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Farmers' Safe Behavior of Using Wastewater for Irrigation: The Case of Northeast Iran

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Abstract

In countries facing physical water shortages, the safe use of treated wastewater can increase agricultural yields. However, farmers' willingness to reuse water in agriculture is very low. Therefore, the purpose of this study is to determine the factors that influence 217,215 Iranian farmers who use treated wastewater to adopt safe irrigation practices. This study, which developed the Theory of Planned Behavior (TPB) by including risk perception (RP) and knowledge factors, is a groundbreaking endeavor in the field of the safe use of treated wastewater at the farm level in Iran and around the world. The final model analysis was conducted based on structural equation modeling (SEM). The findings reveal that attitudes, perceived behavioral control (PBC), RP, and knowledge significantly influence farmers' behaviors regarding safe wastewater use, while subjective norms did not impact intentions. The subjective norm in this study includes the perceived social pressure by farmers (through family, friends, the farming community, and local authorities) to perform or not perform safe behavior in using treated wastewater for irrigation. Notably, PBC was the most important component in the original TPB model, because intention has a beneficial impact on behavior. In the extended model, knowledge and risk perception emerged as critical elements. Therefore, intervention policies should prioritize enhancing farmers' knowledge, risk perception, and perceived behavioral control to promote safe treated wastewater usage. This study offers valuable insights for developing countries in agricultural practices.

Keywords: knowledge; risk perception (RP); structural equation modeling (SEM); irrigation methods

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1. Introduction

Using treated wastewater in agriculture can ease pressure on water supplies and lessen the need for conventional fertilizers [1–3]. Approximately 30 million hectares of agricultural land worldwide are irrigated with untreated, partially treated, or diluted wastewater [4]. The control of pathogen threats was given top priority in the 2006 World Health Organization (WHO) guidelines for the use of wastewater and graywater in agriculture [5]. These guidelines, however, now place greater emphasis on nations where the safe use of wastewater in agriculture requires more than just wastewater treatment. To guarantee the safe use of wastewater in agriculture, they stress the necessity of extra non-treatment procedures or post-treatment practices [4,6].

In this context, the WHO [7] recommends the implementation of additional safety measures, both on and off the farm, in regions where conventional wastewater treatment methods may not be sufficient to ensure public health protection [4,6]. Taking a gradual and systematic approach can effectively mitigate health risks. It is important to acknowledge that the specific approach, encompassing treatment and post-treatment alternatives, should be tailored to the developmental circumstances of each country [6,8].

To comprehensively tackle the health risks linked to wastewater pollution in agriculture and elevate food safety standards, especially in developing and low-income nations with inadequate wastewater treatment infrastructure, it is imperative to broaden the scope beyond wastewater treatment alone. This approach is essential for mitigating the potential hazards associated with microbial contamination, chemical residues, and other pollutants in crops and soil, ultimately safeguarding public health and the quality of our food supply. It is imperative to implement additional measures aimed at mitigating the adverse effects of wastewater pollution [4,6,9]. In this regard, in cases where wastewater collection and treatment systems have limited reach and effectiveness, it becomes vital to prioritize altering farmer behavior to adopt measures that reduce risks on the farm. This is because wastewater treatment relies on institutional capabilities to maintain technical performance, while alternative approaches at the farm level necessitate changes in farmers' behavior [6]. For example, the risks associated with the use of wastewater in agricultural endeavors can be considerably reduced by making careful decisions when choosing suitable irrigation systems, adopting cropping patterns that are well suited, putting effective irrigation management techniques into place, and regularly monitoring the quality of the water, soil, and plants [4,9–12]. Therefore, relying solely on economic and social factors is insufficient when attempting to change farmers' behavior. Instead, focusing on psychological factors can also enhance farmers' responsibility, as these factors form the basis of farmers' decision making [13]. To effectively promote positive and sustainable behavioral changes among farmers at the farm level, such as the safe use of treated wastewater or food safety, it is essential to consider a strong understanding of farmers' psychology. This psychological understanding of farmers helps develop approaches that effectively influence farmers to adopt new practices and maintain them over time [4]. Therefore, it is crucial to carry out studies on the psychological aspects that affect farmers' actions with regard to the safe use of treated wastewater on farms. Accordingly, this study can contribute to enhancing the safety of irrigation water from treated municipal wastewater, particularly in low-income, developing countries, promoting the health of the irrigated crops. (In this study, "treated urban wastewater" refers to urban wastewater that has undergone treatment but cannot be employed indefinitely for irrigation due to the absence of advanced treatment facilities in developing and low-income countries.) Regional and national rules, such as those issued by the US Environmental Protection Agency and the World Health Organization, regulate water reuse methods worldwide [7]. However, implementation of these guidelines may vary across regions due to climatic, economic, and institutional disparities [14]. In Iran, water reuse policies face institutional and legal challenges. For example, the 1992 "Wastewater Effluent" standards set limits for BOD, heavy metals, and pathogens in reused water, but they lack enforcement mechanisms [15]. Additionally, the lack of coherence between different institutions has led to mismanagement in monitoring and allocating water resources. In other words, in Iran, the Ministry of Energy oversees water allocation, while the Environment Organization oversees quality—often leading to conflicting priorities [16].

Wastewater treatment is considered an alternative solution in many developing countries. However, a significant barrier to the safe use of wastewater for irrigation is the lack of proper wastewater treatment facilities [4]. Some studies (e.g., Vera-Puerto et al. [17]) identify the lack of adequate treatment facilities and high maintenance costs, especially in developing countries, as barriers to water reuse. In such a context, the World Health Organization [7] emphasizes non-treatment solutions (such as appropriate cropping patterns and safe irrigation methods) as a necessary complement, since improving the treatment infrastructure alone is often unrealistic, given financial and technical constraints. Therefore, the adoption of treated water reuse faces several challenges, including technical, economic, and behavioral challenges [18]. Health and environmental risks, such as pathogen contamination, heavy metal accumulation, and soil salinization, are also important challenges to the adoption of water reuse [14]. Moreover, farmers' distrust of water quality and operational barriers may create behavioral resistance to the adoption of treated water reuse [16]. In this regard, previous studies (e.g., Ahmmadi et al. [1]; De-Haqqi et al. [16]) have examined the acceptance of treated wastewater by farmers. Furthermore, Esfandiari et al. [19] believe that in the Mashhad metropolis, despite government regulations for the safe use of wastewater, many farmers do not comply with these regulations due to a lack of awareness of health consequences or to resource limitations (such as access to drip irrigation systems). This indicates that the determinants of safe practical behavior (such as observing the irrigation-to-harvest interval or choosing low-risk irrigation methods) among farmers have not yet been investigated. This research gap is critical, because even with farmers' positive intentions, the lack of technical knowledge or risk perception can lead to unsafe behaviors. These studies have investigated farmers' behavior from various perspectives when it comes to accepting treated urban wastewater. However, there is a limited amount of information available regarding the factors that influence farmers' safe behavior in using wastewater for irrigation. Therefore, the findings of this research will add new insights to the existing literature in this field. Research relies heavily on environmental psychology and related ideas, which provide important insights into human behavior [20]. One of the most effective psychological–social frameworks to forecast pro-environmental behavior among these theories is the Theory of Planned Behavior (TPB). TPB offers a thorough grasp of how people's attitudes, perceived behavioral control (PBC), and subjective norms (SNs) affect their intentions and subsequent conduct with regard to environmental issues. By examining these key factors, TPB enables researchers to make reliable predictions about individuals' likelihood of engaging in pro-environmental behaviors. The practical applicability and empirical support of TPB make it a practical tool in the study and promotion of sustainable behaviors [21,22].

