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Research Article

Farmers' perception about hazards related to wastewater irrigation

Fahad Iftikhar Virk[1,2]*, Ahmad Ali[3], Noor Ul Ain[3]

[1]Department of Geography & Environment, University of the West of England, Bristol, United Kingdom
[2]Institute of Soil & Environmental Sciences, University of Agriculture Faisalabad, Pakistan
[3]Department of Chemical Engineering, NFC Institute of Engineering & Fertilizer Research (IEFR), Faisalabad, Pakistan

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*Corresponding author: Fahad Iftikhar Virk, E-mail: fahadiftikharvirk@gmail.com

Abstract

Water scarcity driven by rapid population growth, urbanization, and climate change has intensified the use of alternative water sources for agriculture, particularly in developing countries. In Pakistan, untreated or partially treated wastewater is widely used for irrigation in peri-urban areas such as Sheikhupura due to limited freshwater availability. Although wastewater irrigation supports crop production and farmer livelihoods, it poses serious environmental and public health risks. This study assesses farmers' awareness and perceptions of potential health hazards associated with wastewater irrigation in Sheikhupura, Punjab, Pakistan. A quantitative research approach was adopted, using structured questionnaires administered to 100 farmers engaged in wastewater-irrigated agriculture. Data were collected on demographic characteristics, irrigation practices, perceptions of contamination, and health risks. Statistical analyses, including the Kruskal–Wallis H test and multivariate probit regression, were performed to examine the influence of socio-demographic factors on farmers' perceptions. Results indicate that while most farmers recognize that irrigation water is contaminated; their understanding of specific health risks remains limited. Skin-related problems were perceived as the most common health issue, whereas gastrointestinal and eye-related risks were less recognized. Farmers continue to use wastewater primarily due to its availability, low cost, and nutrient content. The study highlights the need for targeted awareness programs, improved wastewater management, and policy interventions to reduce health risks while sustaining agricultural productivity in water-scarce regions.

Keywords: Wastewater reuse, Peri-urban agriculture, Farmer risk perception, Public health impacts, Water management, Developing countries

Introduction

Global population growth, climate change, and rapid urbanization have placed increasing pressure on limited freshwater resources. It is estimated that the global population will reach nearly 9.5 billion by 2050, requiring an increase of approximately 60% in food production. At the same time, freshwater scarcity is emerging as a major global concern, with around 60% of the world's population expected to face water shortages by 2025 (Faria & Naval, 2022). More than four billion people already experience severe water scarcity for at least one month each year, making the fair allocation and sustainable management of water resources a critical challenge worldwide Partyka and Bond (2022).

Agriculture is the largest consumer of freshwater, accounting for up to 70-90% of total water withdrawals in many regions, and this demand is expected to increase further under changing climatic conditions (Khanpae *et al.,* 2020). Although agriculture is highly vulnerable to water shortages and extreme weather events, it also plays a crucial role in addressing climate change and ensuring food security (Salam *et al.,* 2022). Given the growing competition for freshwater resources, the identification and use of alternative water sources for irrigation have become increasingly important.

Agriculture contributes approximately 14% of global greenhouse gas emissions and is closely linked to water demand and land use, making it central to sustainable water resource management (Mwadzingeni *et al.,* 2022). Poor water governance and inefficient management could result in a global water supply shortfall of up to 40% by 2030. In developing countries, rapid urban expansion has intensified competition for freshwater among domestic, industrial, and agricultural sectors. In Sheikhupura city, Pakistan, urban population growth and industrial development have significantly increased water demand, diverting groundwater resources away from agriculture (Akhtar *et al.,* 2018). As a result, farmers increasingly rely on untreated or partially treated municipal and industrial wastewater for irrigation (Rashid *et al.,* 2017).

Wastewater irrigation has emerged as a coping strategy in response to freshwater scarcity, environmental degradation, pollution of available water resources, and climate variability. While wastewater provides a reliable and nutrient-rich source of irrigation water, its use without adequate treatment poses serious risks to soil quality, crop safety, and human health. Globally, more than 70% of freshwater is consumed by agriculture, encouraging interest in wastewater reuse as an alternative irrigation source (Khan *et al.,* 2022). In developed regions, wastewater treatment and reuse systems are well established. The European Union operates over 18,000 wastewater treatment plants, while the United States treats more than 60 billion gallons of wastewater daily through over 16,000 treatment facilities (Minhas *et al.,* 2022). Several regions, including Singapore,

Orange County, Windhoek, and Perth, have successfully implemented wastewater reuse systems, even for potable purposes (Ricart & Rico-Amorós, 2021).

