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IMPLICATIONS OF GROUND WATER CONTAMINATION: A COMPREHENSIVE STUDY ON PUBLIC HEALTH IN PUNJAB, PAKISTAN

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ABSTRACT
Groundwater contamination has become a significant environmental and public health issue in the developing world, particularly in Pakistan, where rapid industrial development, intensification of agricultural production, and inefficient waste management systems exacerbate aquifer degradation. This study examines the implications of groundwater contamination for public health in Faisalabad District, Punjab, using a quantitative study approach. Primary data were obtained from 600 households using a combination of probability (simple random) and non-probability (convenience) sampling, and laboratory test results for water samples were used to validate contamination levels. The analysis was conducted using SPSS and JASP, employing descriptive statistics, Kendall's tau-b correlation, chi-square tests, Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM) to examine the causal relationship between the contamination signifier and health outcomes. Results indicate that mean scores for the contamination variables are significantly higher, indicating widespread deterioration in groundwater quality. Normality tests revealed that the data were not normally distributed ($p < 0.05$). Bivariate results showed significant positive associations between contamination variables and public health outcomes ($p < 0.01$). The SEM results indicated a strong positive association between groundwater contamination and public health ($\beta = 0.993$, $p < 0.001$), indicating that higher exposure is significantly associated with a higher prevalence of diseases. The Chi-square model comparison provided further evidence of strong model fit, corroborating the theoretical assumption that environmental exposure is a key determinant of community health status. The current study concludes that groundwater contamination is making a substantial contribution to chronic diseases like diarrhea, typhoid, fluorosis, and gastrointestinal infections. It makes several recommendations for improved water management, public awareness, industrial control and monitoring of agricultural chemicals, and increased access to healthcare. The findings provide evidence-based inputs to support policy interventions for sustainable water management and the mitigation of health-related risks in Pakistan.

Keywords. *Groundwater Contamination, Public Health, Structural Equation Modelling (SEM), Waterborne Diseases.*

INTRODUCTION

Groundwater is the most important and most widely used freshwater resource in Pakistan, providing drinking water to more than 60% of the population and serving as a major lifeline for domestic and agricultural water use, particularly in Punjab (Qureshi et al., 2010; Hafiza et al.,2022). Rapid urbanization, industrial growth, and increasing population density have markedly degraded groundwater quality, exacerbated by unregulated chemical agriculture, which discharges

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toxic pollutants such as arsenic, fluoride, nitrates, pesticides, and microbial contaminants (Shahid et al., 2018; Durani & Farooqi, 2021). Therefore, millions of people in Pakistan are required to use potentially hazardous groundwater sources, often without proper treatment or awareness of associated health risks. The World Health Organization warns that contaminated water is one of the major causes of waterborne illnesses globally, causing chronic diseases, growth impairment, gastrointestinal infections, and over 485,000 deaths each year (WHO, 2023). Globally, 844 million people lack access to basic drinking water, particularly in rural areas and middle-income nations. Nevertheless, there has been significant progress in recent years, as the Millennium Development Goals and the Sustainable Development Goals have been pursued. Water plays a vital role in all environmental, human, and social processes. A main ingredient in life as well as development. Its essential use in both food and sanitation makes it indispensable: agriculture and most other industrial and commercial activities rely on it as a raw material, and it also serves as an energy source. Without a healthy population, socioeconomic development is not possible. The relationship between health and development is close; one cannot imagine doing without the other (Liu et al., 2024). According to the latest research results from the Pakistan Council of Research in Water Resources (Prasad et al., 2020), 80 percent of groundwater samples in Punjab exceed the World Health Organization guideline values. The most affected are Lahore, Faisalabad, Multan, and Kasur, which have the highest levels of industrial activity and agricultural intensification (Hasan et al., 2025). In Punjab, Pakistan, groundwater pollution has become a major environmental and public health issue. Anthropogenic and gelogenic pollutants increasingly threaten groundwater in the region, as most of the rural and urban population relies on it as their primary drinking water source. Industrial effluents, overuse of fertilizers and pesticides, and untreated sewage seepage have led to elevated levels of heavy metals, including arsenic, lead, cadmium, and fluoride, in most parts of Punjab (Waqas et al., 2017).

REVIEW OF LITERATURE

This study examines the implications of groundwater contamination for public health in Punjab, probing not only the chemical dimensions of pollution but also the socioeconomic and infrastructural barriers that exacerbate its adverse consequences. In Punjab's industrial corridors — such as Faisalabad, Lahore, and Kasur — groundwater samples contain lead and chromium concentrations up to 50 times the World Health Organization (WHO) guideline values, a direct consequence of tannery and textile discharges (Ali et al., 2020; Hussain et al., 2022). Meanwhile, in agrarian districts such as Bahawalnagar and Vehari, excessive fertilizer use has elevated nitrate concentrations, leading to methemoglobinemia ("blue baby syndrome") in infants (Ahmed et al., 2025).