The TPB has been effectively utilized by researchers to investigate and comprehend the determinants that impact individuals' behaviors within particular circumstances. For instance, Khan and Damalas [23] used TPB in a study to investigate the factors influencing people's wastewater treatment-related behaviors. Similarly, Zhang et al. [24] employed TPB to investigate the factors that determine people's environmental protection behaviors. These studies highlight the flexibility and effectiveness of TPB as a theoretical framework to analyze and predict various pro-environmental behaviors. In accordance with the TPB and theoretical foundations highlighting the influence of attitudes, PBC, social norms

(SNs), knowledge, and risk perception (RP) in the context of farmers' safe use of treated wastewater in agricultural settings, the current study has two primary goals. In the first stage, based on the classic TPB model, this study investigates the relationship between farmers' safe behavior and three key components of the theory: attitude, SNs, and PBC. In order to investigate the direct and indirect effects of attitude, PBC, and other influencing factors, such as RP and knowledge, on farmers' behavior in safely using treated wastewater, the study suggests an expanded model of TPB in the second stage.

2. Conceptual Framework

2.1. The Original Planned Behavior Theory (TPB)

The Theory of Planned Behavior (TPB), originally developed by Ajzen (1991) [25], is a foundational model in psychology that explains how individuals form behavioral intentions. A wide range of studies have applied the TPB model to examine behavior in agriculture and water resource management. These applications confirm the model's versatility and empirical strength in environmental contexts. In one study, Aliabadi et al. (2020) [26] investigated rural communities' willingness to adopt rainwater harvesting systems in Iran. Their findings revealed that factors such as moral obligation, attitude, and personal identity were significant in predicting the intention to use sustainable water management practices. The TPB framework explained 61 percent of the variance in behavioral intention, and its predictive power was stronger than that of the health belief model. Another example is the study by Zhang et al. (2023) [27], which focused on water usage behavior among college students in China. This research integrated TPB with demographic and environmental variables, confirming that behavior is shaped by a combination of personal beliefs and institutional influences. Their results showed that TPB remains a valid model even when adapted for younger populations and institutional settings. In the agricultural sector, Xu et al. (2024) [28] examined green agricultural production behaviors among ethnic farmers in China. Their study combined TPB with the Norm Activation Model to capture both cognitive and moral influences. They discovered that behavioral intentions were strongly influenced by attitude, perceived behavioral control, and subjective norms. Moreover, moral norms had a direct effect on actual behavior, while factors such as awareness of consequences and responsibility shaped intention through their impact on attitude and personal norms. Furthermore, Ding et al. (2020) [29] applied TPB to understand residents' acceptance of using desalinated water in coastal regions of China. The study concluded that the three main constructs of TPB all had significant and positive effects on behavioral intention. Additionally, they discovered that subjective norms could influence attitude, which highlights the interactive nature of these factors within the model. The findings under consideration show that the Theory of Planned Behavior offers a thorough and trustworthy framework to comprehend behavioral intentions pertaining to water management and sustainable agriculture. Researchers across diverse contexts have validated the model's core components and often extended it with additional constructs such as moral norms or self-identity. These modifications enhance the model's ability to reflect the complex realities of environmental decision making and behavioral change.

According to TPB, behavioral intention, which is the most immediate predictor of behavior, is influenced by three independent constructs. These constructs include the individual's attitude toward the behavior, their perception of social pressure known as subjective norms, and the degree to which they feel capable of performing the behavior, referred to as perceived behavioral control. The first construct is attitude. The term "attitude" describes how much a person views a particular conduct favorably or unfavorably, or how they assess the behavior in general. However, it is important to note that attitude alone cannot directly determine behavior; it exerts its influence indirectly through behavioral intentions [30]. For instance, if a rural resident believes that rainwater harvesting contributes to environmental sustainability, reduces costs, and ensures long-term water availability, this positive evaluation enhances their intention to adopt such behavior [26]. SN is another variable in this theory, representing the perceived social pressure or influence to engage or not engage in a behavior. It encompasses the perceived social pressure to conform to certain behaviors, including the influence of others' opinions. People's perceptions of how much other people accept or disapprove of their behavior are reflected in SN. For instance, if farmers believe that their community members or agricultural experts expect them to adopt environmentally friendly practices, they may be more inclined to align their behavior accordingly [28]. Perceived behavioral control (PBC), the third element, is a person's assessment of how simple or complex the behavior is to perform. This perception includes both internal factors like knowledge and skills, as well as external conditions such as financial or infrastructural support. When individuals believe that they have sufficient resources and capabilities to perform a behavior, they are more likely to form a strong intention, and this belief may even lead directly to action [23,31]. For example, when farmers perceive they have the necessary skills, resources, and institutional support, they are more likely to intend and act safely in using semi-treated wastewater for irrigation [32]. Building upon the TPB framework, our study posits the following hypotheses (Figure 1).

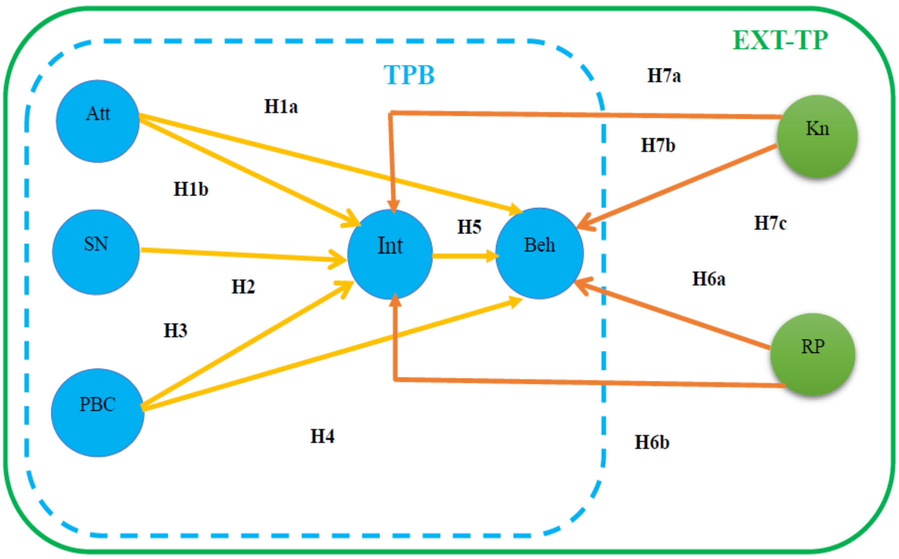

Figure 1. The study's theoretical foundation for the original and expanded Theory of Planned Behavior (TPB) is as follows: Attitude (Att), subjective norms (SNs), and perceived behavioral control (PBC) are important determinants of intention (Int) and behavior (Beh) in the original TPB. To improve the model's predictive ability in predicting farmers' safe use of treated wastewater for irrigation, the extended TPB model adds two more constructs: knowledge (Kn) and risk perception (RP).