Despite these advancements, wastewater reuse in agriculture remains limited in many developing countries due to inadequate infrastructure, regulatory challenges, and public opposition. Public perception and acceptance are major barriers to wastewater reuse, particularly for food production. Negative attitudes are often driven by concerns related to health risks, odour, taste, and microbial contamination (Saldías *et al.,* 2017). Emotional responses such as disgust further reduce acceptance of wastewater reuse practices (Saliba *et al.,* 2018). Studies suggest that awareness, education level, trust in authorities, and confidence in treatment technologies significantly influence acceptance (Sohail *et al.,* 2021). Individuals with higher education levels are generally more supportive of wastewater reuse, as they better understand its benefits and associated risk management strategies (Mu'azu *et al.,* 2020).

Pakistan's Indus Basin Irrigation System is one of the largest in the world, yet the country has transitioned from being water-rich to water-scarce. Per capita water availability has declined from 1,299 m^3 in the late 1990s to below 1,000 m^3 and is projected to fall under 700 m^3 by 2025 (Kirby & Ahmad, 2022). Climate change and population growth have further widened the gap between water supply and demand (Asif *et al.,* 2022). Pakistan generates approximately 6.4 billion m^3 of wastewater annually, much of which is discharged untreated into water bodies (Batool & Shahzad, 2021). Untreated wastewater irrigation is widely practiced, exposing farmers and consumers to health risks such as skin diseases, gastrointestinal infections, and heavy metal contamination (Ilyas *et al.,* 2022; Maqbool *et al.,* 2022). Outside major cities such as Islamabad and Karachi, most urban centers lack effective wastewater treatment facilities (Javed & Hobson, 2022).

Sheikhupura, an industrial city in Punjab, Pakistan, hosts numerous industries including textiles, leather, pharmaceuticals, food processing, and steel manufacturing (Benjamin & Nishat, 2021). Agriculture remains a vital livelihood in the region, with major crops including wheat, rice, sugarcane, and vegetables (Shaheen *et al.,* 2019). Due to industrial effluent discharge and limited freshwater access, wastewater irrigation is widely practiced in peri-urban agricultural areas, raising serious concerns about environmental contamination and public health. Understanding farmers' awareness and perceptions of wastewater irrigation is essential for developing effective risk mitigation strategies and informing policy decisions. Urban and peri-urban agriculture plays a critical role in food security and income generation for low-income populations (Iqbal *et al.,* 2022b). Assessing farmers' knowledge of health risks associated with wastewater use can help design targeted awareness programs and promote safer irrigation practices. This study therefore aims to evaluate farmers' perceptions of health hazards related to wastewater irrigation in Sheikhupura, contributing to sustainable water management and improved public health outcomes in water-scarce urban environments.

Research methodology

The study was conducted in Sheikhupura city, Punjab Province, Pakistan, located between latitudes 31°20′–33°05′ N and longitudes 73°37′–74°41′ E (Figure 1).

Sheikhupura is a rapidly urbanizing and industrialized city characterized by extensive discharge of untreated municipal and industrial wastewater. The area experiences substantial seasonal climatic variability, with an average annual rainfall of approximately 630 mm. Agriculture in the peri-urban zones includes the cultivation of wheat, rice, sugarcane, vegetables, and fruits. Due to limited freshwater availability, agricultural fields in the outskirts of Sheikhupura are commonly irrigated using untreated wastewater mixed with tube-well water (Figure 2).

A quantitative, cross-sectional research design was employed to assess farmers' perceptions and awareness of health risks associated with wastewater irrigation. The study was empirical and explanatory in nature, aiming to identify relationships between socio-demographic characteristics and farmers' attitudes, knowledge, and agricultural practices. A structured survey approach was selected to enable objective measurement and statistical comparison across different respondent groups. Primary data were collected using a structured questionnaire consisting of closed-ended questions. The questionnaire covered farmers' demographic characteristics, cropping patterns, irrigation practices, fertilizer and manure use, perceptions of wastewater quality, awareness of contamination sources, and perceived health risks. Responses were measured using a four-point Likert scale and binary (yes/no) options where appropriate. The target population included adult farmers aged 25-55 years who were directly or indirectly engaged in wastewater-irrigated agriculture. Given the low literacy levels among respondents, data were collected through face-to-face interviews to ensure accurate understanding of the questions. Two trained local volunteers assisted in administering the questionnaires to improve communication and response reliability. In addition, semi-structured interviews were conducted with a randomly selected subset of farmers to provide contextual insights into irrigation practices and perceived health risks. A stratified probability sampling technique was adopted to ensure representative coverage of farmers from different agricultural locations within Sheikhupura. Stratification was based on geographic location and irrigation practices. This approach minimized sampling bias and facilitated comparative analysis across sites. A total of 100 farmers were included in the study, which was considered adequate for statistical analysis within the scope of the research.