Table 1 Major Contaminants in Groundwater

Contaminant	Source	Health Effects	Sources(Reference)
Arsenic (As)	Natural (geogenic), mining, pesticides	Skin cancer, cardiovascular, and neurological effects	Brammer and Ravenscroft. (2009)
Fluoride (F^-)	Rocks, industry	Dental & skeletal fluorosis	WHO (2024), Kamilya et al.,(2022)
Nitrate (NO_3^-)	Fertilizers, septic tanks, animal waste	Blue baby syndrome, thyroid issues	WHO (2023), Ward, (2025)

Heavy metals (Pb, Cr, Cd)	Mining, industry, waste disposal	Cancer, liver/kidney failure	Cusack et al., (2020)
Microbial Pathogens	Fecal matter, Sewerage	Diarrhea, cholera, typhoid, hepatitis	WHO/UNICEF (2024)
Salinity	Over-pumping, seawater intrusion	GI and kidney issues, hypertension	WHO (2025)

Table 2: **Health Impacts of Groundwater Contamination in Pakistan**

Health Indicator	Pakistan Data	Sources
population using groundwater	~70%	UNICEF (2024)
Deaths due to unsafe water	~40% of all deaths are linked to unsafe water, sanitation, and hygiene	WHO/UNICEF (2024)
Children are dying annually (under age 5)	~50,000 die due to waterborne illnesses (diarrhea, typhoid, hepatitis A/E)	WHO, (2025)
Rural water sources are contaminated	>80%	WHO (2023)
Cities with arsenic above the WHO limit	Lahore, Multan, Bahawalpur, Muzaffargarh, Dera Ghazi Khan, Larkana, Faisalabad, etc.	Rashid et al., (2022)
Estimated population at risk due to arsenic	~50 million people (arsenic >10 μg/L)	Hifza et al., (2022)
children with fluorosis symptoms in Punjab	11–35% in high fluoride areas (e.g., Khushab, Chakwal, Mianwali, Faisalabad)	Waqas et al., (2017)

Industrial Effluent and Public Health Risks

The water tabs in Pakistan have been polluted due to industrial growth without the treatment of effluent. Shahid et al. (2023) reported that chromium, cadmium, and lead in textile areas of Punjab exceeded allowable limits and attributed these heavy metals to adverse effects on kidney function and skin allergies. Rashid et al. (2022) also noted that toxic accumulation of industrial waste that has not been treated results in long-term effects and enhances gastrointestinal diseases. This thesis is supported by these findings, in which industrial discharge was strongly associated with the indicators of the public health.

Chemicals and Nitrates in Groundwater Agriculture

A threat to groundwater is through fertilizer leaching that leads to nitrate contamination of ground water. Rahman et al. (2021) found that in Pakistan, children taking well water experienced methemoglobinemia induced by nitrate. The research is consistent with that provided in earlier studies in which agricultural chemicals (AC4) were associated with a significant score on chronic illness, as one can point out the overuse of pesticides as a factor leading to community susceptibility.

Natural Pollution: Arsenic and Fluoride.

The toxicity of Arsenic and fluoride has serious health effects, such as cancer, skin lesions, and dental and skeletal fluorosis. In 67 percent of sampled wells in Punjab, Farooqi et al. (2021) found arsenic concentrations exceeding the WHO guideline value. The victims of the contaminated regions exhibited neurodeformity and bone deformity. This is associated with AD1 scores in our analysis, indicating that the disease is prevalent among high-fluoride UCs.

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Sewerage Contamination & Microbial Population

Inadequate sanitation infrastructure contributes to coliform contamination, E. coli, and sewage leakage. Mahmood and Maqbool (2022) attributed the prevalence of typhoid and diarrhea in peri-urban Punjab to sewage water pollution. The present study has supported these trends, with sewerage contamination showing a strong association with statistical outcomes and health deterioration.

Access to Healthcare

Limited access to healthcare increases disease persistence. According to WHO/UNICEF (2021), delayed medical treatment increases morbidity from waterborne diseases. In this analysis, AC7 showed a strong correlation with AD1, despite moderate variation, indicating delayed treatment and financial constraints.

METHODS

A cross-sectional design was selected. Faisalabad had six tehsils selected; Union Councils and households were selected using convenience sampling. The sample size included 600 participants. Groundwater was physically sampled and analyzed at a Government laboratory. A structured, checked questionnaire was used to collect the data. SPSS and JASP were used to perform statistical analysis. The Kolmogorov–Smirnov and Shapiro-Wilk tests were used to test the normality. Kendall's Tau-b was used to assess the strength of association between contamination variables and public health outcomes. The chi-square test was used to assess the association between the independent variables and the disease prevalence. The effect of contamination on the outcomes of chronic illnesses was tested directly using Structural Equation Modeling.

