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Determinants of Health Cost Associated with Arsenic Contaminated Groundwater: A Case Study of Sindh, Pakistan

Abdul Sattar*

Department of Agricultural Economics, Sindh Agriculture University, Tandojam, Sindh, Pakistan

*Correspondence for materials should be addressed to AS (email: Sattar.lagharioo@gmail.com)

Abstract

The study examines the health costs associated with drinking arsenic-polluted groundwater based on primary survey from the Sindh province of Pakistan. The paper applies the ordinary least square technique to a primary data of one fifty (n=150) households. To check the arsenic concentration of groundwater, samples were carefully examined from the laboratory and the report revealed that 90% of groundwater samples were above the safe limit 10ug/l. Furthermore, most people were unaware about its harmful impact on health due to arsenic poisoning. Steady and long-term use of arsenic-contaminated groundwater has led to various health problems among residents, including Skin diseases, liver, kidney and lung failure, gastrointestinal problems and chest illnesses (Asthma and Tuberculosis). Many households do not take treatment due to financial limitations, further worsening health among community members. In addition to this, high arsenic concentration in drinking water has resulted in numerous deaths and most of these individuals were only earning people of their families. The study found that visits to doctors, quality of water and the interaction between sources of water and arsenic concentration significantly impact on total health cost, this ultimately exposed that drinking groundwater polluted with arsenic from long years raises the indirect and direct health cost of the residents in the study area.

Keywords: Arsenic; Health cost; Social awareness; Groundwater intake; Policy recommendation

Introduction

Life is dependent on water and when this essential resource is contaminated then it can cause numerous risks. The water contains specific minerals, some of which are essential to human health. There are certain concentrations of each of these minerals in the water. This concentration can cause health problems if it increases above the permissible levels. Over 2 billion people use groundwater sources for drinking and washing for daily basis, and from 200 million people, 20 million of them are youths, live in areas of the world where the drinking water contains more arsenic compared to the WHO recommendations (Rehman et al., 2018).

One of the minerals that naturally exists in the crust of the earth as inorganic compounds is arsenic (Arain et al., 2007; WHO 2022). Moreover, human activities such as the use of pesticides in farming, industrial pollution, burning fossil fuels, mine waste, smelting and sewage are major sources of their increasing quantity (Thakur et al., 2013). Groundwater contaminated with arsenic is a serious environmental public health concern in the world (Nishita, 2025). If there is arsenic in the water, we cannot see or smell it (Roy et al., 2008). Arsenic basically exists in two different forms: inorganic and organic. Groundwater contains the majority of inorganic arsenic. Arsenic (As) poses a significant health risks to public, particularly in its inorganic form (Walls et al., 2025) which is ten times more harmful than organic arsenic. It enters into an individual's body through food consumption or drinking arsenic-contaminated water. But the impact through water consumption is more than other contamination (Pointus et al., 2019).



In Pakistan, only about 20 percent of the population has access to safe drinking water, while the majority is forced to use polluted water. This has led to widespread health issues, including Hepatitis, skin diseases, Typhoid, and Diarrhea, due to the consumption of contaminated water. Many research studies found that water-borne illnesses contribute around 80 percent in overall sicknesses (Daud et al., 2017) and about 50–60 million individuals are prone to arsenic exposure from drinking water that exceeds the country's safe limits (Guglielmi et al., 2017), which is 50ppb (parts per billion) according to Pakistan National Drinking Water Quality Standard (PNDWQS, 2021). On the other hand, the arsenic level is greater than 300 ppb in Pakistan (Majidano et al., 2011). Compared to other provinces, Punjab and Sindh have more severe levels of arsenic contamination in their water systems. Approximately 38% of the population in Sindh province is exposed to arsenic pollution over 10 ppb and 16% of the population is exposed to contamination exceeding 50 ppb (Arain et al., 2007 and Sanjrani et al., 2017).