Collected data were coded and entered into the Statistical Package for the Social Sciences (SPSS) for analysis (Figure 3). Descriptive statistics were used to summarize socio-demographic variables and farming characteristics. Data normality was assessed before inferential analysis,

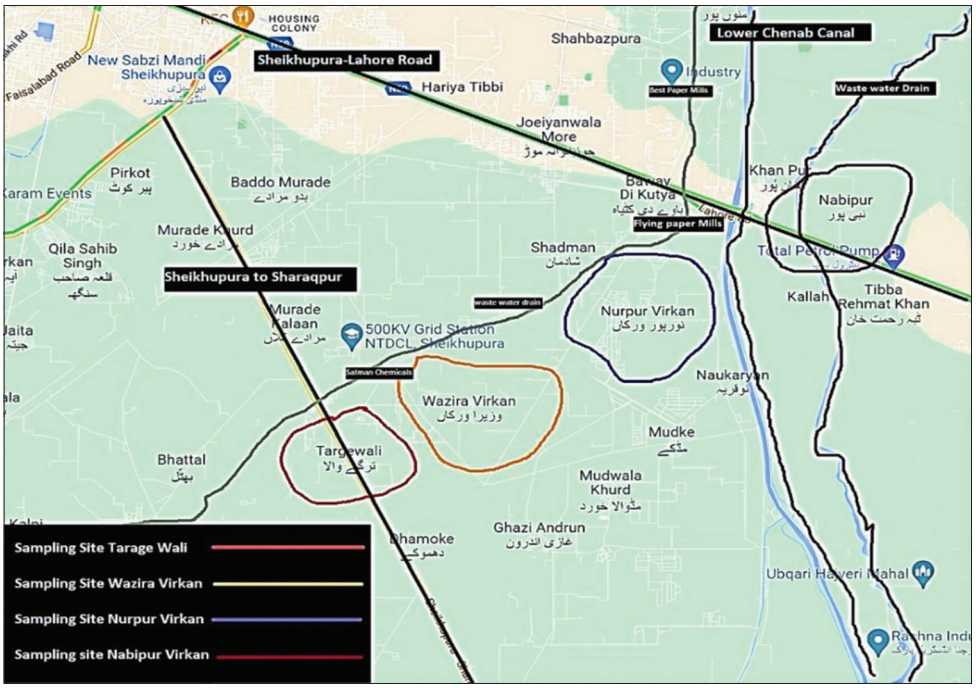

Figure 1: Study area map representing sampling points of study area (Self- Editing on Google map)

Figure 2: Source of wastewater irrigation in the study area

Figure 3: Data collected about farmers' perception about wastewater irrigation in Sheikhupura

and as the assumptions of normality were not met, non-parametric statistical methods were applied. The Kruskal–Wallis H test was used to examine differences in perceptions and awareness across gender, age groups, education levels, and agricultural locations. Furthermore, multivariate probit regression analysis was performed to evaluate the influence of demographic factors including gender, age, education level, and farm location on agricultural decision-making, irrigation frequency, and fertilizer and manure use. Statistical significance was assessed at a 5% confidence level. All procedures involving human participants were conducted in accordance with ethical research standards. Participation was voluntary, and informed consent was obtained from all respondents before data collection. Confidentiality and anonymity were strictly maintained, and no personal identifiers were recorded. The collected data were used exclusively for academic research purposes.

Results

Wastewater irrigation is extensively practiced for vegetable cultivation in urban Sheikhupura. As per Table 1, this study evaluated farmers' perceptions of irrigation water quality, health risks, and mitigation practices across four wastewater-irrigated sites. Data were collected through 100 structured questionnaires and 10 semi-structured interviews. Most farmers acknowledged the polluted nature of irrigation water, although awareness of specific health risks varied. Kruskal–Wallis H analysis indicated male farmers perceived water quality more favorably (mean=1.32) than females, while perceived vegetable quality showed no significant gender differences. Skin-related issues were consistently ranked as the most severe health risk, with eye irritation, foot discomfort, and gastrointestinal ailments considered less severe. Participation in health promotion programs and cessation of wastewater irrigation prior to harvest were identified as the

most effective protective measures. Crop restriction practices favored cooked over raw-consumed vegetables ($p<0.001$), reflecting awareness of microbial contamination risks.

