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Need to educate farmers about the benefits of using treated wastewater for agriculture

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ABSTRACT

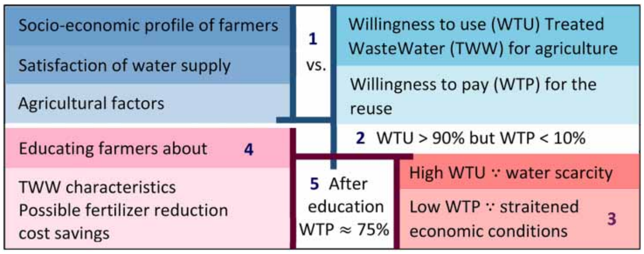
Treated wastewater (TWW) reuse is one of the strategic options for preserving available freshwater resources and ensuring sustainability. The success of any utility project is centered on public acceptance and utilization. A questionnaire is randomly distributed to 397 farmers to study the willingness to use TWW reuse for agriculture and pay for the reuse. The socio-economic profile of the farmers, satisfaction of water supply, and agricultural factors are considered as the influential parameters. Descriptive analysis, χ^2 test, Mann–Whitney *U* test, and binary logistic method are used for statistical analysis. The analyses reveal that more than 90% of the farmers have willingness to use TWW due to water scarcity. However, most of them are unwilling to pay for the reuse due to their straitened economic conditions. The physicochemical characteristics of the TWW from a wastewater treatment plant are analyzed and possible reductions in the application of fertilizer quantity and cost are quantified. An attempt to improve the percentage of willingness to pay for the TWW reuse is made by detailing the economic benefits of TWW reuse. A significant percentage of the farmers who were initially opposed to paying for the TWW reuse have budged to pay for TWW at a subsidized cost.

Key words: Agriculture, Farmer, Treated wastewater reuse, Water reuse, Willingness to pay, Willingness to use

HIGHLIGHTS

- Farmers' perceptions towards treated wastewater (TWW) reuse for sustainable agriculture purposes are explored.
- Farmers' Willingness To Use (WTU) and Willingness To Pay (WTP) for TWW reuse are statistically analyzed.
- The physicochemical characteristics of TWW are analyzed and validated for its agricultural suitability.
- The need to educate farmers about the benefits of TWW reuse is explained.

GRAPHICAL ABSTRACT



1. INTRODUCTION

India is a big tropical country with diverse climatic features varying from humid dry tropical in the south to temperate alpine in the Himalayan north. Even though the Indian subcontinent is surrounded by water on three sides, the country's demand for freshwater accelerates steadily. Both surface and groundwater levels have been decreasing over the past decades due to population thresholds, rapid urbanization, irregularity in precipitation, and intensive use for agricultural activity (Chatterjee *et al.*, 2020; Sahoo *et al.*, 2021). The limited availability of freshwater resources is a major hurdle for many sectors, particularly agriculture and its allied sectors (Sheidaei *et al.*, 2016).

Agriculture is the primary source of life sustenance in India. More than half of the rural population depends on agriculture for their living (Food and Agriculture Organization (India)). It makes a significant contribution (20.2%) to India's economic growth rate (PIB, 2021). The major fraction of water withdrawal in India is by the agricultural sector, and it accounts for more than 70% of available freshwater (World Bank, 2020). Improvement in policies, plans, strategies, and awareness among the farmers is necessary for sustainable resources management (NMSA, 2010).

Today's agriculture is in a race that propels farmers to generate more yields with the limited available water. It is necessary to search for and prioritize alternative resources as well as proper management of existing water resources to ensure sustainability (Hamdan *et al.*, 2021). Sustainable agriculture is essential for meeting the communities' present and future needs in terms of food security, rural employment, and living standards (FAO, 2014). Various strategies have been developed to meet the growing demands for water such as interstate water transfer, desalinization, efficient water use technologies such as micro-irrigation, and water reuse (Haghi *et al.*, 2020).

Water reuse can be considered as one of the credible alternative water resources even under dry weather conditions. It can mitigate the unyielding pressure on the available resources and provides sustainability in resources management (Po *et al.*, 2003; Garcia & Pargament, 2015). Water reuse is not a new technique; it has evolved and progressed along with the development of mankind (Angelakis & Snyder, 2015). It not only reduces the freshwater demands but also minimizes the pollutant discharge into water bodies. It can compensate for the water demand throughout the hydrological year. The success of water reuse in agriculture depends on considering all the environmental, ecological, and social issues linked to it (Kretschmer *et al.*, 2002), however, the quality of water that is used for the reuse has a significant influence on the success rate.

Reuse of untreated wastewater in cultivable land can lead to detrimental effects but it can be avoided by treated wastewater (TWW) reuse (Qishlaqi *et al.*, 2008; Liang *et al.*, 2014). Properly treated wastewater can be used as a supplementary source of irrigation water (Mizyed, 2013; Leonel & Tonetti, 2021). However, the TWW shall satisfy the quality criteria of irrigation water, and a well-planned water supply system is essential for the effective implementation of water reuse projects. Also, the TWW can supplement the fertilizers due to its inherent nutrient value, and thereby increases crop yield and net income (Pereira *et al.*, 2012; Dare & Mohtar, 2018).

The lead factors to be considered for the implementation of water reuse projects are public interest, cost-benefit analysis, and environmental impacts (Lazarova *et al.*, 2001). The success of water reuse projects is primarily attributed to the stakeholders' acceptance. Farmers are the prime beneficiaries of TWW reuse projects. The clinching factors of acceptance or rejection of TWW reuse among the farmers are water availability, climatic conditions, irrigation water sources, and cultural and socio-economic conditions (Ganoulis, 2012). When addressing the water reuse project, it is also necessary to ensure the possible revenue generation to support the operation and maintenance costs as well as transportation costs so as to make it successful and sustainable.