H1: *Farmers' intentions to use wastewater properly are significantly and favorably influenced by their attitudes toward the safe use of treated wastewater.*

H2: *Farmers' intentions to handle treated wastewater correctly are positively and significantly impacted by their SNs regarding its safe usage.*

H3: *Farmers' intention to use treated wastewater responsibly is positively and significantly impacted by their PBC regarding its safe usage.*

H4: *Farmers' behavior in handling treated wastewater responsibly is positively and significantly impacted by their PBC regarding this topic.*

H5: *Farmers' conduct regarding the safe use of treated wastewater is positively and significantly impacted by their intentions toward this use.*

2.2. Extension of the TPB

Planned behavior models serve as valuable tools for comprehending human behavior and forecasting factors associated with intention. The fundamental model consists of three key elements: attitude, SNs, and PBC. Researchers have expanded this theory by integrating additional variables customized for specific subjects and target audiences, as demonstrated by studies such as [7,33]. Additionally, Maleksaeidi et al. [34] has proposed the inclusion of novel elements to enrich the theory further. Numerous scholars [14,18,22,33] have explored variables beyond the existing framework and argue that their incorporation can enhance the predictive capability of the model [35,36].

The TPB is a highly useful framework, but it does not incorporate the notion of RP, which is a fundamental element found in the health belief model (HBM) [37]. RP is concerned with a person's perception or comprehension of the probability, seriousness, consequences, and timeliness of a possible threat or danger. Studies have shown that RP influences individuals' intentions to engage in responsible and safe behaviors [38]. Perceptions of environmental dangers can improve pro-environmental behavior in the context of environmental protection, especially when it comes to the safe application of treated wastewater in agriculture. RP plays a vital role in incentivizing farmers to adopt precautionary measures that ensure the safety of human health and the environment [6,39].

In addition to RP, the incorporation of knowledge into the theoretical model of planned behavior has been found to significantly reduce the intention–behavior gap. Knowledge refers to precise and detailed information pertaining to a particular subject or behavior, and its positive impact on individuals' decision-making confidence has been well documented [22]. For example, research studies such as Mehmood et al. [40] and Mianaji [22] have shown that increasing farmers' knowledge about the adverse effects of pollution on food safety increases their willingness to adopt safe production practices. Nonetheless, it has been discovered that adding knowledge to the TPB model improves comprehension of a variety of actions and increases the model's prediction power [22,41,42]. Additionally, [6] emphasized the significance of knowledge as a key factor in promoting the safe utilization of treated wastewater in agricultural settings by farmers. According to the above, to offer a more all-encompassing elucidation of farmers' behavior, the principal framework of the TPB is enriched by integrating two variables, namely RP and knowledge. This amalgamation augments the theoretical construct's capacity to comprehend the multifaceted factors that shape farmers' decision-making processes. Hence, this study extends the TPB by introducing the following two hypotheses (Figure 1).

H6: *Farmers' behavior to use treated wastewater safely is significantly and favorably impacted by their RP over its safe usage.*

H7: *Farmers' conduct toward the safe use of treated wastewater is significantly and favorably impacted by their understanding of this topic.*

Taking into consideration earlier points, Figure 1 depicts the study's linkages and theoretical framework. Based on the original TPB, Hypotheses 1 through 5 aim to clarify the behavioral patterns of farmers. Two variables, RP and knowledge, are added to the TPB in this study to help farmers adopt safe practices while using treated wastewater. As a result, two hypotheses, namely Hypotheses 6 and 7, are developed using the extended TPB framework, with a specific emphasis on examining how these variables influence farmers' responsible use of treated wastewater.

3. Materials and Methods

3.1. Framework and Measures

The present study employed the conceptual model depicted in Figure 1 to explore the factors influencing farmers' safe use of treated wastewater (The abbreviations used throughout the study are listed in Appendix A, Table A1). Data collection was conducted using a questionnaire comprising two main sections. The first section of the questionnaire examined the characteristics of participating farmers and their fields. It gathered information regarding the demographics of the farmers and the status of their farms. The second section consisted of a series of designed questions aimed at measuring the main variables derived from the TPB. These questions were developed to assess and gauge the factors that influence farmers' safe use of treated wastewater. Table 1 presents the measurement items for the seven variables under study, along with their respective sources. Responses to each topic were measured using a 5-point Likert scale, which goes from "strongly disagree" to "strongly agree." To construct the measurement tool and evaluate the indicators, a preliminary survey and the set of questions underwent a review process by a group of experts prior to conducting interviews with farmers. The panel included professionals with expertise in agricultural economics, agricultural extension and education, water engineering, psychology, and social sciences. By incorporating their feedback and suggestions, we made appropriate modifications, which led to improvements in the questionnaire. Additionally, the phrase "safe use of treated wastewater by farmers at the farm level" in this study refers to how closely farmers follow suitable cultivation practices that match the quality of treated wastewater, use appropriate irrigation techniques, and observe the required interval between the last irrigation with treated wastewater and crop harvest.

Table 1. Concepts and variables for research measurement.

Construct	Measurement Items	Sources
Behavior (Beh)	1. I adjust my cultivation pattern based on the quality of the treated wastewater. 2. I employ an effective irrigation method to mitigate the pollution.	[19,43]
Intention (Int)	1. I have a desire to safely use treated wastewater in the future. 2. I am highly inclined to partake in a program that advocates for the responsible and secure use of treated wastewater. 3. I would like my farm to have better facilities for using treated wastewater safely.	[20,21,44]
Attitudes (Att)	1. I think there is a lot of value in making investments in the safe use of treated wastewater. 2. I believe it is essential to adhere to all necessary standards for the safe production with treated wastewater. 3. Even if it leads to an increase in my production costs, I am committed to using treated wastewater safely.	[21,44]
Perceived Behavioral Control (PBC)	1. I am fully capable of using treated wastewater safely. 2. I am well-versed in the appropriate procedures for the secure application of treated wastewater. 3. I have enough resources to guarantee that treated wastewater is used safely. 4. I am adept in using treated wastewater in a safe manner.	[20,21,44]

Table 1. *Cont.*

Construct	Measurement Items	Sources
Subjective Norms (SNs)	1. I am encouraged to use treated wastewater on the farm in a safe manner by the folks who are very important to me. 2. The safe use of treated wastewater on the farm is supported by my family and friends. 3. On the farm, my neighbors and I both think that treated wastewater must be used safely.	[20,21,44]
Risk Perception (RP)	1. I feel concerned and endangered by the environmental devastation caused by the unsafe use of treated wastewater. 2. I hold a firm conviction that the hazardous application of treated wastewater poses significant risks to both human health and the natural environment. 3. I personally know several farmers who have suffered from illnesses directly caused by the hazardous application of treated wastewater.	[20]
Knowledge (Kn)	1. I possess a more comprehensive understanding of environmental and health issues compared to other users of treated wastewater. 2. I have a deep understanding of the detrimental consequences of unsafe treated wastewater use on the health of farmers, consumers, and the environment. 3. I am capable of providing a clear explanation of the techniques for safely using treated wastewater and the advantages they bring.	[21,44]