Participants were predominantly male (72%), with females having fewer years of formal education. Farmers' ages ranged from 18-70 years (Table 2). Wazira Virkan and Noor Pur Virkan respondents were on average 25-30 years younger than those from Nabi Pur Virkan and Taragy Wali. Only 30% had completed matriculation or higher education. Approximately 50% inherited land, whereas one-third received land allocations through sub-city employment initiatives, most notably in Nabi Pur Virkan (43%). Marketability was the primary determinant of crop selection (>90%), with consumer preference and seasonality influencing only 14% of decisions. Fertilizer use was diverse: 65% applied mineral fertilizers, 35% used manure, with Noor Pur farmers favoring manure (75%) and Nabi Pur Virkan farmers preferring mineral fertilizers ($p<0.01$). Irrigation frequency averaged twice per week.

A multivariate probit regression was applied to examine the influence of continuous and discrete predictors on farm management decisions explained in Table 3. Model fit, indicated by the pseudo-R-squared, reflected strong concordance between observed and predicted values. Results revealed a positive correlation between consumer demand and water usage. Gender, age, agricultural location, and schooling significantly influenced decision-making ($p<0.05$). Female farmers were 20% more likely than males to prioritize consumer preferences. Farmers over 30 and those from Nabi Pur Virkan also emphasized consumer requirements, with agricultural location exerting the strongest influence ($p<0.001$, 14%).

Farmers' awareness of water contamination and vegetable safety was assessed through six binary-response questions (Table 4). Male farmers exhibited slightly more favorable attitudes toward water quality (mean=1.34), whereas females demonstrated greater awareness of the risks associated with consuming wastewater-irrigated vegetables ($p<0.05$). No significant gender differences were observed regarding wastewater use for handwashing or awareness of links between contaminated vegetables and disease. Farmers in Nabi Pur Virkan reported higher perceived benefits of vegetable washing with wastewater compared to Wazira Virkan and Noor Pur Virkan ($p<0.05$). Age (25-30 years) and higher education levels were positively associated with risk awareness, while younger and less-educated farmers displayed lower awareness. Overall, perceptions and attitudes toward wastewater irrigation and vegetable quality improved with age and education.

Fear of vegetable-borne diseases was the primary deterrent to wastewater use (Figure 4). Nevertheless, 79% of farmers reported no negative customer perception, and 39% cited adverse media coverage as a barrier. Despite these concerns, 80% continued using wastewater due to its status as the only available water source. Positive drivers included access to cheap and abundant water (95%), with 80%

Table 1: Comprehensive overview of the parameters

S. No.	Parameters	Explanation	Alphabets to represent variables
1	Which types of crops they are growing	Soil type and population growth rate are two factors that influence agricultural decisions	A (yes); B (other)
2	How frequently your crops require watering	From planting to harvesting, many crops have varied irrigation requirements	A (yes); B (other)
3	Dung	Is dung being used as a soil amendment?	A (yes); B (No)
4	Fertilizer	Farmers are using fertilizer in their crops or not	A (yes); B (No)
5	Fields Location	Villages in Sheikhupura city	A (NPV); B (others)
6	Participants Gender	Both male and female	A (Male); B (Female)
7	Participants Age	Participants>30	A (>30); B (other)
8	Participants Schooling	Intermediate	A (yes); B (No)
		Matriculation	A (yes); B (No)

Table 2: Demographic profile of study area participants

Parameters (%)	Nabi Pur Virkan (NPV)	Taragy Wali (TW)	Wazira Virkan (WV)	Nur Pur (NP)
Participants Gender				
Male	75	69	70	72
Female	25	31	30	28
Participants Age				
25-30	49	27	48	15
31-40	28	43	34	30
>40	24	29	19	55
Participants Schooling				
Middle	41	44	22	50
Matriculation	35	40	48	17
Intermediate	23	17	29	32

Table 3: The marginal effects of demographic factors on selected agricultural characteristics using multivariate probit regression (n=100)

