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Assessing Groundwater Contamination, Health Risk And Health Cost: A Regression Analysis And Fuzzy AHP Approach

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Abstract

The environmental and health effects of groundwater pollution resulting from industrial activity in Tehsil Bhalwal, District Sargodha, Pakistan, have been investigated in this paper. The research focuses on the sugar industry's role in polluting local groundwater and its consequences for public health and economic well-being. Employing a combination of regression analysis and the Fuzzy Analytical Hierarchy Process (AHP), the study analyzes data collected from 200 households to evaluate the relationships between water quality perceptions, health risks, and healthcare costs. Findings indicate that groundwater contamination poses significant public health challenges, contributing to widespread diseases and increased healthcare costs. Key contaminants, including heavy metals and chemical pollutants, exacerbate health risks and economic burdens on affected

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communities. The study also highlights the need for stricter regulatory enforcement, improved waste management, and investment in modern water treatment infrastructure to mitigate these issues. The findings provide a basis for policy recommendations aimed at enhancing water quality, protecting public health, and promoting sustainable industrial development. By addressing the interconnection of environmental, health, and social challenges, the study contributes valuable insights into sustainable management practices for industrial zones, particularly in developing nations.

Keywords: Groundwater contamination, Health cost, Health Risk, Bhalwal, soil degradation.

Introduction

Environmental Impact Assessment (EIA) is a thorough and proactive evaluation process demonstrating the interdependencies among several scientific fields, including the social, biological, and earth sciences. The EIA process evaluates the environmental, socioeconomic, and other implications of development plans before they are approved or rejected by a governing authority. (Nita, Fineran, & Rozylowicz, 2022). EIA is vital for incorporating ecological factors into rational decision-making, impacting humanity's future, and assuring sustainability and adherence to the precautionary principle. Soil, water, noise, social, and health environmental receptors in EIAs, and soils are crucial to the sustainability of global and local settings. Over the decades, the application of EIA has expanded globally, and EIA assessments play a pivotal role in balancing environmental preservation with economic and social progress.

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In developing nations such as Pakistan, the importance of Environmental Impact Assessment (EIA) is heightened industrialization and urbanization accelerated pace, which frequently advances with limited consideration for its environmental repercussions. Industrial estates, designed to centralize manufacturing activities, serve as economic engines and focal points for environmental scrutiny. While contributing to economic growth fostering innovation and creating jobs, their environmental impacts can be profound if left unchecked. Groundwater contamination, soil degradation, and air pollution are some of the critical issues linked to industrial activities (Chandnani et al., 2022). Addressing these challenges requires robust regulatory frameworks and comprehensive assessments to ensure that economic development does not come at the cost of environmental degradation. (Liu et al., 2023).

Despite these regulatory efforts, Pakistan's implementation of EIA confronts significant problems, including limited resources, insufficient technical expertise, and a lack of political will (Khan & Chaudhry, 2021). Consequently, new reforms strengthen the EIA process and guarantee fulfill its intended aim of safeguarding the environment while enabling sustainable development. However, its rapid growth has also resulted in significant environmental challenges. Groundwater contamination, primarily caused by effluents from the sugar industry, has emerged as a pressing concern. Groundwater contamination represents a major issue associated with urbanization. Groundwater contamination is an imperceptible and irreversible process, with prohibitive costs and time requirements potentially

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limiting efforts to improve groundwater conditions (Din et al., 2023). The effluents, containing harmful chemicals and organic pollutants, have degraded water quality and posed significant health risks to the local population.

Groundwater pollution in Tehsil Bhalwal is exacerbated by effluents from the sugar sector, which enter local wastewater channels that run through residential areas. This condition poses significant hazards to both the environment and the population's health. As a result, a variety of health problems have arisen, including diarrhea, typhoid, eye infections, skin illnesses, gastrointestinal troubles, and cardiovascular ailments. (Khan & Chaudhry, 2021). Groundwater became the primary source of freshwater for drinking, agricultural, and industrial needs in arid and semiarid regions. The sugar industry, in particular, is notorious for discharging untreated or inadequately treated effluents into nearby water bodies. These effluents contain heavy metals such as lead, cadmium, and mercury, as well as high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The cumulative effect of these pollutants is a degradation of groundwater quality, rendering it unsafe for human consumption and agricultural use. (Hossain et al., 2022). In regions like Bhalwal, where groundwater serves as a primary source of drinking water, the consequences of contamination are particularly dire.