The World Health Organization (WHO) has established a threshold level of arsenic in drinking water at 10 ppb or $\mu\text{g/l}$ (WHO, 2022; Jain et al., 2024; Abbasnejad, 2024). However, in developing countries such as Pakistan, the permissible limit is set at 50 ppb or $\mu\text{g/l}$ (Karim et al., 2000). Arsenic acts as a slow poison, with symptoms of related illnesses typically taking between 4 to 20 years to manifest (Khan et al., 2007; Alam et al., 2010). Numerous studies have shown that consuming water contaminated with arsenic can lead to various cancers, including those of the lung, kidney, bladder, skin, and liver (Arain, 2007; Lara et al., 2020). Additionally, arsenic exposure can cause reproductive system issues and negatively impact unborn babies (Karim et al., 2000; Neeti et al., 2013; Henson et al., 2016). Arsenic-related diseases are generally classified into three stages. In the early stage, symptoms such as melanosis (darkening of parts or the entire body), keratosis (thickening and roughness of the palms and soles), conjunctivitis (redness of the conjunctiva), respiratory tract inflammation, and gastroenteritis (nausea and vomiting) may develop due to arsenic poisoning. If a patient continues to consume arsenic-contaminated water without seeking medical attention, the symptoms worsen and become more pronounced in the secondary stage. These symptoms include peripheral neuropathy, liver and kidney disorders, hyperkeratosis (nodular growth on the palms and soles), swelling of the feet and legs, and leukokeratosis or "rain drop syndrome" (white spots within blackened areas). In the third (final stage), the patient's health declines rapidly and the symptoms become irreversible. This stage is characterized by gangrene in the distal organs and other body parts, as well as the development of skin, liver, and lung cancers and kidney failure (Khan et al., 2007).

When arsenic-contaminated water is consumed frequently over a long period of time with medical avoidance, these symptoms become irreversible in poor countries such as Pakistan, medical expenses associated with arsenic related sicknesses put further pressure on already burdened individuals (Thakur et al., 2013). Further research has revealed that the symptoms of arsenic-related diseases differ due to several factors, including a person's general health, diet, (Karim et al., 2000; Alam et al., 2010) regular consumption of arsenic polluted drinking water and food, arsenic concentration, age, and strength of the immune system (Alam et al., 2010). Arsenic levels exceeding 50 ppb have been found to significantly raise the risk of cancer, which may develop within 10 years of exposure (Arain et al., 2007).

Access to safe water is crucial for both public health and socio-economic development. Arsenic contamination not only poses health risks but also significantly impacts socio-economic factors. Social stigma and ignorance surrounding arsenic-related illnesses can lead to depression and even suicide. In affected villages, marriages and relationships become challenging, as parents face difficulties finding suitable partners for their daughters suffering from arsenic-induced skin conditions such as melanosis and keratosis. Arsenicosis affects husband and wife relationships, job opportunities, and social exclusion, causing isolation and sometimes suicide (Thakur et al., 2013). On the other hand, (Roy et al 2008; Samal et al., 2013) found that poor household population is facing arsenic related skin problems (melanosis and keratosis) more commonly compared to wealthy people. He also concludes that poor individuals experience a greater number of sick days compared to wealthier individuals, because wealthy people have better access to protecting measures. Research findings further reveal that females are more vulnerable to arsenic-related illnesses than males and infants and children are more severely affected than adults. The risk of developing conditions such as melanosis and keratosis increases with prolonged exposure to arsenic, and this risk varies across socioeconomic classes. wealthier individuals are more likely to adopt preventive measures to reduce their exposure. Additionally, females are more prone to respiratory tract inflammation caused by arsenic compared to males (Khan et al., 2008).