3.2. Study Area

The study was carried out in Mashhad County, Khorasan Razavi province, in the northeastern Iranian region, which is the catchment area of the Kashafrud River (Figure 2). The water supply in this area relies on both underground and surface sources; however, the available resources are insufficient to meet the drinking water and agricultural needs. Over the past few years, the region has been facing water scarcity issues. According to the most recent statistics published by the Regional Agricultural Office in 2021, Mashhad County, with its vast agricultural land covering an area of 56,536 ha (comprising 46,771 ha of irrigated land and 9765 ha of rain-fed land), holds significant potential for the use of water and soil resources [31]. It is recognized as an important agricultural hub within the Khorasan Razavi province. Despite the presence of 1097 deep and semi-deep wells, 351 springs, 326 qanats, and three dams, water scarcity remains a challenge [32]. In response to the water shortage, many peri-urban farmers in the area resort to using treated municipal wastewater, both officially and unofficially. However, due to its limited quality, treated wastewater cannot be used indefinitely. As a result, relevant authorities, including the province's Khorasan Razavi Department of Environment and the Khorasan Razavi Regional Water Company, have placed restrictions on the use of treated wastewater. Farmers that violate the rules set forth by the government for the safe use of treated wastewater on farms risk fines. Farmers are obligated to adhere to specific cropping patterns and irrigation methods that align with the quality of the treated wastewater. Nevertheless, these restrictions impose additional costs on farmers, limiting their ability to cultivate their desired crops. Consequently, some farmers may be reluctant to comply with these regulations.

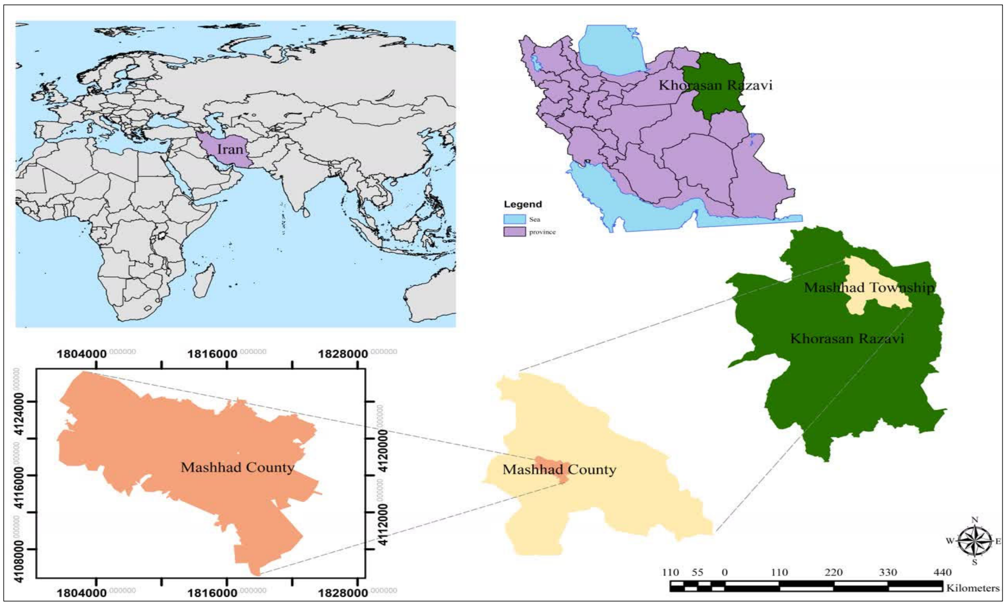

Figure 2. The geographical position of the study area within Razavi Khorasan province, Iran.

3.3. Statistical Population and Sampling Method

The statistical population in this study consists of members of agricultural cooperatives in Mashhad County who utilize treated municipal wastewater for irrigation. A simple random sampling method was employed, and a sample of 215 farmers was selected based on the Karjesi and Morgan table [45]. Table 2 presents the demographic characteristics of the farmers. According to age distribution, 25.581% of the farmers were below 30 years old, 55.348% fell within the age range of 30 to 50, and 19.069% were older than 50. Regarding educational attainment, 23.25% of the participants were unable to read or write, 48.37% had completed primary education, 24.65% had completed secondary education, and a small proportion (3.72%) had obtained a university degree.

Table 2. Age and educational attainment distribution of the studied farmers in Mashhad County who used treated municipal wastewater.

Variable	Category	Frequency	Percentage
Age	Lower than 30	55	25.58
	From 30 to 50	119	55.35
	More than 50	41	19.07
	Sum	215	100
Education	Illiterate	50	23.26
	Elementary	104	48.37
	High school	53	24.65
	College education	8	3.72
	Sum	215	100

3.4. Model

This study looks at how farmers' intentions and actions regarding the safe use of treated municipal wastewater for irrigation are influenced by variables taken from the Theory of Planned Behavior (TPB) and its extensions, such as risk perception (RP) and knowledge (Kn). Due to the latent and subjective characteristics of these psychological constructs, structural equation modeling (SEM) was selected as a suitable analytical technique to capture complex relationships between unobservable variables and their observed indicators. The analysis was conducted using SmartPLS, a variance-based SEM software particularly well suited for predictive modeling and exploratory research in the social sciences.

3.4.1. Model Development Procedure

The development of the SEM followed a systematic and structured approach to ensure both conceptual soundness and statistical rigor:

1. Definition of Latent and Observed Variables:

Based on accepted theoretical frameworks and pertinent research, seven latent dimensions were identified: attitude (Att), subjective norms (SNs), perceived behavioral control (PBC), risk perception (RP), knowledge (Kn), intention (Int), and behavior (Beh). These constructs were operationalized through observed variables derived from validated survey items, each measured on a Likert scale with five points.

2. Specification of the Measurement Model:

The measurement model defined the relationships between each latent construct and its corresponding indicators. The items for each construct were adapted from previous studies and underwent validation through expert evaluation and pilot testing. To ensure reliability and content validity, each construct included at least three reflective indicators. These relationships are expressed mathematically in Equations (2) and (3).

3. Specification of the Structural Model:

The proposed causal connections between the latent constructs were delineated by the structural model. Consistent with the extended TPB framework, it was hypothesized that attitude, perceived behavioral control, risk perception, and knowledge would exert a positive influence on farmers' safe behavioral practices, either directly or indirectly through the mediating role of intention. These relationships are formalized in Equation (1) and visually depicted in the conceptual path diagram.

4. Model Estimation and Validation:

Model estimation was carried out employing the Partial Least Squares (PLS) algorithm within the SmartPLS environment. Standard assessment metrics, such as factor loadings, composite reliability, average variance extracted (AVE), Cronbach's alpha, and discriminant validity based on the Fornell–Larcker criterion, were used to evaluate the model's quality. Additionally, path coefficients, significance levels obtained via bootstrapping, and R^2 values were used to assess the structural model's capacity for explanation.

Measurement equations and a structural equation make up the SEM framework. The link between endogenous and exogenous latent variables is described by the structural equation (Equation (1)) [46]:

$$\eta = B \cdot \eta + \Gamma \cdot \xi + \zeta \quad (1)$$

The matrix of coefficients Γ measures the impact of internal factors on exogenous variables, while B reflects the connection between the endogenous variables, and ζ represents the error term in SEM. The equations for measurement establish links between observable and potential variables. Equation (2) represents the vector of endogenous indicators (Y), connecting measurable variables (Y) to latent variables (η). ΛV is the factor loading matrix, and ε is the measuring error term associated with Y [46].

$$Y = \Lambda V \cdot \eta + \varepsilon \quad (2)$$

Equation (3) pertains to the vector of external indicators (X), signifying quantifiable variables (X) of the latent variables (ξ). ΛX is the factor loading matrix, and δ is the measuring error term associated with X [46].

$$X = \Lambda X \cdot \xi + \delta \tag{3}$$

SEM allows researchers to analyze and model relationships between latent and observable variables, enhancing the understanding of complex constructs like behavior [42].

