unaffected household does so. However, the rise in probability of adoption due to higher spread of arsenicosis in a household or due to higher intensity of such illness in a household is very low calculated at 0.0051 and 0.0061 respectively. In contrast, the rise in average year of illness by 1 year, raises the probability of adoption by 0.01%. Therefore, we conclude that the risk perception of not using arsenic-free piped water source is higher among the households that have long experience of suffering from the related ailments, the social and economic loss.

3.4. Discussion

The chapter studies the mitigation behaviour of the households in the arsenic affected regions by adoption of piped water sources. It uses primary survey data collected from the arsenic affected and unaffected households of Kolsur village in North 24 Parganas District of the State of West Bengal in India during 2015-16. It runs probit regressions that control for co-variates like adoption costs and demographic variables like religion, literacy, percentage of female at the household and per capita monthly household income, to find that the probability of adoption is higher among the arsenic affected households vis-à-vis the unaffected households. The study also checks whether the spread, the intensity and the experience of such health hazards at the households also matter in the adoption decision and finds that their marginal impact on adoption decision is small. Among the three factors mentioned above, the chapter finds, the years of experience matters the most in the adoption decision. Therefore, the risk perception of not using arsenic-safe piped water source is higher among the households that have long experience of suffering from the related ailments, the social and economic loss. While the factors like affordability (per capita monthly household income), awareness (the literacy) and the percentage of female members in the households play little role in adoption decision. Interestingly, the Muslim households in the sample were found to adopt more compared to the Hindu households. The chapter explored the reason behind such a result. It turned out that the village had majority of the Muslim households. As the religious communities lived in locational cluster in the sampled village, location of the piped water source nearer to the Muslim cluster deterred the Hindu households from its adoption. The results also show, even if the piped water was provided free of cost, the time cost associated with intermittent supply of water created a bias in adoption in favour of the high per capita income households, as these households could possibly employ someone to negotiate the cost.

The chapter contributes to the literature being one of its kind on the voluntary adoption of arsenic-safe piped water source in an arsenic affected area. The earlier adoption studies such as Delaire et al. (2017) could not distinguish between adoption against microbial contamination and adoption against arsenic contamination. It was specially so because while the microbial symptoms get remedied in short duration, the manifestation and remedial of arsenic related symptoms take longer time. This chapter contributes by studying the piped water adoption behaviour of the arsenic affected households via-vis arsenic unaffected households. It also studies the effect of spread, intensity and experience of arsenic related symptoms on piped water adoption decision. The results derived in the chapter have important policy implications. For policy-making, the results suggest that greater adoption of piped water sources in arsenic affected villages can be facilitated if the awareness is spread through the households, who suffered from arsenicosis for a long time. The piped water sources must be located more evenly in the clustered villages for greater adoption. A more continuous supply of piped water may remove the high-income bias from adoption of piped water in arsenic affected villages, where it is provided free of cost.

3.5. Conclusions

The chapter studies the adoption of arsenic-safe piped water source both by the arsenic-affected and unaffected households. The data is collected from Kolsur village in West Bengal, India. Controlling for the other factors, it is found that the households affected by arsenicosis are more likely to adopt piped water source as mitigation strategy compared to the unaffected households. The study analyses separately the role of the spread of arsenicosis and the intensity of its symptoms among the household members in adoption piped water source. The effect of the years of experience about the health and social hazards associated with arsenicosis is also checked. The chapter also finds that although the marginal impact of all these factors on the adoption decision is small, the effect of years of experience is stronger than the other two factors. Among other factors, it seems that the uneven allocation of publicly-provided free piped-water sources and its intermittent supply discourages its adoption by raising the cost of adoption. Therefore, the households either located near the source, or having higher per capita income adopt it more easily than the households located further away from the source and the poor.

The results derived in the chapter have important policy implications. The results suggest that greater adoption of piped water source in arsenic affected villages can be facilitated if the awareness is spread through the households, who suffered from arsenicosis for a long time. The piped water sources must be located more evenly in the villages, where population lives in spatial clusters, for greater adoption. A more continuous supply of piped water may remove the observed high-income bias from adoption of piped water in arsenic affected villages, where it is freely provided.

There are some limitations of the study undertaken in the chapter. The most important of them is its small sample size. A more extensive study may externally validate the results of the chapter, which remains our future research agenda.

CHAPTER 4

ECONOMIC LOSS DUE TO ARSENICOSIS: A DID APROACH

4.1. Introduction

In chapter 2 we applied the Propensity Score Matching (PSM) method to measure economic loss due to arsenicosis. The PSM method controlled for heterogeneity across the households on the basis of observed confounding factors. It attributed the estimated income loss of the group of ‘arsenic affected households’ relative to the group of matched ‘arsenic non-affected households’ to the unobserved factors like social discrimination, which is commonly faced by the affected households. In this chapter we apply the Difference-in-Differences (DID) method to refine our estimation of relative economic loss of the arsenic affected households. The DID method is able to control the unobserved heterogeneity among either type of households if it does not vary over time. It also controls for the common time trend faced by both types of households. Therefore, the income loss due to arsenicosis that we estimate in this chapter arises purely from the time-dependent unobserved factors that differentiates the treatment (arsenic-affected) and control (arsenic-unaffected) group households.

For our present purpose we use data collected by School of Environmental Studies, Jadavpur University from the same households at Kolsur village in North 24 Parganas District of the State of West Bengal in India that maintained their treatment and control group identity as of 2005-2006 in 2015-2016. First we convert all the income and expenditure data of these households at 2004-2005 base using the all commodities Whole Sale Price Index (WPI) provided by Office of the Economic Advisor, Ministry of Commerce and Industry, Government of India[21]. Then we first match the households in 2005-2006 on the basis of their observable characteristics by applying PSM method as we did in Chapter 2. We consider four different sets of background covariates for our study. The first set relates to the demographic characteristics of the households and contains variables like religion, percentage of male and female members, and the percentage of people of working age (15–64 years old) in the

[21] The WPI data is provided in Appendix 1.

household. The second set relates to the medical expenditure of the households. The third set is related to labor market participation of the households. This includes whether the household earns farm income or non-farm income. Under farm income, whether the income is earned by working on own land or on land owned by others is considered. Other variables included are the household's per capita working days per month in different seasons (summer, winter, and monsoon) and the level of educational attainment in the households. Land being the major asset in rural areas, we also include the per capita land ownership of households in terms of *katha*[22] to record the wealth of the households. We assume that the treatment is given in the form of arsenicosis to the treatment group of the matched households, which is a random allocation. This justifies the 'common trend' assumption between the two groups of households used in the 2×2 DID analysis to construct the counterfactual observation for the treatment group in 2015-2016. We compare the 'household monthly per capita income' of the treatment group in 2015-2016 with its counterfactual to derive the DID estimate of income loss.