This study aims to address the critical gaps in understanding the environmental and health impacts of industrial activities in Bhalwal. By focusing on groundwater contamination and its

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associated risks, the research provides valuable insights into the complex interplay between industrial development and environmental sustainability. This contamination, primarily of a physicochemical nature, is having a detrimental impact on the health of individuals living in this area. In particular, residents near the wastewater channels are exposed to polluted water, which may lead to various health issues. The primary objective of this study is to evaluate the health status of individuals in households affected by this contamination. Specifically, the research aims to assess the current condition and levels of contamination in groundwater within Tehsil Bhalwal, examine the health effects experienced by residents near the sugar industry and its associated wastewater channels, and estimate the health-related costs incurred by these individuals as a result of using contaminated water.

The significance of this study lies in its ability to address critical environmental, health, and policy-related challenges in Tehsil Bhalwal, District Sargodha. By investigating the impact of industrial effluents, particularly from the sugar industry, on groundwater contamination and public health, the research contributes valuable insights to the existing body of knowledge on environmental degradation in industrial zones, especially in developing countries like Pakistan. The study highlights the severity of pollution and its direct consequences on local communities' health, providing a foundation for informed decision-making by policymakers and environmental authorities.

These findings can improve regulatory frameworks by emphasizing the need for stricter enforcement of environmental laws, such as the

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Pakistan Environmental Protection Act (PEPA), and better waste management practices within industrial estates. The study also has far-reaching implications for public health, identifying specific health conditions caused by contaminated water and assessing the economic burden of healthcare costs on affected households. This enables health authorities to design targeted interventions, prioritize resource allocation, and promote safe water initiatives in the region, with a focus on vulnerable low-income populations to address social equity. Furthermore, the study promotes sustainable industrial development by encouraging industries to adopt cleaner technologies and more effective waste management practices, emphasizing the need for a balance between economic growth and environmental sustainability. By empowering local communities with scientifically grounded evidence of environmental and health risks, the research fosters greater public participation in environmental decision-making, enabling residents to advocate for stronger protections and hold industries and authorities accountable. Overall, this study provides a comprehensive understanding of the interconnection of environmental, health, and social issues, driving positive change toward a more sustainable and equitable future for industrial regions like Bhalwal.

Literature Review

EIA communicates the government's decisions regarding the licensing of privatized and government projects that may have social and environmental impacts. Environmental Assessment (EA) is still formally unemployed. However, The USA is described as the brain

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and origin of EIA. It formulated the National Environmental Policy Act (NEPA) of 1969, promulgated as Public Law 91–190 on 1st January 1970, to manage federal projects anticipated to affect the environment adversely. The purposes of NEPA are: "To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality. Likewise, EIA serves as a decision-making tool for integrating environmental considerations into development projects (Karjalainen et al., 2013). These challenges undermine the effectiveness of EIA in protecting the environment and public health, particularly in industrial zones like Bhalwal, where groundwater pollution is rampant.

Groundwater contamination refers to the degradation of water quality in aquifers, making the water unsafe for consumption, agriculture, or industrial use. Contamination often results from the discharge of pollutants; including chemicals, waste, and untreated effluents, into water bodies that eventually seep into the groundwater. Industries, particularly the sugar industry, contribute significantly to groundwater pollution by releasing toxic substances, including heavy metals and organic compounds, which degrade water quality (Karjalainen et al., 2013).

Health Risk

Health risk refers to the likelihood that an individual or population

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may experience negative health outcomes due to exposure to specific risk factors. These factors can be physical, biological, behavioral, or socioeconomic, each contributing to varying degrees of health problems. The assessment and management of health risks are essential for preventing disease, enhancing public health, and improving quality of life. Understanding health risks involves exploring their sources, impacts, and the strategies needed to mitigate their effects. Health risks can arise from multiple sources, including environmental, behavioral, biological, and socioeconomic factors (Parvin & Tareq, 2021).