3.4.2. Underlying Assumptions of SEM

The application of structural equation modeling (SEM) is grounded in a set of foundational statistical and methodological assumptions that must be satisfied to ensure the validity of the analytical outcomes. Among these, normality presumes that observed variables follow a multivariate normal distribution, while linearity assumes that the relationships among both observed and latent variables are linear in nature. Ensuring an adequate sample size is also essential, as SEM requires a sufficient number of observations relative to the number of estimated parameters to yield stable and interpretable estimates. Furthermore, the absence of multicollinearity is critical; variables should be sufficiently distinct to prevent inflated variances and distorted results. Lastly, model identification must be achieved, meaning that the model must have enough information to allow for the estimation of all parameters. Typically, this involves specifying a sufficient number of indicators per latent variable and ensuring positive degrees of freedom. Collectively, these assumptions form the analytical framework that underpins SEM, enabling the examination of complex relationships between latent constructs and their observable indicators in a statistically rigorous manner.

4. Results

4.1. Model of Measurement

Before estimating the structural model, confirmatory factor analysis (CFA) was performed using the measurement model to investigate the link between the set of observed variables and the latent hypothetical variables. The measuring model validated the fit between the TPB and expanded TPB models. The t-values in Table 3 indicate that the factor loadings (λ) were statistically significant for both models' observed variables. This suggests that the chosen observed variables effectively measure the latent variables. The data robustness was confirmed through the evaluation of the latent variables' convergent validity and reliability in both models, as indicated in Table 4. The values of composite reliability in both models exceed the recommended threshold of 0.7 by Fishbein et al. [47], ranging from 0.835 to 0.903. Furthermore, all constructs in both models had average variance extracted (AVE) values above 0.613, which is within the range suggested by Liu et al. [48]. Both models' Cronbach alpha values fall between 0.706 and 0.810, supporting the criterion (above 0.5) that [49] suggested. Table 5 presents the extracted average variance extracted (AVE) values for the latent variables, and it is notable that these AVEs exceed their respective correlations. This observation aligns with the criteria proposed by Hameed et al. [50] and provides support for the discriminant validity of the study's structure in both models. Therefore, the measurement model analysis's findings verify that the latent variables are effectively assessed by the observable variables. Additionally, the confirmed reliability and validity of the data underscore the sufficiency and resilience of both the TPB and extended TPB models.

Table 3. Standardized factor loadings (λ) and t-values from confirmatory factor analysis (CFA) for constructs in the original and extended TPB models; all observed indicators show statistically significant loadings, confirming good measurement validity.

		Original TPB		Extended TPB	
Constructs	**Measurement Item**	ƛ	**t**	ƛ	**t**
Attitude (Att)	Att1	0.854	34.161	0.848	32.804
	Att2	0.804	23.606	0.802	24.589
	Att3	0.786	26.833	0.793	27.917
Perceived behavioral control (PBC)	PBC1	0.870	54.470	0.852	54.882
	PBC2	0.620	8.576	0.832	27.877
	PBC3	0.803	25.161	0.814	19.685
Subjective norms (SNs)	SN1	0.796	26.824	0.854	22.543
	SN2	0.787	23.234	0.754	19.570
	SN3	0.856	38.861	0.770	22.543
Risk perception (RP)	RP1	.....	.....	0.835	29.868
	RP2	.....	.....	0.813	27.339
	RP3	.....	.....	0.824	31.592
Knowledge (Kn)	Kn1	.....	.....	0.837	36.212
	Kn2	.....	.....	0.839	26.760
	Kn3	.....	.....	0.845	30.942
Intention (Int)	Int1	0.769	16.062	0.772	17.386
	Int2	0.847	49.249	0.842	45.949
	Int3	0.837	35.720	0.839	36.523
Behavior (Beh)	Beh1	0.909	75.489	0.905	61.103
	Beh2	0.906	56.183	0.910	69.971

Table 4. Latent constructs' convergent validity and reliability in the original and expanded TPB models: composite reliability (CR), average variance extracted (AVE), and Cronbach's alpha all meet recommended thresholds.

		Original TPB			Extended TPB		
			Convergent Validity			Convergent Validity	
Constructs	**Measurement Item**	**Cronbach's** α	**Composite Reliability**	**AVE**	**Cronbach's** α	**Composite Reliability**	**AVE**
Attitude (Att)	Att1	0.747	0.856	0.664	0.747	0.856	0.664
	Att2						
	Att3						
Perceived behavioral control (PBC)	PBC1	0.680	0.812	0.595	0.791	0.872	0.693
	PBC2						
	PBC3						
Subjective norms (SNs)	SN1	0.746	0.855	0.662	0.706	0.836	0.630
	SN2						
	SN3						
	PBC4						

Table 4. *Cont.*

Constructs	Measurement Item	Original TPB			Extended TPB		
		Cronbach's α	Convergent Validity		Cronbach's α	Convergent Validity	
			Composite Reliability	AVE		Composite Reliability	AVE
Risk perception (RP)	RP1	.....	.....	.....	0.764	0.864	0.679
	RP2						
	RP3						
Knowledge (Kn)	Kn1	.....	.....	.....	0.792	0.878	0.706
	Kn2						
	Kn3						
Intention (Int)	Int1	0.754	0.858	0.670	0.754	0.859	0.670
	Int2						
	Int3						
	Int4						
Behavior (Beh)	Beh1	0.786	0.903	0.824	0.786	0.903	0.824
	Beh2						

Table 5. Discriminant validity assessment of TPB constructs using the Fornell–Larcker criterion; square roots of AVE exceed inter-construct correlations, confirming discriminant validity.

Constructs	(Att)	(PBC)	(SNs)	(Int)	(RP)	(Kn)	(Beh)
1. Attitude (Att)	0.815						
2. Perceived behavioral control (PBC)	0.502	0.833					
3. Subjective norms (SNs)	0.764	0.551	0.794				
4. Intention (Int)	0.673	0.696	0.647	0.818			
5. Risk perception (RP)	0.741	0.616	0.744	0.731	0.824		
6. Knowledge (Kn)	0.672	0.711	0.657	0.750	0.739	0.840	
7. Behavior (Beh)	0.685	0.655	0.678	0.719	0.731	0.770	0.908

4.2. Structural Model

Following confirmation of the measurement models' accuracy, the original and extended TPB structural models were utilized to test the research hypotheses.