The 2×2DID methodology adopted in this chapter is a modification of the seminal work by Card and Krueger (1994)[23]. The chapter uses PSM method at the base year to identify the treatment and control groups households who are similar in their observable characteristics. It is expected that without intervention of arsenicosis these households would show similar change in their monthly per capita income from 2005-06 to 2015-16. This assumption is known as the 'common trend' assumption in the DID method and plays a crucial role in constructing the counterfactual. In an earlier work similar strategy as ours has been used by Benavente and Zuniga (2021) in a different context. The most of the earlier studies in the existing literature on economic effect of arsenicosis estimates the income loss due to arsenicosis only on the basis of observable characteristics. The papers like Khan (2007), Roy

[22] 1 *katha* = 0.017 acre.

[23] See Angrist and Pischke (2009), Villa (2016), Cunningham (2021) for detailed exposition of the methodology.

(2008), Mahanta et al. (2016) and Thakur et al. (2019) estimate the income loss of arsenic-affected households from their reduced labour market participation due to illness. However, it does not provide any measure of income loss such households face from the discrimination they face either at the labour market or at everyday life at their social neighbourhood. In an earlier paper Chakraborty and Mukherjee (2020) attempted to fill the gap by using PSM method. Chapter 2 of the present thesis is based on Chakraborty and Mukherjee (2020). According to Chakraborty and Mukherjee (2020) the income loss of a household due to arsenicosis on account of social discrimination is INR 688.20 (equivalent to $13.76) per month per capita, which is more than the income-loss figure calculated by Roy (2008) which stands at $7[24]. However, one major limitation of Chakraborty and Mukherjee (2020) is that while comparing income levels of the two groups of households, it controls only for the observable characteristics of the households. It ascribes the estimate of income loss due to unobservable characteristics entirely to the cost of social discrimination. Although this can be true, it is also possible that the income loss is reduced over time because of some time-dependent unobserved characteristics of the households. The examples would be, adoption to arsenic-safe water sources by a household, which reduces the intensity of arsenicosis over time, or reduced experience of social discrimination by a household as the social awareness about the disease spreads over time. Chakraborty and Mukherjee (2021)[25] indeed justifies this possibility as it has been observed that as the piped water supply project was started by the government during 2011-2012, in the same village, the households affected by arsenicosis adopted arsenic-safe piped water source with higher probability compared to the arsenic-unaffected households. The income loss evaluated through the DID method allows us to net out the income loss due to the unobserved household-specific fixed effects and the common

[24] 1 INR = $ 0.02 on 04.05.2005. See https://www.poundsterlinglive.com/bank-of-england-spot/historical-spot-exchange-rates/usd/USD-to-INR-2005. Roy (2008) also uses the same exchange rate.

[25] Chapter 3 of the present thesis is based on Chakraborty and Mukherjee (2021).

time trend experienced by both groups of households. Therefore, we end up estimating the income loss due to the idiosyncratic time-dependent changes both in the treatment and the control group households.

The papers like Ahamed et al. (2006), Chakraborti et al. (2009), Shewale et al. (2017), and Jamil et al. (2019) also evaluated the impact of arsenic contamination over the years, but with objectives different from the present study. Ahamed et al. (2006) focuses on several surveys of the arsenic contamination situation and consequent clinical manifestations of arsenicosis among the villagers of Eruani village, Laksham upazila, Comilla district, Bangladesh during 1997-2005. It shows that due to lack of proper awareness among the villagers about different aspects of arsenic toxicity, even after eight years of known exposure, village children were still drinking arsenic-contaminated water, and many of them had arsenical skin lesions and also there were social problems due to the symptoms of arsenicosis. Jamil et al. (2019) analyses the effectiveness of different approaches to arsenic mitigation over 18 Years (during 2000-2001 to 2018-2019) in Araihazar, Bangladesh. However, none of the papers studied the dimension of income loss as we do it in the present chapter.

The chapter is organized as follows. Section 4.2 and Section 4.3 describe the methodology and the data collection respectively. Section 4.4 analyzes the data and discusses the results. Section 4.5 draws conclusions.

4.2. Methodology

The study applies Difference in Difference (DID) method for evaluating impact of the arsenicosis on the per capita monthly household income over the years 2005-2006 and 2015-2016. In this method the averages of the per capita monthly household income for the treatment group i.e. arsenic affected households and the control group i.e. arsenic unaffected households are compared over the years 2005-2006 and 2015-2016. Initially the difference between the averages of the per capita monthly household income of the two periods 2005-2006 and 2015-2016 (say, 'a') is calculated for the treatment group. Further, the same difference (say, 'b') is calculated for the control group between 2005-2006 and 2015-2016. Finally, applying DID method i.e. taking the difference of 'a' and 'b' (or the difference between 'a' and the counterfactual outcome of the treatment group of the year 2015-2016) and by checking whether the difference is significant or not, the result is obtained.

Conceptual Framework

(a) DID: Pre and Post, Treatment and Control

Let us define,

Y_{ist} = per capita monthly income of household i in period t.

Since the households will either be arsenic affected or unaffected, in practice, we only get to see one or the other. The heart of the DID setup is an additive structure for potential outcome in the no-treatment state. We assume,

$$E(Y_{ist}|s,t) = \gamma_s + \lambda_t$$

where, s denotes treatment status (i.e. the individuals who do not receive treatment here we consider the arsenic-unaffected household and the individuals who receive treatment here we consider the arsenic-affected household) and t denotes time period (i.e. here we consider the two time periods 2005-2006 and 2015-2016).

Let D_{st} be a dummy for household, where arsenic exposures are index by s and observed in period t. It takes value of 1 if the household is arsenic affected in the later time period.