One of the biggest problems in Pakistan is groundwater pollution, which has a major effect on human resource productivity and raises healthcare costs. This study is important because it tries to determine the cost that people are bearing in the study area who drink groundwater poisoned with arsenic. People can move from one source to another, but it all depends on how aware they are about the risks associated with consuming groundwater contaminated with arsenic and the danger of low-quality groundwater. Thus, the level of awareness on the risks associated with groundwater quality has been investigated. Recently in the last three months, water-borne illnesses took the lives of 32 people, mainly due to liver failure, kidney disease, and hepatitis (Dawn, 7 feb 2020). In one of the villages of district Tando Allahyar, out of 282 persons, 69 have been diagnosed with Hepatitis B and C (Health Report, 2020). This situation encourages me to calculate the healthcare costs that suffered by respondents due to consuming groundwater contaminated with arsenic in the district. Thus, the primary goal of the research is to calculate the health care costs associated with drinking arsenic-contaminated groundwater in the study region (District Tando Allahyar). Thus, objectives of the study were (i) To estimate the health costs associated with consuming arsenic-contaminated groundwater (ii) To evaluate the awareness level regarding the presence of arsenic and its harmful health effects in the study area; and (iii) To propose policy recommendations based on research findings.

Study area

Tando Allahyar, is one of districts of Sindh province with a population of 922, 012, is the study area (GoP, 2023). The district, which consists of three tehsils, is dealing with an arsenic poisoning problem with the groundwater. While groundwater is the primary supply of drinking water, however it is heavily contaminated with TDS, PH, and both inorganic and organic arsenic. The objectives of this research are to estimate the associated with consuming arsenic-contaminated water and to investigate the awareness level regarding arsenic existence and harmful effects on health in the study area.

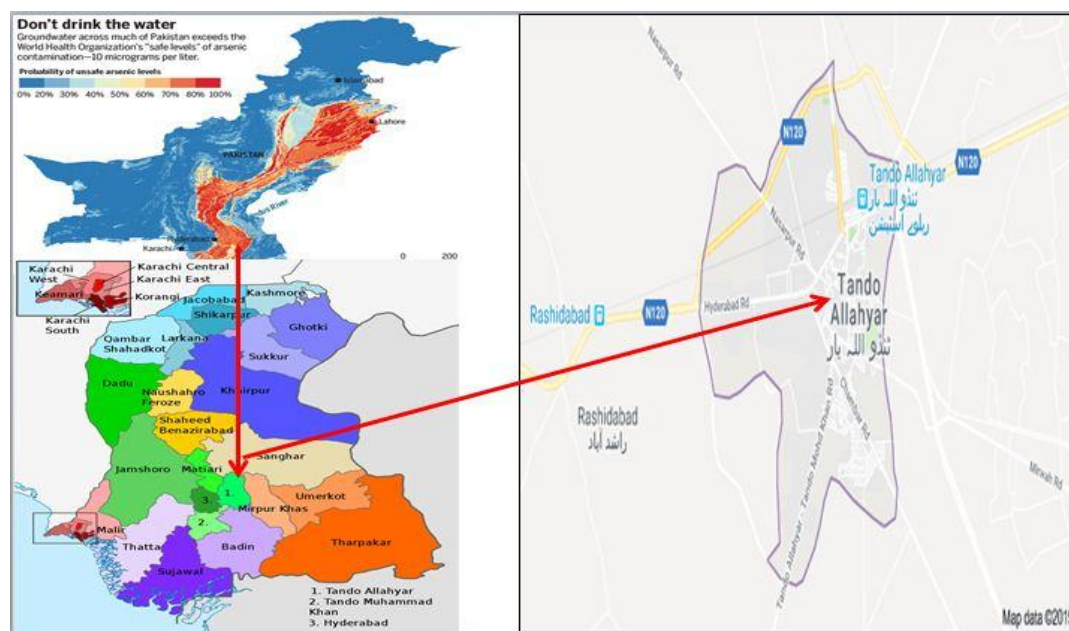


Fig.1. Map of the study area (Tando Allahyar)

Data and Methodology

Data Collection Procedure

Primary data was gathered using a structured questionnaire conducted through household interviews in a selected village within the study area. The questionnaire covered health-related information and the effects of consuming arsenic-contaminated groundwater. Additionally, respondents were asked about their perceptions of their drinking water quality, and do they have access to any reliable water sources? Numerous water samples were collected and carefully analyzed in a laboratory to evaluate the drinking quality of groundwater in the study area.