4.3. Original TPB Model

In this phase of the investigation, SEM was utilized to analyze the connections between latent variables and assess the proposed hypotheses. The outcomes of the analysis indicated that the three variables, namely Att, PBC, SNs and intention, collectively explain 57.2% of the variance in farmers' behavior in using cleaned wastewater safely (as depicted in Figure 3). The path coefficients along with their corresponding p-values are presented in Table 6 and Figure 3. The three variables were shown to have a substantial positive structural link based on the derived coefficients, Att (β = 0.316, $p < 0.01$), PBC (β = 0.415, $p < 0.01$), and SNs (β = 0.188, $p < 0.05$), with farmers' intention to safely use treated wastewater. Also, the variable effect of PBC (β = 0.370, $p < 0.01$) and intention (β = 0.370, $p < 0.01$) on farmers' behavior in the safe use of treated wastewater was positive and significant. Therefore, the information contained in the original structural model of TPB corroborates the suppositions of H1, H2, H3, H4, and H5. Notably, the variables PBC, Att, and SN have been identified as the most consequential factors, respectively, as indicated in Table 6 and Figure 3.

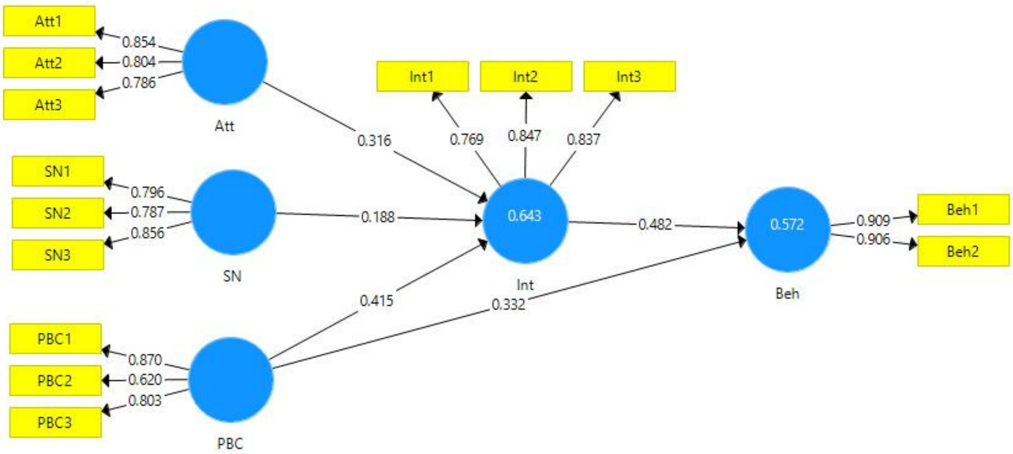

Figure 3. The initial TPB model's structural path coefficients showed that farmers' intentions are strongly influenced by their attitudes, perceived behavioral control, and subjective standards, whereas safe conduct is predicted by intention and PBC (R^2 = 57.2%).

Table 6. Hypothesis testing results for the original TPB model using SEM: all five hypotheses supported; the best indicators of safe behavior are intention and perceived behavioral control (R^2 = 57.2%).

Hypotheses	Hypotheses Paths	Path Coefficients	*p* Value	Supported
H1	Att → Int	0.316	0.000	Yes
H2	SN → Int	0.188	0.011	Yes
H3	PBC → Int	0.415	0.000	Yes
H4	PBC → Beh	0.332	0.000	Yes
H5	Int → Beh	0.482	0.000	Yes

4.4. Extended TPB Model

The structural model's conclusions analysis conducted on the extended TPB is presented visually in Figure 4 and outlined in a concise manner in Table 7. The extended version of the TPB includes two additional variables, RP and Kn, in addition to the primary components of the TPB. The extended model accounted for the overall impact as well, including both direct and indirect effects of Att, PBC, RP, and Kn influencing the safe behavior of using treated wastewater. The research findings reveal that the inclusion of these variables in the extended TPB model explains the difference of 68.5% in farmers' practices in using treated wastewater safely. This finding highlights a significant enhancement in the model's capacity for prediction when it comes to elucidating the behavior of farmers. It is particularly noteworthy that the results indicate that a greater extent of variance in behavior can be accounted for by incorporating two additional variables, surpassing the original TPB model's capacity to explain (Figure 4). Additionally, the findings emphasize that the total effects (direct effects and indirect effects) of Att and PBC on behavior showed statistical significance, with values of 0.200 and 0.167, respectively (each $p < 0.01$) (refer to Table 7). In the extended TPB model, the Att variables and PBC manifest a noteworthy and affirmative correlation with the farmers' behavior toward using cleaned wastewater safely. However, the SN variable was found to be statistically insignificant (Table 7). The total effects, which encompass both direct and indirect impacts, of Kn and RP on behavior exhibited statistically significant values of 0.515 and 0.213, respectively ($p < 0.01$). This statistical evidence lends empirical support to hypotheses 6 and 7, as illustrated in Table 7. This observation highlights a strong and significant correlation between the factors mentioned above and farmers' willingness to use treated wastewater in a safe manner. Additionally, the study's findings showed that the extended TPB model emphasized the Kn variable's noteworthy significance in relation to other factors. (Table 7).

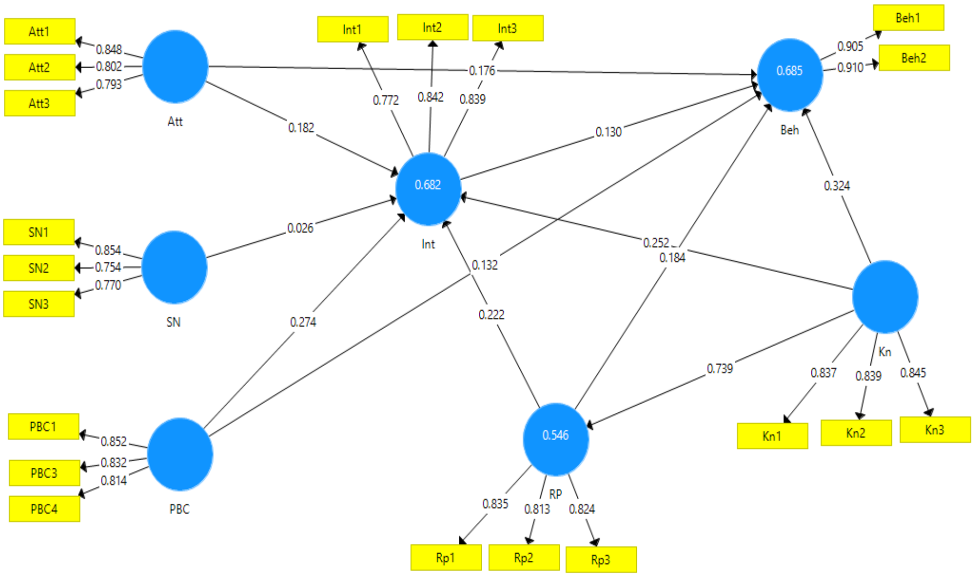

Figure 4. Structural path coefficients in the extended TPB model: knowledge and risk perception significantly strengthen the prediction of farmers' safe behavior; the model explains 68.5% of behavioral variance.

Table 7. Total effects (direct + indirect) of TPB and extended variables on farmers' safe behavior based on SEM: knowledge and risk perception are the most influential predictors; subjective norms are not significant.