Parameters	Coefficient	Standard error	Significant value	Marginal value
Consumer Need				
Participants Gender	2.105	0.340	0	0.218
Participants >30	0.502	0.245	0.309	0.101
Participants from NPV	0.735	0.217	0	0.146
Matriculation	-0.097	0.265	0.706	-0.018
Intermediate	0.143	0.266	0.572	0.027
Water Usage				
Participants Gender	-6.557	0.001	0.000	0.012
Participants >30	-0.251	0.347	0.467	0
Participants from NPV	-0.635	0.356	0.076	0.002
Matriculation	-0.525	0.375	0.160	0.002
Intermediate	-0.440	0.411	0.281	-0.000
Dung usage				
Participants Gender	0.042	0.183	0.814	-0.016
Participants >30	0.153	0.177	0.385	0.060
Participants from NPV	-0.577	0.163	0	-0.228
Matriculation	0.017	0.193	0.923	-0.006
Intermediate	0.192	0.208	0.355	0.075
Application of Fertilizer				
Participants Gender	0.323	0.185	0.080	-0.128
Participants >30	0.086	0.177	0.621	-0.034
Participants from NPV	0.479	0.162	0.002	0.190
Matriculation	0.128	0.192	0.502	0.050
Intermediate	-0.211	0.208	0.299	0.083

Model Statistic	Consumer Need	Water usage	Dung usage	Application of fertilizer
pseudo-R-squared	0.185	0.140	0.050	0.040
Prediction accuracy (%)	84.5	94.5	60.3	58.9

Table 4: Farmer Perception and awareness about wastewater irrigation

	Agree with wastewater irrigation			Wastewater used for vegetables production			Crops produced using wastewater quality is good			Community knows about diseases associated with wastewater irrigation			Wastewater-irrigated crops are unhealthy		
	Y	N	Mean	Y	N	Mean	Y	N	Mean	Y	N	Mean	Y	N	Mean
Gender															
Male	31	63	1.35	12	80	1.10	78	16	1.80	89	10	1.93	79	15	1.82
Female	10	20	1.10	9	27	1.23	29	8	1.75	36	5	1.96	35	5	1.94
P value		<0.001			<0.01			>0.05			>0.05			<0.05	
Agricultural location															
NPV	15	42	1.26	13	44	1. 21	44	18	1.76	55	5	1.96	50	7	1.87
TW	9	26	1.25	6	32	1.07	28	7	1.80	33	6	1.93	30	5	1.85
WV	8	13	1.20	4	14	1.14	14	6	1.84	15	3	1.92	115	4	1.90
NPV	7	15	1.32	2	21	1.04	20	5	1.90	21	4	1.90	18	6	1.81
P value		>0.05			<0.01			>0.05			>0.05			>0.05	
Age															
25-30	5	47	1.02	10	45	1.06	38	15	1.68	46	2	1.98	49	1	1.97
31-40	14	29	1.31	8	35	1.17	36	8	1.81	42	4	1.96	37	7	1.84
41-70	21	20	1.50	7	31	1.19	38	5	1.95	34	6	1.85	28	11	1.71
P value		<0.001			<0.05			<0.001			<0.001			<0.001	
Schooling															
Elementary	22	32	1.40	11	43	1.19	51	6	1.94	47	10	1.88	42	12	1.77
Matric	10	21	1.31	6	25	1.18	23	8	1.73	30	4	1.96	27	6	1.86
Intermediate	8	42	1.07	7	41	1.05	33	15	1.69	46	1	1.99	45	4	1.96
P value		<0.001			<0.01			<0.001			<0.01			<0.001	

Y-Yes, N-No

identifying it as the main motivation, and supplementing household food supplies (50%) (Figure 5). While 63% could not distinguish between high yield and nutrient value as motivators, 22% considered both important. Convenience of access influenced 37% of respondents. These results indicate that practical benefits, particularly water availability, outweigh perceived health risks in driving adoption.

Farmers in Nabi Pur Virkan identified industrial chemicals (80%) and solid waste (70%) as primary contamination sources, followed by household sewage (50%) and greywater (45%) (Figure 6). Additional contributors included runoff (28%), gasoline/oil (15%), and medical waste (10%). Open defecation and rainfall runoff further exacerbate contamination. Regarding perceived impacts,