Sampling Technique

Purposive sampling was used as a technique for data collection in order to collect information from respondents in the study area. Based on the level of arsenic contamination, a sample size of 150 was selected and the samples were being thoroughly analyzed in the laboratory.

Analysis of arsenic levels in groundwater sources of the study area

Groundwater samples were collected from multiple locations throughout the village and precisely analyzed at the water and soil testing laboratory of the Drainage and Reclamation Institute of Pakistan (DRIP) in Tando Jam, a branch of the Pakistan Council of Research in Water Resources (PCRWR). The analysis revealed that approximately 90% of the groundwater samples were contaminated with varying levels of arsenic, which have arsenic concentrations of 250 µg/l and 100 µg/l, or ppb in 15% and 59% groundwater samples, respectively. Approximately 15% of the groundwater samples had arsenic concentrations of 50 µg/l, which aligns with the country's safe limit for arsenic. Meanwhile, 2% of the samples showed arsenic levels of 25 µg/l or ppb and only 9% had arsenic concentrations ranging from 0 to 5 ppb or µg/l, which is within the limitation (10 ppb or µg/l) of WHO in the groundwater samples which were collected from the groundwater sources in study area. Additionally, water samples from filtration plant and external hand pumps were also checked which were free from arsenic poisoning, from where villager's fetch the water for drinking and cooking purposes.

Econometric model

There are numerous factors that can either directly or indirectly impact the health cost. In Pakistan public spending on health care accounts for approximately 33% of total spending with the majority of spending coming from private sources (Muhammad et Al., 2015). The model includes the variables that account for the largest portion of health costs. The ordinary least square approach is used in which the dependent variable is health cost in rupees.

Equation

$$HC = \beta_0 + \beta_1age + \beta_2edu + \beta_3inc + \beta_4hhs + \beta_5wsd + \beta_6time + \beta_7novist + \beta_8wq + \beta_9f_{symptom} + \beta_{10}liverd1 + \beta_{11}gastrod2 + \beta_{12}AS_{conc} \epsilon \quad (1)$$

Variable Descriptions and Expected Signs

It illustrates the expected results for the variables used in the health cost analysis of polluted groundwater. (Chowdhury et al., 2015) employed the same variables. In order to thoroughly investigate the differences or similarities in the connection between health cost and its other associated factors, these indicators will serve as the foundation for the study's findings.

The dependent variable is health cost (HC), measures the total healthcare expenses (in rupees) incurred by households due to illnesses such as skin diseases, liver failure, and gastrointestinal problems (Chawdhury et al., 2015).

Socioeconomic and Demographic Variables

Age (in years) is expected to have a positive association with health costs, as older individuals may face higher medical expenses. Education (Edu), measured in schooling years, is anticipated to reduce health costs (–) due to better health awareness and preventive care. Total Income (monthly household income in rupees) is expected to negatively correlate with health costs (–), as higher income may enable access to better sanitation or preventive measures. Household Size (HHS) (number of family members) could have an ambiguous effect (+/–), as larger families might share costs but also face compounded health risks.

Water-Related Variables

Water Source Dummy (Wsd) (groundwater from home = 1; otherwise = 0) is expected to increase health cost (+) due to potential contamination. Water Quality (1 = good, 2 = average, 3 = poor) is hypothesized to worsening health outcomes (+), with poorer quality of drinking water linked to higher expenses. Arsenic Concentration (AS_conc) (measured in ppb or µg/l) and duration of groundwater use (years) are both expected to positively affect health cost (+), as prolonged exposure to contaminants like arsenic exacerbate health risks.

Health Behavior and Outcomes

Time lost per visit (Time) (hours spent on clinic per visit) and number of visits (Novist) (monthly doctor visits) are both expected to increase health cost (+). Frequency of symptoms (skin diseases, liver failure, gastrointestinal problems) and specific disease dummies (Skin Disease, Liver Failure, Gastrointestinal Problems) are all anticipated to have positive associations (+) with health expenditures.