Hypotheses	Hypotheses Paths	Original Sample	Standard Deviation	T Statistic	*p* Value	Supported
H1	Att → Beh	0.200	0.058	3.445	0.001	Yes
H2	PBC → Beh	0.167	0.059	2.830	0.005	Yes
H3	SN → Beh	0.003	0.011	0.302	0.763	No
H4	RP → Beh	0.213	0.078	2.729	0.007	Yes
H5	Kn → Beh	0.515	0.063	8.116	0.000	Yes
H6	Int → Beh	0.130	0.065	1.992	0.047	Yes

5. Discussion

This study aimed to develop a comprehensive psychosocial model to analyze the factors contributing to farmers' behavior in using treated municipal wastewater safely. The SEM results show that Att, PBC, SN, and intention can predict 57.2% of farmers' behavior toward treated wastewater use. The study conducted by Mullan et al. [38] suggests that one or more structures of the TPB alone may not be sufficient to fully predict intention and behavior. Although factors like Att, SN, and PBC are significant, the findings indicate that incorporating RP and Kn improves the model's explanatory power. Furthermore, the study reveals that both RP and Kn have a positive influence on farmers' intentions and behaviors toward the safe use of treated wastewater. These results are consistent with previous studies conducted by Lahlou et al. [51] and Arbuckle et al. [13].

According to both the original and extended TPB models (refer to Figures 3 and 4), the present study has demonstrated a significant relationship between Att and both intention and actual behavior among farmers in their adherence to safe practices concerning the use of treated wastewater. This finding aligns with the research conducted by Khanpae et al. [52] and Khan and Damalas [23]. It can be inferred that when farmers hold a favorable attitude toward the implementation of safe treated wastewater use practices, it inherently signifies a heightened cognitive readiness to actively participate in such practices. As a result, they demonstrate a stronger propensity to adopt treated wastewater safe use approaches, recognizing them as beneficial, valuable, and logical behaviors. Hence, farmers who possess a positive outlook toward safe production tend to be better equipped to engage in treated wastewater safe use behaviors. Therefore, it is essential to reinforce farmers' positive beliefs regarding the secure irrigation using wastewater that has been treated.

The study's conclusions showed that PBC, as included in both the original and extended TBP models, exerts a significant impact on farmers' intention and behavior. This result supports the conclusions drawn in earlier studies, including those conducted by Khanpae et al. [52]. Also, these findings are consistent with the study by Mianaji [22], which identified PBC as a significant predictor of intentions in various food safety practices. The level of adherence to safety practices is directly influenced by the ease or difficulty associated with performing a behavior. Therefore, when farmers face constraints due to inadequate abilities or resources and perceive significant barriers to implementation, their engagement in safe treated wastewater use practices is less likely [13]. In the initial structural model of the TPB, it is demonstrated that PBC has the highest level of significance in terms of forecasting the intention and behavior of the safe use of treated wastewater. A potential rationale could be that the successful adoption of safe treated wastewater utilization practices necessitates farmers' capabilities, ample resources, and expertise in various aspects. These encompass choosing appropriate cultivation patterns that align with treated wastewater quality, employing suitable irrigation techniques with treated wastewater, and managing the time gap between the final irrigation and harvest. Hence, farmers who possess greater resources and skills in this context are more inclined to exhibit a stronger behavioral intention to adopt safe practices in treated wastewater use. Therefore, a pivotal prerequisite to improve farmers' safe behavior in treated wastewater use is to enhance their perceived control over their actions. This can be achieved by facilitating and providing the necessary prerequisites, resources, and infrastructure to implement safe methods of utilizing treated wastewater.

In its original form, the TPB model identified a positive correlation between SNs and farmers' intention to adopt safe practices for the use of treated wastewater. This result is consistent with previous research by Hosney et al. [18] and Burusnukul [53], which focused on promoting behaviors to ensure food safety. However, SN was found to be the least influential predictor of intention in the TPB model, consistent with [33]'s findings. One explanation for this is the lack of sufficient sensitivity or understanding of safe production among Iranian farmers. Safe treated wastewater use is not perceived as a strong social norm, and there is a lack of social pressure from reference groups to participate in safe practices. Additionally, the absence of specific standards and regulations, such as Good Agricultural Practices, contributes to the weaker influence of SNs.

Subjective norms (SNs) are thought to have a major impact on behavioral intention in the original Theory of Planned Behavior (TPB) framework. However, in this study's enhanced TPB model, which integrates knowledge (Kn) and risk perception (RP), SNs were found to have no statistically significant effect on intention. This finding aligns with previous research (e.g., Mianaji [22]), suggesting that in contexts where individual cognitive factors such as knowledge and risk awareness are highly salient, social influences may become less predictive of behavioral intentions. One plausible explanation is that in the study area, safe treated wastewater use has not yet evolved into a socially normative behavior. As such, farmers' decisions are likely driven more by internalized knowledge and personal risk assessments than by external social pressures. Furthermore, from a statistical standpoint, the strong explanatory power of Kn and RP may have suppressed the effect of SN, a phenomenon often observed when new predictors overlap conceptually with the existing constructs. These results emphasize that in the context of safe wastewater use, strengthening farmers' knowledge and risk awareness may be more effective than relying on normative social influence to drive behavioral change.

The results of hypothesis test 6 uncovered a significant and positive link between farmers' RP and their intention to use treated wastewater safely as well as their behavior in doing so. This result is consistent with previous studies conducted by Li et al. [37] and Arbuckle et al. [13], all of which emphasize the role of RP in shaping farmers' behavioral intentions. Research has indicated that farmers who are well-informed about the detrimental consequences of unsafe practices on the health of agricultural products are more likely to adopt safety behavior [3]. Therefore, farmers are more inclined to adopt safer practices when they believe that a certain behavior, such as the unsafe use of treated wastewater, carries a higher amount of risk.

The results presented in Figure 4 provide compelling evidence supporting Hypothesis 7, which suggests a significant positive association between Kn and farmers' behavior toward using cleaned wastewater safely. In the extended TPB model, knowledge (Kn) emerges as the most influential variable in predicting farmers' behavior toward the safe use of treated wastewater, surpassing the effects of attitudes (Atts), perceived behavioral control (PBC), risk perception (RP), and subjective norms (SNs). This finding underscores the pivotal role of farmers' understanding of safe wastewater use practices—encompassing appropriate cultivation patterns, irrigation techniques, and timing of irrigation relative to crop harvest—in driving sustainable agricultural behaviors in Mashhad, Iran. The dominance of Kn aligns with prior studies, such as Rezaei et al. [21] and Wang and Lin [44], which demonstrate that knowledge about safe agricultural practices enhances farmers' confidence and motivation to adopt such behaviors. In the context of Mashhad, where water scarcity necessitates reliance on treated wastewater [54], farmers' Kn about the health and environmental implications of unsafe practices, as well as the technical requirements for safe irrigation, are critical drivers of decision making. The regulatory restrictions enforced by the Department of Environment and the Khorasan Razavi Regional Water Company, which is especially pertinent [17], mandate specific cropping patterns and irrigation methods aligned with wastewater quality.

Theoretically, Kn's prominence can be attributed to its role in bridging the intention–behavior gap, a key challenge in behavioral models [22,41]. Kn enhances farmers' cognitive readiness and self-efficacy, enabling them to translate intentions into actionable behaviors. For instance, farmers with comprehensive Kn about the adverse effects of unsafe wastewater use are better equipped to implement precautionary measures, such as selecting crops compatible with wastewater standards or adhering to recommended irrigation schedules [6]. This aligns with Li et al. [42], who found that knowledge significantly strengthens behavioral intentions in contexts involving environmental and health risks. In Mashhad, Kn likely amplifies the effects of PBC by providing farmers with the technical expertise to overcome barriers such as resource limitations or regulatory complexities [6].