Assuming that $E(Y_{ist} - Y_{ist}|s,t)$ is a constant for $s = 1, 0$ respectively, denoted by β , we have:

$$Y_{ist} = \gamma_s + \lambda_t + \beta D_{st} + \varepsilon_{ist} \quad (1)$$

where, $E(\varepsilon_{ist}|s,t) = 0$. From here, we get

$$E[Y_{ist}|s = arsenic\ affected\ household, t = (2015 - 2016)] -$$
$$E[Y_{ist}|s = arsenic\ affected\ household, t = (2005 - 2006)]$$
$$= \lambda_{(2015-2016)} - \lambda_{(2005-2006)} + \beta$$

and

$$E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2015 - 2016)] -$$
$$E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2005 - 2006)]$$
$$= \lambda_{(2015-2016)} - \lambda_{(2005-2006)}$$

The difference in difference estimator is defined as the difference in average per capita monthly household income in the treatment group of both time periods minus the difference in average per capita monthly household income in the control group of both the time periods. Therefore, the population difference –in –differences,

$$\beta = \{E[Y_{ist}|s = arsenic\ affected\ household, t = (2015 - 2016)] -$$
$$E[Y_{ist}|s = arsenic\ affected\ household, t = (2005 - 2006)]\} -$$
$$\{E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2015 - 2016)] -$$
$$E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2005 - 2006)]\},$$

is the causal effect of interest. The key identifying assumption here is that per capita monthly household income trends would be the same in both states (arsenic affected household and arsenic unaffected household) in the absence of treatment (arsenic related health hazards). The derivation of the causal effect is explained in figure 4.1 below.

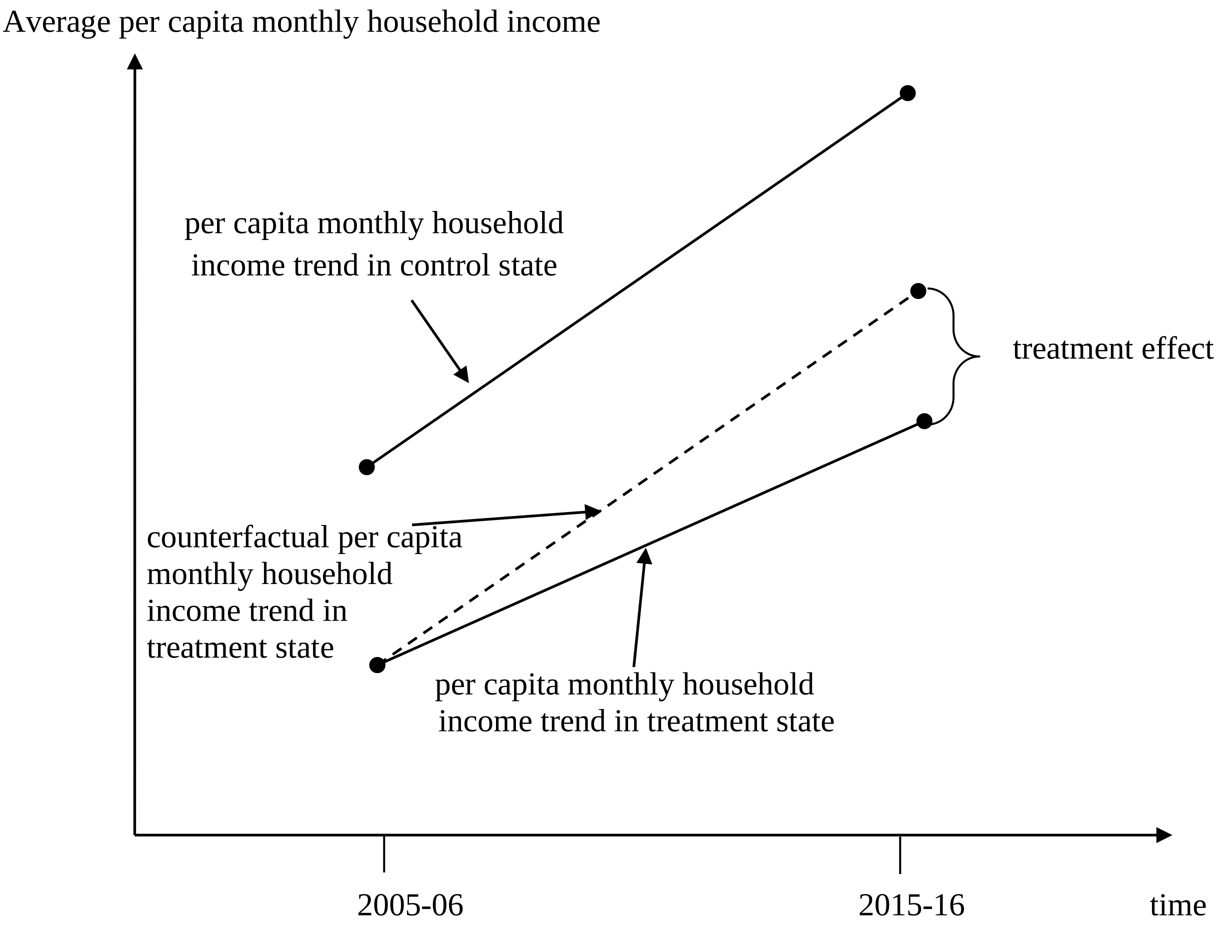

Figure 4.1: Causal effects in the DID model

In figure 4.1, we assume the monthly per capita income of the arsenic unaffected households rises between 2005-06 and 2015-16. Using the "common trend" assumption we derive the counterfactual per capita monthly household income of the treated group in 2015-16. Then the actual income level is compared with the counterfactual income level to derive the estimate of the income loss.

(b) DID Regression

Let T_s be a dummy for treatment status [i.e. $T_s = 0, 1$; where 0 indicates the control group (i.e. arsenic unaffected household) and 1 indicates the treatment group (i.e. arsenic affected household)] and d_t be a time dummy [i.e. $d_t = 0, 1$; where 0 indicates a previous time period (i.e. the time period 2005-2006) and 1 indicates a later time period (i.e. the time period 2015-2016)] then

$$Y_{ist} = \alpha + \gamma T_s + \lambda d_t + \beta(T_s d_t) + \varepsilon_{ist} \qquad (2)$$

is the same as equation (1) where$T_s d_t = D_{st}$. The conditional mean function $E(Y_{ist}|s,t)$takes on four possible values and there are four parameters. The link between the parameters in the regression equation (2), and those in the DID model for the conditional mean function, equation (1), is

$E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2005-2006)] = \alpha$;

$E[Y_{ist}|s = arsenic\ affected\ household, t = (2005-2006)] = \alpha + \Upsilon$;

$E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2015-2016)] = \alpha + \lambda$;

$E[Y_{ist}|s = arsenic\ affected\ household, t = (2015-2016)] = \alpha + \beta + \Upsilon + \lambda$.