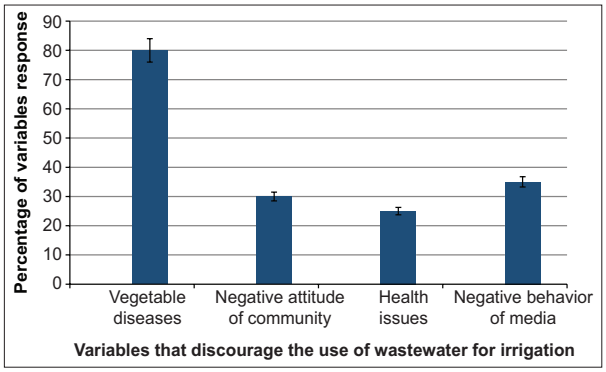

Figure 4: Aversion factors towards the use of wastewater for irrigation

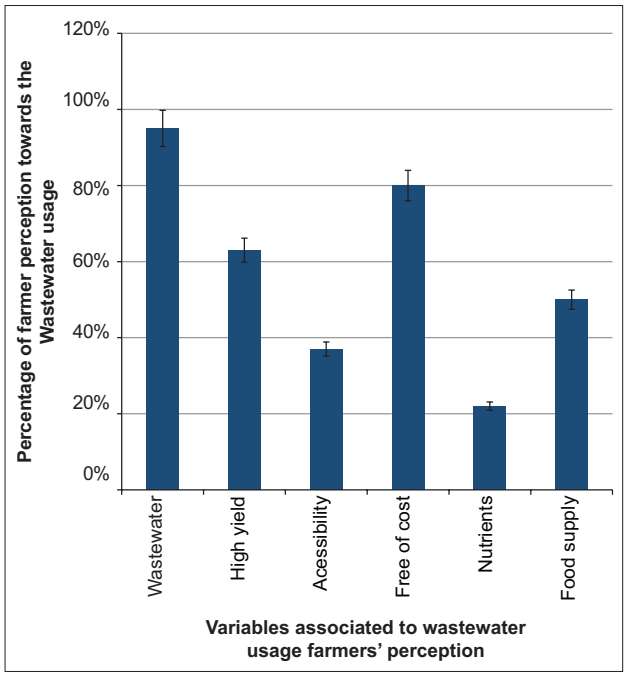

Figure 5: Variables related to perception of and motivations for using wastewater in agriculture

87% believed pollution adversely affects health (Figure 7), and 70% reported agricultural challenges, including difficulties in soil preparation and water application. Less than 20% expressed concern about microbial or chemical contamination of crops. Farmers emphasized that solid waste damaged irrigation infrastructure, illustrating the intersection of environmental, operational, and health challenges associated with wastewater irrigation.

Farmers consistently ranked skin-related conditions as the highest risk from wastewater exposure, whereas eye irritation, foot discomfort, and gastrointestinal ailments were rated lower (Table 5). Male farmers reported higher risks of skin problems and aching feet, while females rated muscle discomfort lower. Noor Pur Virkan farmers experienced more muscle soreness, likely due to physically demanding work and advanced age. Evaluation of eleven WHO-recommended health measures revealed women were more likely to adopt safe sanitation and drinking water practices, though gender differences in deworming and immunization were not significant (Table 6). Health promotion programs received the highest effectiveness