Contextually, Kn's dominance reflects the unique socioeconomic and environmental challenges of Mashhad's Kashafrud River catchment, where limited water resources and regulatory pressures prioritize informed decision making [54]. Unlike Att or PBC, which rely on psychological predispositions or resource availability, Kn directly addresses informational deficits that hinder safe wastewater use. Farmers with greater Kn are better positioned to navigate regulatory requirements and mitigate the risks of microbial contamination or chemical residues, as supported by Moradnezhadi et al. [9]. This is critical in

Mashhad, where non-compliance with regulations can lead to penalties, and the costs of safe practices may deter farmers without adequate knowledge [17]. The study's findings suggest that Kn empowers farmers to act responsibly, reducing reliance on less salient factors like SN, which was found insignificant in the extended model [22].

Research Limitations

There are certain limitations in the study that should be taken into account. Firstly, because of Mashhad's distinct geographic, cultural, and socioeconomic features, the results might not be generalizable to other areas. Generalizing the results without accounting for specific conditions in different regions should be done cautiously. Secondly, the study may not cover all factors influencing farmers' safe behavior when using treated wastewater for irrigation. There are numerous associated variables that pose a challenge when it comes to comprehensive addressing. Lastly, the limited time frame and available resources could have impacted data collection and analysis, potentially limiting the depth and breadth of the study's findings. To overcome these limitations, future research should take a broader geographical approach, use diverse methodologies, and conduct long-term evaluations to better understand farmers' safe behavior in irrigating with purified wastewater. To look into methods for farmers to safely use treated wastewater for irrigation, this study included two new variables (Kn and RP) in the TPB model. To advance approaches aimed at changing farmers' behavior toward the safe use of treated wastewater for irrigation and explore other related research areas, future studies can investigate the role of nudges on farmers' intentions or behavior regarding the safe use of irrigation with treated wastewater. This expansion of scope will provide a broader perspective and deeper insights into the research problem. Nudges are intervention techniques designed to persuade farmers to safely use treated wastewater for irrigation while evading strict laws. Researchers can gain valuable insights through effectively guiding farmers toward the safe use of wastewater by employing various types of nudges, such as informative and normative nudges. This approach will contribute to a deeper understanding of the research problem. In addition, interventions can include educational approaches (e.g., the role of cooperatives), structural interventions (such as government regulations), or a combination of both. By evaluating and comparing the results of different methods, researchers can identify the strengths, weaknesses, and limitations of each approach. This comparative study will help future researchers choose the best methodology for their research by offering insightful information about the suitability and applicability of different interventions in the particular context of farmers safely using treated wastewater for irrigation.

6. Conclusions

The TPB model is being used in this groundbreaking project in Iran to forecast farmers' behavior regarding the safe use of treated wastewater at the farm level. The results achieved by employing SEM have effectively demonstrated the applicability of the TPB model in explaining the behavior of farmers in a developing country, Iran, when it comes to adopting safe practices for using treated wastewater on their farms. Furthermore, the findings validate the suitability and expansion of the TPB model, as the incorporation of the constructs Kn and RP amplifies the explanatory ability and resilience of the proposed framework in forecasting farmers' behavior. This study's findings hold significant practical implications for policymakers, agricultural extension services, and farmers alike. To improve treated wastewater's safe application in agriculture, we recommend policymakers establish robust regulatory frameworks, provide financial incentives, and invest in educational campaigns. Agricultural extension services can offer training and technical support to farmers, while farmers themselves should adopt best practices, invest in wastewater treatment infrastructure, and regularly monitor water quality. Implementing these recommendations can collectively promote safer and more sustainable agricultural practices, especially in regions where treated wastewater is a crucial resource for crop production.

Policy Recommendations

Overcoming the challenges of water reuse requires a multi-pronged approach—one that integrates technology, governance, economic incentives, and behavioral change. Therefore, it is recommended to remove technological and infrastructure barriers and develop decentralized treatment systems such as modular and solar-powered treatment units for rural areas to reduce the dependence on centralized treatment plants. In addition, smart health monitoring can be implemented using IoT sensors to detect pathogens/chemicals in recycled water in real time. Subsidized financing such as low-interest loans can also address the economic and policy challenges for treatment infrastructure with water reuse objectives. To overcome behavioral resistance to accepting water reuse, participatory training among farmers, such as holding farm days, can increase farmers' willingness to test water quality and crop yield. Based on the results, the present study offers four practical suggestions. Firstly, considering the role of farmers' Kn in adopting supplementary actions for safe treated wastewater use, this study recommends the following strategies to increase farmers' Kn in safe treated wastewater use at the farm level: (1) organizing training courses to enhance farmers' awareness of the safe use of treated wastewater, (2) preparing and distributing informational resources such as brochures and videos in simple and understandable language for farmers, and (3) establishing information exchange networks and agricultural groups to share experiences and collective knowledge in safe treated wastewater use. Secondly, considering the significance of PBC, policymakers are suggested to strive toward increasing the financial and skill capacity of farmers to facilitate the provision of prerequisites, resources, and necessary infrastructure for safe treated wastewater use at the farm level. For instance, providing financial assistance for adopting appropriate cropping patterns compatible with treated wastewater quality and purchasing managed irrigation systems can make the necessary resources available to farmers for safe treated wastewater use. Lastly, this study recommends using the capacities of international organizations in Iran, such as the WHO, FAO, and the United Nations, to enhance farmers' Kn, financial capacity, and skills in implementing safe practices of treated wastewater use at the farm level. Policy makers in Iran's agriculture sector can collaborate with international organizations like WHO, UN, and FAO to promote farmers' Kn, financial capacity, and skills in safe treated wastewater use at the farm level. To this end, they can establish contact and initiate collaboration and coordination with relevant units of these organizations in Iran to commence efforts on treated wastewater safety in agriculture. Additionally, studying the materials and guidelines published by these organizations and using their educational and financial resources and programs can be instrumental in achieving the goal. This study proposes a suitable tool both theoretically and managerially for the production of safe agriculture, especially the additional steps taken by farmers to ensure that treated wastewater is used safely for irrigation.

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Appendix A

Table A1. Comprehensive list of abbreviations and their definitions used throughout the TPB-based behavioral study on treated wastewater use.

Abbreviation	Full Term	Description
TPB	Theory of Planned Behavior	A psychological theory explaining behavior through attitude, norms, and control.
Att	Attitude	Farmers' positive or negative evaluation of safe wastewater use.
SNs	Subjective norms	Perceived social pressure to use treated wastewater safely.
PBC	Perceived behavioral control	Farmers' perception of their ability to perform safe wastewater use.
RP	Risk perception	Farmers' understanding of the health/environmental risks of unsafe practices.
Kn	Knowledge	Farmers' awareness and understanding of safe wastewater practices.
Int	Intention	Farmers' motivation or plan to use treated wastewater safely.
Beh	Behavior	Actual practice of using treated wastewater safely.
SEM	Structural equation modeling	Statistical method used to evaluate relationships among latent variables.
CFA	Confirmatory factor analysis	Technique to assess the validity of measurement models.
AVE	Average variance extracted	Indicator of convergent validity of constructs.
CR	Composite reliability	Reliability measure for the internal consistency of constructs.

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