Therefore,

$$\begin{aligned}\beta = \{&E[Y_{ist}|s = arsenic\ affected\ household, t = (2015-2016)] - \\ &E[Y_{ist}|s = arsenic\ affected\ household, t = (2005-2006)]\} - \\ &\{E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2015-2016)] - \\ &E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2005-2006)]\}\end{aligned}$$

As DID regression model is applied for comparison of outcome of the two groups in two different time periods, the two assumptions mentioned below are required to be satisfied.

Assumption 1: The error term is on average zero i.e. $E(\varepsilon_{ist}) = 0$.

Assumption 2: The error term is uncorrelated with the other variables in the equation:

$$cov(\varepsilon_{ist}, T_s) = 0$$

$$cov(\varepsilon_{ist}, d_t) = 0$$

$$cov(\varepsilon_{ist}, T_s . d_t) = 0$$

Assumption 2 ensures that the treatment and the common time trend is exogenous, which helps to drive the causal inference.

Another interpretation of the difference in difference estimator is that it is a simple difference estimator between the actual outcome and the counterfactual outcome. Individuals will typically have two observations each, one for previous time period and another one for latter time period. Let $\overline{Y_0}^T$ and $\overline{Y_1}^T$ be the sample averages of the outcome for the treatment group in two time periods and let $\overline{Y_0}^C$ and $\overline{Y_1}^C$ be the corresponding sample averages of the outcome for the control group in two time periods. Subscripts correspond to time periods and superscripts correspond to the treatment status.

Let, $\overline{Y_1}^T$ be the actual outcome and $\overline{Y_{cf}}^T$ be the counterfactual outcome (i.e. the outcome occurs in the latter time period to the treatment group when there is no presence of treatment). Therefore,

$$\widehat{\beta_{DD}} = \overline{Y_1}^T - \overline{Y_{cf}}^T$$

where, $\overline{Y_{cf}}^T = \overline{Y_0}^T + (\overline{Y_1}^C - \overline{Y_0}^C)$ and $E[\overline{Y_{cf}}^T] = \alpha + \gamma + \lambda$. The observations $\overline{Y_{cf}}^T$ and $E[\overline{Y_{cf}}^T]$ do not exist as they are literally “contrary to fact”.

The purpose of the program evaluation is to find a “good” estimate of β ,$\hat{\beta}$, given the available data.

Kernel-based Propensity Score Matching

Before estimating $\hat{\beta}$, we match the households using kernel-based propensity score matching method developed by Heckman et al. (1997, 1998) at the initial time period, which takes care of the common trend assumption and the assumption of independence of treatment with the covariates. This method constructs matches using all individuals in the potential control sample in such a way that it takes more information from those who are closer matches and downweights more distant observations. By doing so, Kernel-based matching uses comparatively more information than other matching algorithms such calliper matching method used in Chapter 2. The method allows estimation of treatment effect for the treated by using information from all possible controls within a predetermined span. If K(.) is the Kernel function, h_n is the selected bandwidth and p_i is the propensity score of the ith control household calculated through probit regression method, the weight attached to the ith household is calculated as:

$$w_i = \frac{K\left(\frac{p_i - p_k}{h_n}\right)}{\sum K\left(\frac{p_i - p_k}{h_n}\right)} .$$

The households are matched on common support. The Kernel weights are incorporated in the DID regression to obtain a Kernel propensity score matching DID treatment effect in the following way:

$$DID = \{E[Y_{ist}|s = arsenic\ affected\ household, t = (2015-2016)] -$$

$$w_i\ E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2015-2016)]\} -$$

$$\{E[Y_{ist}|s = arsenic\ affected\ household, t = (2005-2006)] -$$

$$w_i E[Y_{ist}|s = arsenic\ unaffected\ household, t = (2005-2006)]\} \quad (3)$$

The regression is run as:

$$w_i Y_{ist} = \alpha + \gamma T_s + \lambda d_t + \beta(T_s d_t) + \varepsilon_{ist} \quad (4)$$

for estimating $\hat{\beta}$.

Using the software STATA 12, in the present study, we apply the Kernel Propensity Score DID regression model with common support to evaluate the impact of arsenic affected households on the outcome variable - per capita monthly household income over the years 2005-2006 and 2015-2016.

4.3. Data

The empirical analysis in this study uses the primary data base created by School of Environmental Studies, Jadavpur University (SOES, JU). The data set contains data both on arsenic affected households and arsenic unaffected households. It was collected during the years 2005-2006 and 2015-2016 from the village Kolsur of Deganga block in the district North 24-Parganas (West Bengal, India). In both the years it was a complete enumeration of households living in the village. The survey found that the total number of households did not change over the years. It remained the same at 1000. However, the composition of the treatment and the control group changed over time. Twenty households, who were in the control group in 2005-2006, was found to be Arsenic affected in 2015-2016. In 2005-2006, out of 1,000 households 374 households were arsenic affected and rest of the households (i.e. 626 households) were arsenic unaffected. In our study we included all the 374 arsenic affected households in the treatment group. The control group was constituted by taking arsenic-unaffected households living within a radius of 6-9 meters from each of the affected households. In this way we had 392 households in the control group. For the purpose of the DID, in our present exercise, since we consider only those households, who did not change their treatment-control identity in 2015-2016 vis-à-vis 2005-2006, we have only 372 households in our control group, while the number of households in the treatment group remains the same as 374.

In 2005-2006 we collected household data on per capita monthly household income [in Indian National Rupee (INR)], which is the outcome variable, and on four sets of background covariates: (1) demographic characteristics of the households: religion, percentage of male and female members, and the percentage of people of working age (15–64 years old) in the household; (2) per capita medical expenditure of the households; (3) labor market participation of households: type of employment (farm or non-farm), per capita working days per month in different seasons (summer, winter, and monsoon); The third set includes variables that capture the level of educational attainment in the households. This includes the percentage of household members having attained middle school education (passed class 8), higher secondary education (passed class 12), graduate education, and the percentage of household members who are literate; (4) Asset holding of the households: land being the major asset in rural areas, we also include the per capita land ownership of households in terms of *katha* to record the wealth of the households. For evaluating the impact of arsenic related health hazards on per capita monthly income of the households between the years 2005-2006 and 2015-2016, we again collected the income data of the same sample of 746 households in 2015-2016. For purpose of comparison we converted the income data of both 2005-06 and 2015-16 in the base of 2004-2005. The converted monthly per capita income data is presented in the table 4.1 below and compared both for the treatment and control groups over the years.