Results and Discussion

This section presents the results, including descriptive statistics and empirical analysis based on an econometric model. There are direct and indirect costs associated with health cost. Travel charges, physician fees, lab test prices, and medication costs for three different illnesses (liver failure, gastrointestinal problems Skin disease) are all considered direct costs. On the other hand, indirect costs consist of the financial loss of workdays because of these illnesses. For this estimation a simple Ordinary Least Squares (OLS) method was employed since all variables are numerical. The detailed results for each variable are discussed below

Descriptive Statistics

Descriptive statistics of the sample are reported in Table 1. The average value of each socio-economic variable is described in the table. The study surveyed 150 households with 784 family members (385 males 389 females) with an average household size of 5 persons with below the matric education status. The average income of the respondents were 19067 rupees and the average health cost was 558 rupees per month. Working days lost are the number of days a person misses from work because they are ill or experiencing severe symptoms of a disease, which prevents them from working. There were 0.26 working days lost per month and the monthly averting cost was about 70 rupees. It took an average of around 30 minutes to travel 1.2 kilometers to reach safe water. The number of visits to the doctor for arsenic related diseases varied between 0 to 20 visits, while many respondents do not visit to the doctor because of financial problems.

Table 1. Socio-economic characteristics of the respondents

Variables	Units	Mean
Age	Years	36.64
Education	Years	7.146
Total Income	Rupees	19067.77
Household Size	Numbers	5.22
Health Cost per month	Rupees	558.26
Averting Cost	Rupees	68.50
Working days lost	Numbers	0.26
Safe source Distance	Kilometer	1.26
Time to bring safe water	Minutes	26.00
Number of Visit	Numbers	0.53

Table 2. Awareness about arsenic and groundwater quality

Questions	Response	Percentage	Description
Groundwater quality	Good	0	The questions about respondents' awareness about the existence of arsenic, the quality of their groundwater supply, and the problems related to arsenic were addressed. A large portion of respondents justified the poor quality of the groundwater which is not suitable for human consumption, mainly for drinking and cooking purposes.
	Average	2	
	Poor	98	
Groundwater quality Test	Yes	28.67	Approximately one-third of the respondents had not tested the quality of their groundwater, while about twenty eight percent groundwater sample were tested by the previous survey team in 2010.
	No	71.33	
Ever heard about arsenic poisoning	Yes	11.33	The study found that only 11% of respondents were aware of arsenic-related health complications and 88.67% of respondents were unaware of the health risks associated with arsenic pollution in their water
	No	88.67	

			supply. This lack of awareness is particularly significant given that: • Arsenic exposure is linked to several health conditions examined in this study (e.g., skin diseases, liver failure, gastrointestinal problems). • All respondents relied on groundwater, a potential source of arsenic contamination.
Contaminated with arsenic	Yes	2.67	According to information provided by a survey team, only 2.67% of respondents were aware that arsenic poisoning affected their groundwater and about 90% of respondents were still ignorant that their groundwater is poisoned with arsenic.

Table 3. Respondents foresee symptoms of diseases in the village

Diseases	Occurrence	Percentage	Affected
Skin disease	Yes	96.67	Ninety-six percent a large number of respondents stated that they have various Skin issues among people living in the study area and 54% respondents were facing various Skin complications
	No	3.33	
Liver failure	Yes	93.33	93% respondents reported having liver dysfunction among the residents, while 16% respondents were also exposed to liver failure (Hepatitis).
	No	6.67	
Gastrointestinal Problems	Yes	68	68% of respondents stated that people are experiencing gastrointestinal problems, from which 30% respondents were also facing gastrointestinal problems
	No	32	
Other arsenic-related diseases	Additionally, it is stated that five individuals who were supporting their families financially died tragically as a result of these deadly diseases. In addition to these illnesses caused by arsenic, individuals of the study area also experienced kidney failure, lung failure (tuberculosis), and chest issues (asthma).		