Health Cost

Health costs refer to the financial burden associated with maintaining, restoring, or enhancing health, affecting individuals and societies. These costs stem from various aspects such as medical treatments, preventive care, pharmaceuticals, hospital stays, diagnostic tests, and long-term care. Furthermore, health costs include indirect expenses like lost productivity, absenteeism, and the long-term economic impact of chronic illnesses. As healthcare systems face increasing demands due to aging populations, the prevalence of chronic diseases, and technological advancements, rising health costs have become a significant global concern. Addressing these costs requires a comprehensive understanding of their economic, social, and behavioral drivers, as well as strategies for reducing them while maintaining quality care (Li et al., 2021)

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Hypothesis Development

Groundwater contamination and Health Risks

Yadav et al. (2021) explain that Groundwater contamination poses significant health risks globally, particularly in developing countries where industrial activities and inadequate water treatment systems prevail. In Pakistan, groundwater is a major source of drinking water, especially in rural areas such as Tehsil Bhalwal, District Sargodha.

Furthermore, previous research estimated that 1.8 million people in developing countries die every year from diarrhea and cholera, and suffering from unsafe water supply (Mussa et al., 2019). The situation is even worse in the Pakistan area of Bhilwal. Likewise, Industrial effluents particularly from sugar mills, are key contributors to groundwater contamination. Industrial processes release harmful pollutants, including heavy metals, organic chemicals, and suspended solids, into nearby water bodies or directly into the ground, leading to contamination of groundwater sources. These contaminants, including lead, cadmium, mercury, and arsenic, pose severe health risks when consumed over prolonged periods (Parvin & Tareq, 2021)

In response to widespread worries about water quality, earlier research offered a conceptual model that explains the connections between variations in groundwater quality and the household services that are supplied (Iqbal et al., 2023). In addition, other researchers described heavy metals, for instance, accumulate in the human body over time, leading to chronic health issues such as cancer, neurological disorders, and organ damage. Lead exposure is known to impair cognitive development in children, while prolonged

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exposure to arsenic can result in arsenicosis, a condition associated with skin lesions and an increased risk of various cancers (Parvin & Tareq, 2021). Cadmium and mercury are linked to kidney damage and neurological dysfunction, making the presence of these contaminants in groundwater sources particularly dangerous. Additionally, agricultural runoff containing nitrates from chemical fertilizers further worsens groundwater contamination. High nitrate levels in drinking water are known to cause methemoglobinemia, or "blue baby syndrome," a condition that limits the blood's ability to carry oxygen in infants. Other agricultural pollutants, such as pesticides and herbicides, can disrupt endocrine function and increase the risk of reproductive health issues (Clinton-Ezekwe et al., 2024; Raza et al., 2017).

Groundwater contamination is a significant problem related to quality that often depends on inadequate water treatment infrastructure. In Pakistan, many water treatment facilities are outdated, lacking the capacity to effectively remove contaminants (Daud et al., 2017). Moreover, aging water distribution systems can introduce additional contaminants, such as pathogens and chemical residues, during the process of delivering water to households. As a result, water in many rural areas, including Tehsil Bhalwal, remains unsafe for consumption.

The health impacts of contaminated water are far-reaching. Waterborne diseases such as diarrhea, cholera, and dysentery are prevalent in regions where water quality is compromised. In Pakistan, diarrheal diseases are among the leading causes of child mortality,

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with unsafe drinking water being a major contributor. Cholera outbreaks, which are linked to bacterial contamination of water supplies, also pose a severe health risk, particularly in communities without access to clean water and sanitation. Beyond waterborne diseases, exposure to industrial pollutants in water can lead to long-term health consequences, including cancer and organ damage. Lead-contaminated water, for instance, has been shown to cause kidney damage, hypertension, and cognitive decline, while arsenic exposure increases the risk of skin, lung, and bladder cancers (Daud et al., 2017).

Addressing groundwater and water contamination in regions like Tehsil Bhalwal requires a multifaceted approach. Stricter regulation of industrial effluents is essential to limit the discharge of harmful pollutants into water sources. Regular monitoring of water quality is also crucial to ensure that contaminants are identified and addressed before they pose significant health risks. In addition to regulation, investment in modern water treatment infrastructure is critical. Upgrading water treatment plants to effectively remove contaminants such as heavy metals and nitrates will help improve the quality of contaminated water and reduce health risks for communities relying on groundwater sources (Pang, Luo, Zhang, & Hao, 2024; Raza et al., 2017). Overall, groundwater contamination presents significant public health challenges, particularly in areas where industrial activities and inadequate water treatment systems are prevalent. The health impacts of consuming contaminated water, including waterborne diseases and chronic conditions such as cancer

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and organ damage, are severe and place a heavy burden on affected communities. Addressing these challenges requires coordinated efforts from governments, industries, and communities to ensure access to safe and clean drinking water for all. Therefore, proposed that:

H1: The groundwater contamination quality perception has a negative and significant impact on the respondents' Health Risk.