TABLE 4.1

COMPARISON OF THE OUTCOME VARIABLE FOR ARSENIC AFFECTED HOUSEHOLDS AND ARSENIC UNAFFECTED HOUSEHOLDS

Outcome Variable	Arsenic affected (no. of observations = 374)			Arsenic unaffected (no. of observations = 372)			Mean difference
	Mean	Min	Max	Mean	Min	Max	
Per Capita Monthly household income (Rs.) [at 2004-05 base] [2005-2006]	1411.99 (433.99)	478.47	2631.58	2116.69 (743)	797.45	4465.71	-704.70***
Per Capita Monthly household income (Rs.) [at 2004-05 base] [2015-2016]	997.82 (252.13)	565.93	1509.15	1492.57 (643.21)	636.67	3018.30	-494.75***

(Note: Standard deviations are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

In terms of the outcome variable, per capita monthly household income, as expected on average the control group performs better than the treatment group i.e. arsenic unaffected households in both the time periods 2005-2006 and 2015-2016 earn significantly higher monthly per-capita income than the arsenic affected households. The arsenic affected households and the arsenic unaffected households on average earn INR 1411.99 and INR 2116.69 per month per capita respectively in the year 2005-2006. In the year 2015-2016 on average they earn INR 997.82 and INR 1492.57 per month per capita respectively. Both the standard deviations of the converted per capita monthly household income of year 2005-2006 of arsenic affected and arsenic unaffected households are high in nature. The incomes in year 2005-2006 are showing more variations.

The background covariates follow the description of Table 2.2 of chapter 2 is presented in the table below. The medical expenditure has been converted at the base of 2004-2005.

TABLE 4.2

COMPARISON OF THE BACKGROUND COVARIATES FOR ARSENIC AFFECTED HOUSEHOLDS AND ARSENIC UNAFFECTED HOUSEHOLDS 2005-2006

Background Variables	Arsenic affected (no. of observations = 374)			Arsenic unaffected (no. of observations = 372)			Mean difference
	Mean	Min	Max	Mean	Min	Max	
Religion dummy (Hindu=1, Muslim=0)	0.40 (0.49)	0	1	0.50 (0.50)	0	1	-0.10
% of Males in the household	36.07 (14.13)	0	75	37.59 (12.92)	0	66.67	-1.52*
% of Females in the household	33.70 (12.86)	0	75	36.81 (13.06)	0	66.67	-3.11
% of household members in working age (15-64 years)	74.75 (20.55)	33.33	100	75.75 (22.39)	0	100	-1.00*
Working in own land (Yes=1, No=0)	0.47 (0.50)	0	1	0.48 (0.50)	0	1	-0.01*
Working on others land (Yes=1, No=0)	0.23 (0.42)	0	1	0.19 (0.39)	0	1	0.04*
Other source of income (Non-farm income) (Yes=1, No=0)	0.60 (0.49)	0	1	0.52 (0.50)	0	1	0.08***
Per Capita working days per month in summer	9.70 (3.42)	3.33	30	9.82 (3.19)	4.33	15	-0.12*
Per Capita working days per month in winter	9.71 (3.44)	3.33	30	9.82 (3.19)	4.33	15	-0.11*
Per Capita working days per month in monsoon	9.53 (3.51)	0	30	9.71 (3.20)	3.75	15	-0.18*
Per Capita Monthly household medical expenditure (INR) [At 2004-05 base]	22.99 (20.24)	9.57	215.31	13.20 (6.25)	3.83	47.85	9.79
Middle school (upto class 8) (in %)	75.64 (24.39)	0	100	78.04 (24.07)	0	100	-2.40*
Higher secondary (in %)	1.85 (7.34)	0	50	2 (8)	0	50	-0.15*
Graduate (in %)	1.01 (5.32)	0	50	0.80 (4.82)	0	50	0.21*
% of literate persons	72.96 (23.55)	0	100	76.01 (23.84)	0	100	-3.05**

Per capita land ownership (Katha)	6.87 (7.36)	0.5	55.5	5.79 (5.75)	0.67	40	1.08**

(Note: Standard deviations are in parentheses and ***, **,* respectively denotes 1%, 5% and 10% level of significance)

Among the demographic variables, there are more male members among the arsenic unaffected households compared to the arsenic affected households (significant at 10% level). The percentage of household members in working age (15-64 years) is more among the arsenic unaffected households compared to the arsenic affected households (significant at 10% level). There are households in the control group who work more in own land compared to the treatment group (significant at 10% level). But there are households in the treatment group who work more on others land compared to the control group (significant at 10% level). The other source of income among the arsenic affected households is more compared to the arsenic unaffected households (significant at 1% level). There are households in the control group who work more in different seasons (summer, winter and monsoon) compared to the treatment group (significant at 10% level). The percentage of middle school and higher secondary educated households are more among the arsenic unaffected households compared to the arsenic affected households (significant at 10% level). Whereas, the percentage of graduate households is more among the treatment group compared to the control group (significant at 10% level). But the percentages of literate household members as well as per capita ownership of land are more among the arsenic unaffected households compared to the arsenic affected households (significant at 5% level).

Notice that as we compare the group means of the background covariates for the arsenic affected and unaffected households in Table 4.2 above, the comparison turns out to be different than the similar comparison we did in Table 2.2 in Chapter 2 above. This happens because of the change in the number of households in the control group as discussed at the beginning of this section. In earlier exercise we had 392 households in the control group. Now we have only 372. Particularly, for the covariates ‘households who work more in own land’ as well as ‘households’ per capita ownership of land’ significance levels change from 1% to 10% and 1% to 5% respectively. Also, now there are more male members among the arsenic unaffected households compared to the arsenic affected households whereas, earlier in chapter 2 there are more female members among the arsenic unaffected households compared to the arsenic affected households.

4.4. Analysis and Results

We apply Kernel Propensity Score DID method with covariates and common support to evaluate the impact of arsenic affected households on the outcome variable ‘households monthly per capita income’ over the years 2005-2006 and 2015-2016. Before applying the DID method, using the 2005-2006 data on background covariates for each household we first calculate the predicted probability of being treated by performing a probit regression, known as ‘propensity score’. The propensity scores are further used to match the households through Kernel matching method. We describe the regression results of the data on the background covariates in the Table 4.3 below.