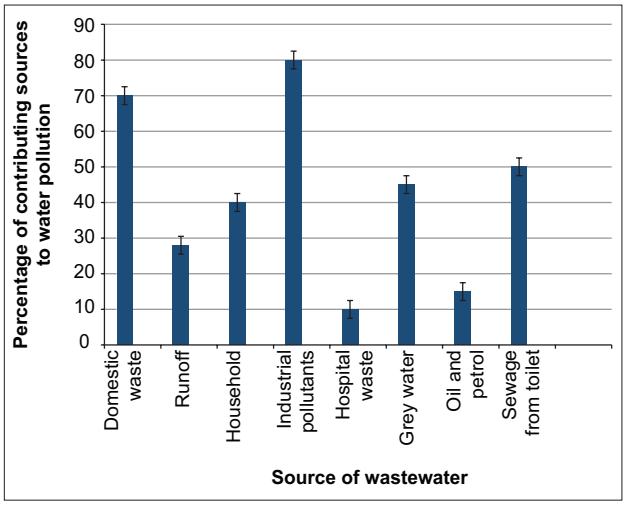

Figure 6: Source of water contamination in Sheikhupura agriculture

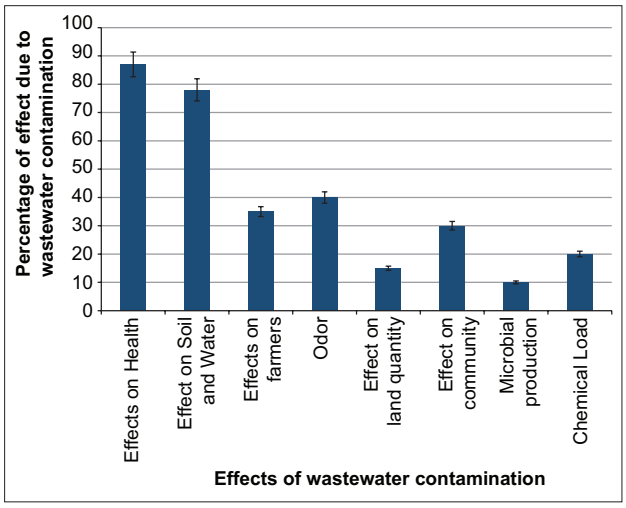

Figure 7: Reported consequences of wastewater pollution

scores, whereas immunization was least effective. Protective practices, including safe irrigation and ceasing irrigation before harvest, varied significantly across regions. Farmers in Nabi Pur Virkan favored cultivating non-food crops, whereas Taragy Wali farmers prioritized access to clean water and sanitation.

Discussion

Farmers' perceptions of wastewater irrigation and associated risks are influenced by experience, exposure voluntariness, perceived benefits, and consequence clarity. Most farmers were aware of wastewater irrigation, yet women, younger farmers, and the well-educated perceived irrigation water as less safe. Practical incentives, particularly in Nabi Pur Virkan, outweighed concerns: wastewater irrigation increased productivity for over 65% of farmers, despite more than 70% expressing uncertainty regarding water quality. Primary determinants of wastewater use were reliance on a single water source, cost-effectiveness, and productivity gains (Mainardis *et al.,* 2021). Negative media coverage reduced adoption, consistent with studies showing that controversial reports can amplify perceived risks (Hiruy

Table 5: Risk perception values (average) by gender and agricultural location

Health problems	Gender		P value	Agricultural locations				P value
	Male	Female		Nabi pur Virkan	Taragy wali	Wazira Virkan	Noor pur Virkan	
Eyes problem	1.28 (0.66)	1.25 (0.55)	0.906	1.26 (0.62)	1.47 (0.93)	1.18 (0.48)	1.42 (0.78)	0.563
Skin disease	3.28 (1.03)	3.52 (1.13)	0.292	3.28 (1.18)	3.16 (1.05)	3.32 (1.02)	3.62 (0.59)	0.289
Muscles problem	2.01 (1.15)	1.94 (1.15)	0.553	1.37 (0.73)	2.53 (1.12)	1.74 (1.16)	3.02 (1.05)	0.01***
Feet problems	1.55 (0.96)	1.64 (1.02)	0.384	1.22 (0.66)	1.76 (1.12)	1.37 (0.69)	2.32 (1.17)	0.001***
Abdominal problems	1.64[a] (0.95)[b]	1.79 (1.05)	0.409	1.79 (0.97)	1.47 (0.93)	1.63 (0.89)	1.89 (1.17)	0.179

Table 6: Overall health risk reduction score, broken down by gender and agricultural region, as suggested by the World Health Organization

Methods for lowering health hazard	Gender		P value	Agricultural locations				P value
	Male	Female		Nabi pur Virkan	Taragy wali	Wazira Virkan	Noor pur Virkan	
Risk management to people								
Shoes, gloves, and other forms of protective apparel	2.75 (1.02)	2.48 (1.08)	0.094	2.93 (0.86)	2.74 (1.02)	2.34 (1.19)	2.06 (1.18)	0.002**
Clean water and flush toilets	2.54 (1.07)	2.72 (1.08)	0.048*	2.61 (1.25)	2.43 (0.77)	2.68 (1.07)	1.89 (0.83)	0.010*
Deworming	1.82 (0.91)	1.71 (0.93)	0.321	1.69 (0.89)	2.05 (1.04)	1.91 (0.92)	1.49 (0.62)	0.064
Vaccination	1.56 (0.79)	1.47 (0.80)	0.312	1.54 (0.70)	1.74 (1.02)	1.53 (0.72)	1.12 (0.34)	0.021*
Initiatives to improve farmers' health	3.64 (0.74)	3.54 (0.82)	0.413	3.67 (0.78)	3.57 (0.84)	3.68 (0.54)	3.46 (0.77)	0.148
The use of crop restraints								
Crops that aren't eaten for nutrition	1.85 (1.11)	1.51 (0.89)	0.043*	2.44 (1.16)	1.12 (0.29)	1.37 (0.63)	1.19 (0.47)	0.001***
Growing food that can't be eaten raw	2.51 (1.22)	2.30 (1.11)	0.243	3.06 (1.10)	1.84 (1.03)	1.79 (0.97)	2.29 (0.94)	0.001***
Methods for utilizing water								
Better, safer techniques for irrigating	2.43 (1.15)	2.68 (1.19)	0.169	2.17 (1.12)	2.74 (1.14)	2.87 (1.17)	2.80 (1.12)	0.004**
Stopping irrigation before harvest	3.06 (1.05)	3.17 (1.08)	0.366	3. 21 (0.96)	3.28 (1.03)	3.07 (1.04)	2.49 (1.21)	0.013*
Wastewater treatment								
Traditional	1.38 (0.71)	1.41 (0.76)	0.936	1.14 (0.21)	1.79 (0.96)	1.53 (0.80)	1.20 (0.54)	0.001***
Minimal cost	2.02 (1.20)	1.39 (0.76)	0.952	1.63 (0.98)	2.28 (1.29)	2.72 (1.14)	2.01 (1.27)	0.001***