Groundwater Contamination and Health Costs

Groundwater contamination presents not only significant health risks but also substantial economic costs for affected communities (Chandnani et al., 2022). Industrial waste, agricultural runoff, and inadequate waste management contribute to the contamination of groundwater, which serves as a primary drinking water source in many regions. In Tehsil Bhalwal, District Sargodha, the sugar industry plays a crucial role in local groundwater pollution, leading to severe public health implications. The presence of heavy metals, pathogens, and chemical pollutants in drinking water increases the incidence of waterborne diseases and long-term health issues, such as cancer and organ damage. These health problems result in direct and indirect costs for households, including medical expenses and loss of income due to illness-related absenteeism or disability (Li et al., 2021).

Contaminated water forces households to bear significant health-related expenses, particularly in areas where access to healthcare is limited or costly. Medical treatments for waterborne diseases such as diarrhea, cholera, and typhoid, as well as long-term treatments for chronic conditions such as kidney damage or

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neurological disorders from heavy metal exposure, impose a financial burden on affected families (Huynh et al., 2024). Households may also face indirect costs, including lost income due to time off from work for treatment, caregiving, or recovering from illness, further worsening the economic strain. This burden is particularly pronounced in rural areas like Tehsil Bhalwal, where many families rely on agriculture and daily wages for their livelihood.

Moreover, when households attempt to mitigate the effects of water contamination, they often face additional costs. These may include purchasing bottled water, installing water filtration systems, or boiling water for safety. While these methods can reduce the health risks associated with contaminated water, they represent an added financial burden, especially for low-income families. In many cases, these mitigation measures are insufficient to fully address the problem, leaving households still vulnerable to the health effects of contaminated water (Huynh et al., 2024). The economic implications of contaminated water extend beyond individual households to affect the broader community. As waterborne diseases spread, healthcare systems in affected areas may become overwhelmed, leading to increased public health expenditures. Additionally, the productivity losses due to illness and premature death reduce economic output, further straining local economies. Thus, groundwater contamination represents not only a public health crisis but also a significant economic challenge for communities in regions (Nita et al., 2022) like Tehsil Bhalwal. Given the direct and indirect costs associated with

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water contamination, the hypothesis for this study can be formulated as follows:

H2: Groundwater contamination quality perceptions are negatively associated with increased health-related costs for households in Tehsil Bhalwal.

Methodology

Study Area

Primary data was collected through an administrated questionnaire from Tehsil Bhalwal, District Sargodha, a region significantly impacted by groundwater contamination quality. With a population of approximately 250,000, the area relies heavily on groundwater for domestic and agricultural purposes. Effluents from the local sugar industry have been identified as a major source of contamination.

Data Collection and Sampling

A structured questionnaire was administered to 200 households in four key areas of Bhalwal. The questionnaire collected data on water usage, health symptoms, and healthcare costs. A simple random sampling technique ensured representativeness. Pilot testing with 60 participants validated the reliability of the survey instruments, achieving Cronbach's alpha values above 0.70.

Analytical Framework

The study employs regression analysis and Fuzzy AHP to evaluate the relationships between groundwater contamination, health risks, and healthcare costs. Regression models quantify these relationships, while Fuzzy AHP prioritizes factors based on expert judgment, providing a comprehensive understanding of the issue.

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Measurement Scale of Study

Perceived water Quality

Perceived water quality was measured by adopted single-item scale adopted from the study (Schuitema et al., 2020). Sample items include: How would you rate the quality of your drinking water?

Perceived Health Risk

Perceived Health Risk was measured by 4 four-item measurement scale adopted by (Schuitema et al., 2020). Sample items include: The drinking water contains contaminants.

Perceived Health Cost

Health cost adopted 4 items measurement scale from a prior study (Lee & Cunningham, 2001). Sample items include: I believe my healthcare costs are too high

Data Analysis

Demographics

Table 4.1 shows study demographic statistics. The sample gender included 53% male and 47% female respondents, with a significant proportion aged 20–30 years. Education levels varied, with 35% having less than a bachelor's degree. Notably, 74.5% of households relied on contaminated water, and 83% reported incurring health-related costs.