Econometric estimation of health costs

The study reveals that age, income, time spent per visit to the doctor, disease frequency, visits to the doctor (numbers), groundwater quality, liver failure and gastrointestinal problems, and the concentration of arsenic in the groundwater are positively correlated with health care costs. Health cost is strongly correlated with age because older people experience greater symptoms due to lower immunity, limited mobility and poor nutrition. Education increases awareness and motivates people to spend more on health, resulting in monthly or six-month cost reductions of Rs.8.87 or Rs.53.2 respectively. Income positively impacts on total health cost, improving access to health facilities, but the coefficient is insignificant due to the majority of respondents earn low-income. Because respondents were mainly working on day-to-day wages. Household size can impact health costs in two ways: if older family members are large, it may lead to a positive effect on health costs, while if children are large, it may negatively affect health costs as they can fetch safe drinking water. Empirical results show a significant negative effect on health costs, with an increase in household size leading to a decrease of 53.09 rupees per month. Health expenditures are highly impacted by groundwater quality; a drop in quality of water from good to average or from average to poor results in a monthly increase in health costs of Rs. 705.17, or Rs. 4231, every six months. There is a strong positive correlation between the number of visits to the doctor and health costs. Increase in 1 more visit to the doctor rise 507.40 rupees health cost per month. In the support of this time spent per doctor visit and frequency of diseases has positive relation and increases health costs as well.

Disease variables (Liver failure and gastrointestinal problems) were taken as dummy while the variable of skin disease was taken as base variable, result show that Gastrointestinal problems and Liver failure have significantly higher health cost values than skin disease. Liver failure costs 1884.64

rupees per month more than skin disease and gastrointestinal problems cost 1216.88 rupees more than base variable (skin disease) per month. This suggests that arsenic poisoning has a larger effect on health costs due to these sicknesses. The interaction between the concentration of arsenic and the water source dummy is positively significant; families that use their own groundwater incur higher health expenditures than those that were using safe water from other sources. We considered the interaction of the water source (dummy) and the duration of time they are consuming this source of water: Hence the coefficient is insignificant. This might be because the respondents have been living there for more than 30 years, although the existence of arsenic affects the body in the primary years. As a result, the respondent's duration does not vary, rendering the coefficient insignificant.

Table 4. Results of the Ordinary Least Squares model for Health Cost Estimation

R-squared = 0.9027		Number of Observations = 150		Prob > F = 0.00
Total health cost	Units	Coefficient	R. Std. Err.	P value
Age	Years	0.705	3.33	0.833
Education	Schooling years	-8.87	9.52	0.353
Income	Rupees	0.002	0.003	0.389
Size of Household	Number of people	-53.09**	20.44	0.010
Time lost during visit to the doctor	Number of hours	189.84	197.18	0.337
Frequency of Symptoms	Numbers	237.46	373.35	0.526
Number of visits to the doctor	Numbers	507.40***	40.63	0.000
Groundwater Quality	(Dummy 1,2,3)	705.17***	250.08	0.006
Disease Liver failure	(Binary 1,2)	1884.64**	718.29	0.010
Diseases Gastro-problems	(Binary 1,2)	1216.88***	462.02	0.009
Water source *arsenic-conc	Dummy*numbers	5.65***	2.076	0.007
Water source * Since how long	Dummy*number of years	0.55	7.504	0.941
Constant	-----	-1927.901	735.07	0.010

Conclusion and recommendation

Arsenic concentration was found alarmingly high in the study area exceeding the recommended national and world criteria. People continue to using arsenic-polluted water due to lack of awareness and facing difficulty in managing water supply from safe sources. Concerned authorities (PHED, local government) must provide safe drinking water through filtration plants and raise awareness through local communities, seminars, and government efforts. The survey data shows that people are continuously drinking water contaminated with arsenic leading to skin, chest, and abdominal diseases. Socio-economic factors with avoidance of treatment due to poor income intensify symptoms. So, the Government (District health authorities) may provide relief to people of the study area by sending medical experts to treat the affected people free of cost.

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Author Contributions

AS conceived the concept, wrote and approved the manuscript.

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Ethics approval

Not applicable.



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