TABLE 4.3

THE COEFFICIENTS OF THE BACKGROUND COVARIATES WITH PROBIT REGRESSION

Background Covariates	Coefficients
Religion dummy (Hindu=1, Muslim=0)	-0.14 (0.11)
% of Males in the household	-0.0053 (0.0055)
% of Females in the household	-0.01** (0.0051)
% of household members in working age (15-64 years)	0.0057 (0.0039)
Working in own land (Yes=1, No=0)	-0.51*** (0.15)
Working on others land (Yes=1, No=0)	0.23* (0.13)
Other source of income (Non-farm income) (Yes=1, No=0)	0.15 (0.13)
Per Capita working days per month in summer	-0.10 (0.32)
Per Capita working days per month in winter	0.11 (0.32)
Per Capita working days per month in monsoon	0.0059 (0.10)
Per Capita Monthly household medical expenditure (INR) [Base Year 2004-2005]	0.09*** (0.0076)
Middle school (upto class 8) (in %)	-0.0002 (0.0055)
Higher secondary (in %)	-0.0038 (0.0075)
Graduate (in %)	0.0042 (0.01)
% of literate persons	-0.0060 (0.0057)
Per capita land ownership (Katha)	0.03*** (0.01)
Constant term	-1.05
No. of observations	746
LR chi2(16)	211.27
Prob >chi2	0.0000
Pseudo R2	0.2043

(Note: Standard errors are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

After using the weights calculated from the Kernel distribution for matching, it was found that 362 households of the treatment group (i.e. arsenic affected group) and 367 households of the control group (i.e. arsenic unaffected group) belong to the common support region. Table 4.4 reports the results of the Kernel Propensity Score DID method estimation with common support.

TABLE 4.4

CHANGE IN PER CAPITA MONTHLY HOUSEHOLD INCOME OF ARSENIC AFFECTED AND UNAFFECTED HOUSEHOLDS OVER THE YEARS 2005-2006 AND 2015-2016

	Per Capita Monthly household income (Rs.) [At 2004-05 base]		Mean difference	DID	t-stat
	Mean [2015-2016]	Mean [2005-2006]			
Arsenic affected (Treatment group)	994.71	1393.24	-398.53	227.29*** (61.20)	3.71
Arsenic unaffected (Control group)	1616.90	2242.72	-625.82		
Diff (Treatment group- Control group)	-622.20*** (43.27) (t = 14.38)	-849.48*** (43.27) (t = -19.63)			
R-square	0.37				

(Note: Standard errors, t statistics and ***, **, * respectively denotes 1%, 5% and 10% level of significance. Means and standard errors are estimated by linear regression)

Notice from Table 4.4 that when the average per capita monthly income of both the groups of households are evaluated at the common base of 2004-05, it shows a declining trend. For the arsenic affected treatment group while the decline is from INR 1393.24 to INR 994.71, for the arsenic unaffected control group the decline is from INR 2242.72 to INR 1616.90. The decline is much more of INR 625.82 for the control group than INR 398.53 for the treatment group. Therefore, even though on average the treatment group households earn significantly lower per capita monthly household income compared to the control group households in both 2005-06 and 2015-16, when the common trend is applied to construct the counterfactual of the treatment group households, it appears that the treatment group households on average earn INR 227.29 (equivalent to $4.55)[26] more per month per capita than the control group households. The result is surprising as it was expected that the arsenic affected group would have more income loss over time than the control group households. However, it turns out that when we eliminate the household specific fixed factors and the common time trend, the arsenic affected households do significantly better than the unaffected households to improve their income. This happens due to their adjustment towards the adversities they faced because of arsenicosis. Perhaps, the factors like piped water adoption, social awareness related to arsenicosis acted in their favour. However, one can be apprehensive about the result obtained above since it might have happened that the arsenic affected households have done better in terms of per capita income as the number of family members in their group on average has decreased over time compared to the other group when their absolute income difference remained insignificant. Below we check for this possibility to verify robustness of our conclusion.

First, we compare the family size of the two groups of households in 2005-2006 as well as in 2015-2016. The result is described in Table 4.5 below.

TABLE 4.5

COMPARISON OF THE FAMILY SIZE OF ARSENIC AFFECTED HOUSEHOLDS AND ARSENIC UNAFFECTED HOUSEHOLDS OVER THE YEARS 2005-2006 AND 2015-2016

	Arsenic affected (no. of observations = 374)			Arsenic unaffected (no. of observations = 372)			Mean difference
	Mean	Min	Max	Mean	Min	Max	
Family size [2005-2006]	3.68 (0.97)	2	7	3.31 (1.12)	2	7	0.37***
Family size [2015-2016]	4.23 (1.05)	2	8	4.12 (0.91)	2	8	0.11

(Note: Standard deviations are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance)

[26] The same value of the exchange rate applies as in footnote 4.

Table 4.5 shows that the average family size of both the groups increased over the years, which should have a depressing effect on their per capita monthly household income. Also, notice that in both the years the arsenic-affected group on average had larger family size compared to the arsenic unaffected group. However, the gap in their average family size was significantly larger in 2005-06, while it was insignificant in 2015-2016. It turns out from Table 4.5 that on average the family size of the arsenic-affected households increased at a slower rate than the family size of the arsenic-unaffected households. Clearly this may have an influence on the result obtained above that the arsenic affected households lost less in terms of their average per capita monthly income than the average per capita monthly income of the arsenic-unaffected group. Therefore, for ensuring that the result is not driven solely by the change in family size of the two groups, we estimate the DID again by using the absolute amount of monthly income of the households. If the similar result holds here also, we are confident about our conclusion that the arsenic affected households adjusted to their situation in such a way that their income fell less than the similar households in the control group. The result of the DID with the absolute amount of monthly income of the households is presented in Table 4.6 below.