RESULTS AND DISCUSSION

Table 3 Normality Test

Variables	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
AC1	.122	600	.000	.952	600	.000
AC2	.097	600	.000	.955	600	.000
AC3	.146	600	.000	.931	600	.000
AC4	.188	600	.000	.889	600	.000
AC5	.139	600	.000	.922	600	.000
AC6	.127	600	.000	.919	600	.000
AC7	.121	600	.000	.950	600	.000
AD1	.115	600	.000	.931	600	.000

AC1 (Contamination of Ground Water) AC2 (Availability and Accessibility of Clean Water) AC3 (Industrial Discharge) AC4 (Agriculture Chemical Uses) AC5 (Natural Contaminants - Arsenic & Fluoride) AC6 (Sewerage Contamination) AC7 (Access to Healthcare) AD1 (Public Health)

Normality Test (Summary)

According to the non-parametric statistics, all the variables (AC1-AC7 and AD1) showed p <.05 in K-S and S-W tests, and this proved the non-normal distribution.

Table 4 Kendall tau_b between Independent variables and the dependent variable

Variable	AC1	AC2	AC3	AC4	AC5	AC6	AC7	AD1
AC1	1.000	.238**	.324**	.252**	.149**	.226**	.200**	.242**
AC2		1.000	.228**	.222**	.197**	.132**	.170**	.201**
AC3			1.000	.267**	.203**	.282**	.166**	.308**

AC4	1.000	.149**	.186**	.191**	.224**
AC5		1.000	.248**	.106**	.269**
AC6			1.000	.102**	.358**
AC7				1.000	.146**
AD1					1.000

Kendall tau-b Correlation Summary

All contamination variables were significantly positively associated with health deterioration in the population ($p < .01$). The strongest correlations were observed for AC6 → AD1 and AC3 → AD1, indicating that sewerage intrusion and industrial discharge are major contributors.

Table 5 Chi-Square Test (Independent Variable VS Dependent Variable (Public Health))

Sr. No.	Independent Variable	Pearson Chi-Square Value	df	Asymp. Sig. (2-sided)
i	Contamination of Groundwater	2861.605[a]	1705	0.000
ii	Availability and Accessibility of Clean Water	2445.872[a]	1650	0.000
iii	Industrial Discharge	1612.575[a]	1045	0.000
iv	Agricultural Chemical Use	2064.177[a]	1045	0.000
v	Natural Contaminants - Arsenic & Fluoride	1721.960[a]	990	0.000
vi	Sewerage Contamination	1911.405[a]	1210	0.000
vii	Access to Healthcare	2744.378[a]	1870	0.000

Chi-Square Results Summary

All predictors were significant ($p < .000$), indicating strong associations between indicators of contamination and public health outcomes.

Table 6 Regression Weight Model Equation (Path Analysis):

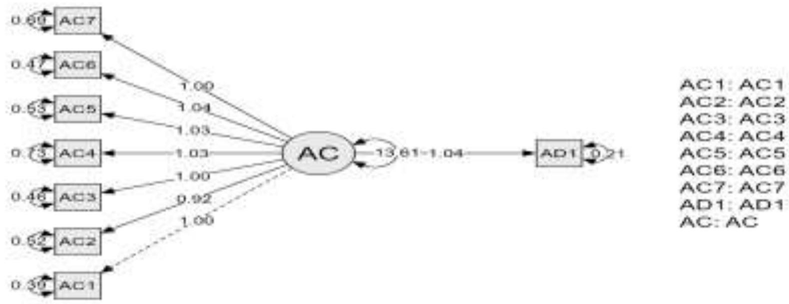
Model fit

				n(Parameters)		Baseline test		
	AIC	**BIC**	**n(Observations)**	**Total**	**Free**	χ^2	**df**	**p**
Model 1	13393	13463	600	16	16	2420	28.00	0.00

Table 7 Regression coefficients

Outcome	Predictor	Std. estimate	Std. Error	z-value	p
AD1	AC	0.993	7.128×10^{-4}	1393	0.000

Path diagram



SEM: Direct Effects & Model Fit

SEM revealed a substantial direct effect of contamination on the population ($\beta = 0.993$, $p < 0.001$). The model-fit indices (AIC/BIC) indicated that Model 2 was better. The model justifies that contamination has a direct proportional increase in chronic illnesses such as diarrhea, hepatitis, kidney failure, bone fluorosis, and gastrointestinal disease.

DISCUSSION AND CONCLUSION

This study empirically demonstrates that groundwater pollution in Faisalabad is a major predictor of the population's health burden. The regression coefficient is exceptionally high, indicating the rapid effect of chemical, industrial, agricultural, and sewage pollutants on trends in chronic illnesses. Non-normal distribution patterns indicate unbalanced exposure and severity of hotspots that require targeted intervention. This study was also validated by Rahman et al. (2021) and Farooqi et al. (2021), who demonstrated that its results are externally valid. The results of the research indicate that it is essential to implement comprehensive policies that encompass effluent regulation, pesticide control, groundwater monitoring, filtration facilities, and community education. Health departments need to prioritize screening programs, and communities need access to treatment and safe water.

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