Table 1: Demographic Analysis

	Frequency	Percentage (%)
Gender-Male	106	53%
Female	94	47%
Age-20–25 Years	65	32.5%

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26–30 Years	55	27.5%
31–45 Years	42	21%
46–50 Years	38	19%
Education-Lower than Bachelors	70	35%
Bachelor Degree	63	31.5%
Master's Degree	45	22.5%
Doctoral Degree	22	11%
Users-Tab Water	51	25.5%
Contaminated Water	149	74.5%
Health Cost-Yes	166	83%
No	34	17%
Health Risk-Yes	173	86.5%
No	27	13.5%

Correlation and Regression Analysis

Correlation analysis revealed moderate positive relationships between water quality perceptions, health risks, and healthcare costs. Table 4.2 demonstrates the significant impacts of water contamination on health risks and healthcare costs, showing r = -0.45 for WCQP and health risk, and r= +0.54 for WCQP and health cost.

Table 4.2: Correlations Coefficient

Variables	X	S. D	1	2	3
Water quality perceptions	3.75	0.85	1		
Health Risk	4.2	0.65	-0.45	1	
Health cost	3.6	0.75	-0.54	0.60	1

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Hypothesis Testing

The hypothesis (H1) posits that groundwater contamination quality perception (WCQP) has a negative and significant impact on respondents' health risk (HR), and the findings strongly support this. The negative coefficient (β = -0.45) indicates that as perceptions of groundwater contamination worsen, health risks decrease, potentially reflecting adaptive behaviors such as reduced reliance on contaminated water sources or improved mitigation strategies. The relationship is statistically significant $p<0.001$, with a high t-value (15.33) providing strong evidence against the null hypothesis. The model explains 35% of the variance in health risk ($R2 = 0.35$), and the adj. ($R2 = 0.347$) confirms the model's reliability and robustness. The F-value (31.72) further demonstrates that the model is statistically significant. These results validate the hypothesized negative impact of WCQP on health risk and provide insights into the potential protective behaviors employed by households in response to contamination perceptions.

Table 4.3: WCQP-HR

Variables	Coefficient (β)	error	t-value	p-value
WCQP-HR	-0.45	0.115	15.33	<0.001

R^2=0.35, Adjusted R^2= 0.347, F-value= 31.72

The hypothesis (H2) suggests that groundwater contamination quality perceptions (WCQP) are negatively associated with health-related costs for households in Tehsil Bhalwal. The coefficient (β = -0.55) supports this negative relationship, indicating that as perceptions of

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groundwater contamination worsen, health-related costs tend to decrease. While the relationship aligns with the hypothesis, it appears counterintuitive and may reflect mitigating factors, such as reduced reliance on contaminated water or limited healthcare access, which warrant further exploration. The intercept is significant, establishing a baseline for health-related costs, and the model demonstrates moderate explanatory power (R2 = 0.40, Adj. R2 = 0.397) with high overall significance (F = 61.79). These results highlight a meaningful, albeit unexpected, relationship between contamination perceptions and health-related costs.

Table 4.4: WCQP-HC

Hypothesis	β	error	t-value	p-value
WCQP-HC	-0.55	0.120	29.17	P≤0.01

R^2=0.40, Adjusted R^2= 0.397, F-value=61.79

Fuzzy AHP Results

Fuzzy AHP assigned the highest weight to water contamination quality perception (63%), followed by health costs (26%) and health risks (11%). This prioritization highlights the critical need for addressing water quality issues as a primary intervention.

Discussion

The study's findings underscore the critical health and economic impacts of groundwater contamination on households in Tehsil Bhalwal, revealing a significant public health issue. The demographic data show that a large proportion of the population is exposed to contaminated water, with 74.5% relying on it for daily use, and a majority incurring related healthcare costs. Analysis of water quality

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perceptions indicates that while respondents generally view their water as moderately safe, there's an apparent disconnect between perceived water quality and health risk awareness. Despite relatively positive assessments, high health risk perceptions suggest an understanding of the hazardous nature of local water contamination, likely influenced by common ailments observed within the community. This aligns with previous research. (Adeloju, Khan, & Patti, 2021) indicating that communities exposed to contaminated water often experience high rates of gastrointestinal, skin, and respiratory diseases, mirroring findings in other regions where contamination is a pervasive issue.

The study's correlation and regression analyses support the hypotheses, confirming significant relationships between water quality perceptions, health risks, and healthcare costs. Health cost perception correlates positively with health risk perception, indicating that as people's awareness of contamination hazards increases, so does their anticipation of associated medical costs. Regression analysis further reinforces these findings, showing that improved water quality perceptions are linked with reduced health risks and lower healthcare costs. These results align with broader research (Siddiqua, Hahladakis, & Al-Attiya, 2022) suggesting that environmental health hazards, such as water contamination, heavily contribute to financial burdens for low-income households, restricting their ability to allocate resources to other essentials.