TABLE 4.6

CHANGE IN MONTHLY HOUSEHOLD INCOME OF ARSENIC AFFECTED HOUSEHOLDS OVER THE YEARS 2005-2006 AND 2015-2016

	Monthly household income (Rs.) [At 2004-2005 base]		Mean difference	DID	t-stat
	Mean [2015-2016]	Mean [2005-2006]			
Arsenic affected (Treatment group)	4182.88	4960.84	-777.96		
Arsenic unaffected (Control group) (N=738)	6600.13	8314.83	-1714.70	936.74*** (267.06)	3.51
Diff (Treatment group- Control group)	-2417.25*** (188.84) (t = 12.80)	-3353.99*** (188.84) (t = -17.76)			
R-square	0.28				

(Note: Standard errors, t statistics and no. of observations are in parentheses and ***, **, * respectively denotes 1%, 5% and 10% level of significance. Means and standard errors are estimated by linear regression)

Notice from Table 4.6 that when the average monthly income of both the groups of households are evaluated at the common base of 2004-05, it shows a declining trend. For the arsenic affected treatment group while the decline is from INR 4960.84 to INR 4182.88, for the arsenic unaffected control group the decline is from INR 8314.83 to INR 6600.13. The decline is much more of INR 1714.70 for the control group than INR 777.96 for the treatment group. Therefore, even though on average the treatment group households earn significantly lower monthly household income compared to the control group households in both 2005-06 and 2015-16, when the common trend is applied to construct the counterfactual of the treatment group households, it appears that the treatment group households on average earns INR 936.74 (equivalent to $18.73) more per month than the control group households. Hence, we can conclude that the slower increase in the family size of the arsenic-affected households compared to the arsenic-unaffected households alone is not sufficient to explain the lower loss in per capita monthly income of the arsenic affected households. Indeed, they on average have performed better than the control group households in terms of income.

4.5. Conclusions and Discussion

In this chapter we have applied Difference-in-Difference (DID) method to estimate income-loss of the arsenic-affected households vis-à-vis arsenic-unaffected households of the Kolsur village, North 24 Parganas district of West Bengal, over the years 2005-2006 and 2015-2016. The DID method controls for time-independent unobserved idiosyncratic characteristics of the both groups of households. It also eliminates the common time trend faced by the households. In this chapter, the 'common trend' assumption has been justified by application of the PSM method. The chapter finds that although the arsenic-affected households lose significantly in terms of per capita monthly income in both 2005-2006 and 2015-2016, over the years they adjust to their situation in such a way that their income loss significantly decreases over time. It calculates that over the study period, both the groups of households lose in terms of their real income, calculated with respect to the base year 2004-2005. But, the arsenic-affected households lose less. On average, they have their per month per capita income INR 227.29 (equivalent to $4.55) more compared to the per capita per month income of the arsenic-unaffected households. The chapter checks that the result is not explained by the rise in the family size of the households alone.

The study in this chapter adds significant insight about the comparison of income of the arsenic-affected households with the arsenic-unaffected households. The previous studies compared the two groups of households at a particular time point and found as expected that the arsenicosis leads to significant income loss. The result is preserved in our study as well. However, our study shows that it is possible that the income gap between the two groups of the households closes over time. Therefore, it is important to study the factors that lead to improvement in income of the arsenic affected households. The two obvious candidates for such kind of factors are the adoption of piped water by the arsenic-affected households with higher probability and the spread of social awareness related to arsenicosis that leads to lower social discrimination of arsenic-affected households. However, their impact needs to be statistically proved, which can be done through application of difference in difference-in-difference (DDD) method. This remains as our future research agenda.

Appendix1

WHOLESALE PRICE INDEX - ANNUAL AVERAGE						
Year	**AC**	**PA**	***of which***		**F&P**	**MP**
			FA	**NF**		
1	**2**	**3**	**4**	**5**	**6**	**7**
			(Base : 2004-05 = 100)			
2004-05	100.0	100.0	100.0	100.0	100.0	100.0
2005-06	104.5	104.3	105.4	96.7	113.6	102.4
2006-07	111.4	114.3	115.5	102.3	120.9	108.2
2007-08	116.6	123.9	123.6	114.4	121.0	113.4
2008-09	126.0	137.5	134.8	129.2	135.0	120.4
2009-10	130.8	154.9	155.4	136.2	132.1	123.1
2010-11	143.3	182.4	179.6	166.6	148.3	130.1
2011-12	156.1	200.3	192.7	182.7	169.0	139.5
2012-13	167.6	220.0	211.8	201.9	186.5	147.1
2013-14	177.6	241.6	238.9	213.2	205.4	151.5
2014-15	181.2	248.8	253.4	212.1	203.5	155.1
2015-16	176.7	249.6	262.1	219.5	179.8	153.4

Source: Office of the Economic Adviser, Ministry of Commerce and Industry, Government of India.

(Note: AC: All commodities, PA: Primary articles, FA: Food articles, NF: Non-food articles, F&P: Fuel and power, MP: Manufactured products, FA and NF are part of PA.)

CHAPTER 5

CONCLUSION

This thesis using the treatment group, control group, background covariates and suitable matching methods; investigates and evaluates the impact of the arsenic affected households on the monthly household per capita income during 2005-2006 and over the years 2005-2006 and 2015-2016. It also examines the nature of adoption of arsenic-safe piped water source among both the arsenic-affected and the arsenic-unaffected households during the years 2015-2016. The thesis mainly focuses on the three research questions: first, whether social discrimination exists against the arsenicosis affected households and whether in consequence the households suffer from significant economic loss both in terms of per capita income and per capita consumption; second, whether the households affected by arsenicosis are more likely to adopt an arsenic-safe piped water source than the unaffected households and how the spread, intensity and years of experience with arsenicosis in the households matter in the adoption decision; third, whether the arsenicosis affected households lose in terms of per capita income over time compared to the arsenic unaffected households and if so, what is the estimate of the loss. It finds that the social discrimination exists and the measures of per capita income and expenditure loss given in the conventional literature, which are based on the labour market outcome only, underestimates the loss. As it evaluates the impact of arsenic affected households on the households' monthly per capita income over the years 2005-2006 and 2015-2016, it finds that although the arsenic-affected households lose significantly in terms of per capita monthly income in both 2005-2006 and 2015-2016 compared to the arsenic-unaffected households, they lose less in 2015-2016 compared to 2005-2006. So, the arsenic-affected households adjust to their situation in such a way that their income loss significantly decreases over time compared to the unaffected group of households. It may happen due to the factors like adoption of piped water by the arsenic-affected households and the spread of social awareness related to arsenicosis that led to lower social discrimination during this period. It also finds that the households who suffer longer period from arsenicosis adopt the arsenic-safe piped water source with higher probability.

The present chapter concludes the thesis by summarizing the results. It also outlines the limitations of the study, discusses the policy recommendations and the agenda for future research.