et al., 2022). Farmers identified solid waste, industrial effluents, and sewage as key contamination sources, with runoff and open defecation exacerbating water pollution (Leonel & Tonetti, 2021; Sohail *et al.,* 2021). Contamination constrained agricultural operations and raised concerns about crop diseases, although few farmers fully recognized consumer health impacts. Health risks differed between producers and consumers. Bacterial infections posed the greatest threat to consumers, while intestinal parasites were a primary concern for producers (Iqbal *et al.,* 2022a). Skin hazards were rated low, while musculoskeletal issues were significant among labor-intensive farmers, particularly older adults. Gender influenced risk perception and mitigation: women prioritized safe sanitation and water use, whereas men rated occupational risks higher (Hagenvoort *et al.,* 2019; Chojnacka *et al.,* 2020). Protective measures, such as health promotion programs, safe irrigation, and cessation of irrigation before harvest, were widely accepted, whereas conventional wastewater treatment was less applicable (Liu *et al.,* 2018). Economic considerations guided adoption of mitigation strategies. Non-food or cooked crops were preferred in Nabi Pur Virkan, facilitated by larger farm sizes, aligning with perceived economic benefits and risk reduction (Elahi *et al.,* 2017; Aljerf, 2018; Dare & Mohtar, 2018). Female farmers were less likely to cultivate non-food crops, reflecting household food security priorities. Musculoskeletal risks were higher among farmers performing intensive irrigation and fieldwork, highlighting occupational hazards over consumption-related risks. Overall, farmers' behavior reflects a balance between risk awareness, economic incentives, and socio-cultural factors. Health risks are acknowledged, but practical benefits, particularly water access and productivity, drive decision-making. Demographics, including gender, age, and education, modulate both risk perception and the adoption of protective measures, indicating the need for tailored, context-specific interventions.

Conclusions

Untreated wastewater irrigation is widespread in Sheikhupura and supports the city's agricultural economy, particularly vegetable production. However, it exposes farmers and consumers to microbial and helminth-related health risks. Survey results indicated that farmers rated consumption-related health hazards relatively low, highlighting a gap in awareness. Health risk mitigation measures, such as WHO-recommended health promotion programs and cessation of irrigation before harvest, were well-received. Crop restriction strategies growing non-food and non-raw-consumed crops were most applicable in Nabi Pur Virkan, likely due to larger farm sizes. Adoption of protective measures is influenced by economic considerations, including potential yield loss, capital requirements, and land availability, explaining why farmers often prioritize commercially beneficial interventions. Farmers continue to use untreated wastewater due to water scarcity, increased yields, reduced production costs, limited access to clean water, and improved soil fertility. The establishment or reinforcement of wastewater treatment facilities is essential, alongside targeted education to enhance farmers' understanding of water quality and public health responsibilities. Outreach through local media, informational pamphlets, and community gatherings

(Panchayats) can effectively communicate risks and promote safer irrigation practices. Well-designed incentives can maintain agricultural productivity while reducing health risks, benefiting farmers, consumers, and society.

Author contributions

Fahad Iftikhar Virk - conceptualization of the study, statistical analysis, interpretation of results, and preparation of the original draft manuscript. Ahmad Ali - survey studies, performed field visits to relevant research areas for data collection, and contributed to manuscript editing and critical revisions.

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