These findings have substantial implications, pointing to the urgent need for water quality management interventions in Bhalwal.

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Implementing stricter water quality standards, along with community-based monitoring and treatment programs, could help mitigate health risks and reduce the economic toll on affected households. Additionally, public health campaigns to enhance community awareness about water safety could bridge the gap between perceived water quality and actual risks, encouraging safer water practices. Such interventions have been shown to reduce waterborne illness rates in similarly affected regions, underscoring their potential effectiveness in Bhalwal. The study advocates for ongoing research and monitoring long-term health and economic impacts of water contamination, which would guide data-driven policies that prioritize the well-being and economics resilience of vulnerable communities.

Theoretical Implication

The current study has provided noteworthy theoretical contributions. Firstly, the novel contribution framework assessing people's groundwater quality as average, and health risk and cost perceptions remain high, indicating contamination awareness. This supports Slovic's theory that resource-constrained populations may be more aware of environmental threats due to health and financial constraints. Secondly, findings also support the Health Belief Model (HBM), particularly with contaminated water's perceived severity and sensitivity to health concerns. As pollution awareness increases, individuals perceive higher health risks and expect higher healthcare expenses. HBM claims that awareness and perceived severity affect health-related behaviors and decisions, including healthcare spending. As predicted by the HBM, perceived health concerns drive economic

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behaviors like seeking medical care, adding a new dimension to the study. Thirdly, study shows how environmental dangers like water contamination disproportionately affect economically disadvantaged populations, contributing to the Environmental Justice Framework.

Waterborne infections in Tehsil Bhalwal cause considerable healthcare expenses, highlighting environmental risks and socioeconomic inequities. This reinforces the framework's notion that marginalized populations face environmental dangers and cumulative disadvantages. The study implies that policies targeting such locations should address environmental and socioeconomic factors to lessen health inequalities and budgetary burdens. Tehsil Bhalwal people use contaminated groundwater, which is unhealthy and expensive. The findings show that community dependence on groundwater increases health hazards and emphasizes the need for alternative water resources. This theoretical finding suggests that policy interventions should diversify water supplies in such places to avoid dependency on contaminated resources. Finally, the study shows how water quality and health concerns affect household economic decision-making, revealing behavioral economics. Water contamination raises health expenditures, forcing households to choose between healthcare and other requirements. This supports the behavioral economics idea that health hazards can affect financial behavior, providing a realistic context for health-related economic decision-making theories.

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Limitation and Future Direction

This study's limitations and future research suggest various ways better to comprehend groundwater contamination's health and economic impacts. Firstly, as a cross-sectional study, it cannot prove causation between water quality, health risks, and healthcare costs. Longitudinal studies could fill this gap. The geographic focus on Tehsil Bhalwal, District Sargodha, limits generalizability because water pollution profiles and socio-economic situations differ by location. Replicating this study across regions might improve its external validity by capturing wider trends and regional variances. Possible response biases restrict self-reported health risks and healthcare expenses. Clinical health data and medical facility healthcare costs could be used in future studies to objectively assess the effects.

Secondly, study's focus on immediate symptoms including gastrointestinal and skin disorders limits long-term health effects. For a more complete health profile, future research should include chronic illnesses like respiratory or developmental disorders linked to extended exposure to contaminated water. This study used perceived water quality rather than laboratory measurements, which may not fully capture pollution levels. Actual water testing combined with perceived quality data would better assess water quality risks. Secondly, longitudinal studies tracking water contamination's health and economic effects could elucidate causal links. Comparative studies across multiple regions with different contamination sources and socio-economic situations will illuminate context-specific health risks and costs, improving policy solutions. Objective health and cost

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criteria like clinical data and hospital invoicing would also improve results, strengthening the relationship between water quality and health hazards. Including chronic illnesses associated with long-term contamination in the health impact scope may reveal the larger effects of exposure. Effective public health strategies would benefit from studying how policies like clean water and public health campaigns affect health and economic results. Integrating environmental, health, and economic views would show intricate relationships between contamination, community health, and financial well-being. Addressing these constraints and exploring future research directions may help water-stressed countries build appropriate health and environmental policies.

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