5.1. Summary of Findings

Chapter 2 matches the arsenic-affected and the arsenic-unaffected households on the basis of their propensity scores and compares their per capita monthly income and expenditure. It constructs a theoretical model to argue that due to social discrimination expenditure of a household would be less than the expenditure that they would have enjoyed only with their labour income and empirically finds that it is indeed the case. So it proves that the social discrimination exists against arsenic-affected households. Controlling for the labour market incomes of the treatment and the control groups, it shows that the arsenic-affected households face significant loss due to discrimination. The results obtained in chapter 2 have important implications for cost-benefit calculation in adoption of policies for fighting the problem of arsenicosis. The underestimation of income-loss in previous studies such as Roy (2008), calculated on the basis only of the labour market outcome, restricts implementation of projects against arsenic contamination as they estimate lower willingness-to-pay for such projects. According to our study $13.76 is the measure of the household income loss per capita due to arsenicosis, which is more than $7 calculated by Roy (2008).

Chapter 3 explores the mitigation behaviour of the households in the arsenic affected regions by adoption of arsenic-safe piped-water source. It checks whether the arsenic-affected households are more likely to adopt piped water compared to the arsenic-unaffected households. It also checks whether the spread, the intensity and the experience of such health hazards at the households also matter in the adoption decision. According to the results obtained, the probability that an arsenic affected household adopts arsenic safe water sources is 35% higher than the probability that an arsenic unaffected household does so. The findings suggest that the years of experience matters the most in the adoption decision. The rise in probability of adoption due to higher spread of arsenicosis in a household either due to higher spread of illness or due to the higher intensity of such illness is very low calculated at 0.0051 and 0.0061 respectively. In contrast, the rise in average year of illness by 1 year, raises the probability of adoption by 0.01%. Therefore, the risk perception of not using arsenic-safe piped water source is higher among the households that have long experience of suffering from the related ailments, the social and economic loss. But the factors like affordability (per capita monthly household income), awareness (the literacy) and the percentage of female members in the households play little role in the adoption decision. According to our study, although only 51% are arsenic affected, 62% adopted piped water. The Muslim households in the sample were found to adopt more compared to the Hindu households probably because the Kolsur village, from where the sample had been collected, had majority of the Muslim households. The results of chapter 3 also show, even if the piped water was provided free of cost, the time cost associated with intermittent supply of water created a bias in adoption in favour of the high per capita income households, as these households could possibly employ someone to negotiate the cost. The earlier adoption studies such as Delaire et al. (2017) could not distinguish between adoption against microbial contamination and adoption against arsenic contamination. Chapter 3 contributes to the literature here. It also suggests the adoption of arsenic-safe piped water can be motivated by sharing the experience of the households suffering from arsenicosis over long time with the masses.

Chapter 4 estimates the income loss due to arsenicosis that arises purely from the time-dependent unobserved factors that differentiates the treatment (arsenic-affected) and control (arsenic-unaffected) group households over the years 2005-2006 and 2015-2016. The study controls for inflation by deflating income of both 2005-2006 and 2015-2016 at 2004-2005 base. We use the Kernel Propensity Score method to match the two groups of households in 2005-2006 and then, apply the difference-in-difference regression model on them that controls for time-independent unobserved idiosyncratic characteristics of the both groups of households. The method also eliminates the common time trend in the outcome variable for the two groups. The results suggest that although the arsenic-affected households lose significantly in terms of per capita monthly real income in both 2005-2006 and 2015-2016, over the years they adjust to their situation in such a way that their income loss significantly decreases over time. On average, they lose their per month per capita income \$4.55 less compared to the per capita per month income of the arsenic-unaffected households. It ensures the robustness of the result by checking that it is not arising because of the change in household-size of the groups over the years. It is possible that the adoption of piped water by the arsenic-affected households with higher probability and the spread of social awareness related to arsenicosis in between the study period lead to the result.

5.2. Limitations

The major limitation about the current study arises in terms of availability of data. The data used in all the chapters are collected from the arsenic-affected Kolsur village located at block Deganga in the district North 24-Parganas, West Bengal, India. Therefore, the questions of external validity of the results remain. A broader study involving more villages would check robustness of the results. In Chapter 2, the evidence about the 'social discrimination' is indirect, as the questionnaire used for data collection did not have direct question on experience of 'social discrimination'. The theory used in the chapter justifies its existence. In chapter 3, the result obtained that the Muslim households adopt arsenic-affected households in higher probability, needs further investigation. In Chapter 4, the thesis applied PSM-DID method but fails to control the time varying factors affecting the households like availability of piped-water sources or increasing coverage of arsenic-awareness programs. An application of difference-in-difference-in-difference could derive the impact of these policy changes on the arsenic-affected households. These remain as future research agenda.

5.3. Policy Recommendations

The thesis brings up several important policy recommendations. On policy front, the analysis in chapter 2 highlights on two aspects. First, since the study shows that social discrimination against arsenic-affected households exists and they face significant loss in income and expenditure due to such discrimination, there should be policies to build awareness against social discrimination faced by such households; Second, the cost-benefit analysis conducted for projects aimed to solve arsenic problem should take into account the estimate of loss from social discrimination, which seems to be significantly high as we show in this chapter, so that more of such kind of projects become viable. The results in chapter 3 suggest that greater adoption of piped water sources in arsenic affected villages can be facilitated if the awareness is spread through the households, who suffered from arsenicosis for a long time. The piped water sources must be located more evenly in the clustered villages for greater adoption. A more continuous supply of piped water may remove the high-income bias from adoption of piped water in arsenic affected villages, where it is provided free of cost. Chapter 4 shows that it is possible that the income gap between the two groups of the households closes over time. Therefore, it is important to study the factors that lead to improvement in income of the arsenic affected households. The role of the factors like the adoption of piped water by the arsenic-affected households with higher probability and the spread of social awareness related to arsenicosis that lead to lower social discrimination of arsenic-affected households, should be investigated and utilized for policy-making.

5.4. Future Research Agenda

This work can be updated in a more recent and a more complete data base. The impact of various policy interventions on the arsenic affected households can also be studied. A more extensive study may externally validate the results of the thesis. In Chapter 4, the thesis applied PSM-DID method but fails to control the effect of policies affecting the households like availability of piped-water sources and more intensive / extensive coverage of arsenic-awareness programs adopted during the period of study. An application of difference-in-difference-in-difference (DDD) could derive the impact of these policy changes on the arsenic-affected households. These remain as future research agenda.

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