The farmers have free power, free water, agricultural loans, and subsidies, but most of the time they are not getting water when it is required. This is owing to either the unavailability of water or poor operating policies. In this scenario, water reuse is a potential alternative. However, wastewater needs to be properly treated and the TWW has to be transported to farms. The government should plan to charge and recover at least a fraction of the cost of treatment and transportation of TWW to farmers' fields instead of offering it for free.

The main aim of the study presented in this paper is to understand the attitude of the Indian farmers towards the Willingness To Use (WTU) TWW for agriculture and the Willingness To Pay (WTP) for the reuse. The WTU and WTP for the TWW reuse are explored by conducting a questionnaire survey. It is assumed that the questionnaire survey conducted on a limited number of farmers is representative of the entire area. The responses are analyzed by the Statistical Package for the Social Sciences (SPSS). The suitability of TWW for agriculture is investigated by testing its physicochemical characteristics. The economic benefits of the TWW reuse are also quantified based on the characteristics of the tested TWW. Finally, an attempt is made to educate the farmers by explaining the nutritional supplements of TWW and its influence on the reduction in quantity and cost of fertilizer application.

2. LITERATURE REVIEW

It is highly challenging to ensure a consistent supply of agricultural goods and services to the community due to population growth and changing climatic conditions (Nam *et al.*, 2015). TWW reuse can be seen as a potential alternative solution to overcome these changing conditions (Jeong *et al.*, 2016). Global interest in TWW reuse for agriculture is seeing an increasing trend as it has several direct and indirect benefits (Pedrero *et al.*, 2010; Chávez *et al.*, 2012; Sathaiah & Chandrasekaran, 2020). There are several factors that influence the implementation of water reuse projects and among them, public acceptance and the attitude of farmers towards the reuse have a significant impact (Chen *et al.*, 2012; Fielding *et al.*, 2018). Farmers are the primary stakeholders of the TWW reuse projects, especially when focusing on the WTU the TWW, and the WTP for reuse. Thus, the earlier studies carried out to understand the attitudes of farmers and the extent of their support towards the reuse of TWW for agriculture as well as public opinion on TWW reuse are reviewed.

Abdelrahman *et al.* (2019) used a *T*-test and one-way analysis of variance (ANOVA) test to analyze the perceptions of the people of the United Arab Emirates regarding TWW reuse. From the analysis, it was found that they were more inclined to reuse the TWW for irrigating non-food crops and ready to pay for the installation of a centralized treatment plant. Baawain *et al.* (2020) also recorded the optimistic approach of the Oman farmers towards TWW reuse for irrigating non-edible crops. Menegaki *et al.* (2009) described that the people of Greece were unwilling to use TWW for personal food production and consumption due to their aversion and disgust towards TWW.

Haghi *et al.* (2020) studied the acceptance of the Iranian farmers and found that knowledge, attitude, and health concerns significantly impact the WTU, while education and information about wastewater reuse impact the WTP. These relationships were arrived at using the Contingent Valuation Method (CVM) and the binary probit model. Abu Madi *et al.* (2003) analyzed the WTP for TWW reuse by the Jordanian and Tunisian farmers using the CVM and logistic regression model, and concluded that the quality concerns and price were the prime influential factors.

Michetti *et al.* (2019) reported that 55% of the Italian farmers had a positive approach towards the TWW reuse for agriculture; the analysis was done using an χ^2 Automatic Interaction Detector (CHAID). Carr *et al.* (2011) analyzed the attitude of Jordanian farmers towards TWW reuse and compared the perceptional differences between direct reuse of TWW and diluting it with freshwater using the χ^2 test. It was noticed from the analysis that the perception was a function of treated water quality and also the ability of farmers to meet the associated challenges such as soil salinity, nutrient management, irrigation system damages, and marketing the products produced. Ambreen *et al.* (2020) evaluated the responses of the farmers of Pakistan towards their WTU, the TWW as an alternative irrigation water source and WTP for reuse using the binary logistic regression model and χ^2 test. From the analysis, it was found that the WTP was positively affected by the socio-economic profile such as age, gender, education and profession of the farmers, and knowledge and awareness of water reuse.

Mu'azu *et al.* (2020) found from the results of descriptive analysis and regression analysis that the socio-economic variables such as age, gender, education, and residential location highly influence the people of Saudi Arabia towards TWW acceptance. Haldar *et al.* (2021) performed interviews and group discussions with the farmers of Bangladesh and reported that they were willing to use and pay for the better quality TWW supply. Hamdan *et al.* (2021) analyzed the willingness of the farmers of Palestine to reuse TWW for agriculture using descriptive analysis, χ^2 test, Kolmogorov–Smirnov test, and Mann–Whitney *U* test. From the analysis, it was found that 75% of the farmers have the willingness to reuse the TWW for agriculture. Also, it was reported that the non-availability of TWW and psychological aversion were the main barriers to reuse.

From the review of earlier studies, it is realized that the involvement and support of local farmers are inevitable for the successful implementation of the TWW reuse project. The percentage of WTU in the TWW for agriculture is significantly high but the WTP for reuse is very low. It is noted that the studies which were focused on the WTP for the TWW reuse are relatively low. Elucidating the farmers about the economic and environmental benefits of the TWW reuse for agriculture has to be done comprehensively to increase the WTP.

3. STUDY AREA DESCRIPTION

The study is conducted in Virudhunagar district; it is a district of Tamil Nadu state located in the southern part of India (Figure 1). The total geographical area of the district is 4,243 km^2 and it has 10 taluks (sub-divisions of a district), namely Aruppukottai, Kariapatti, Rajapalayam, Sattur, Sivakasi, Srivilliputtur, Tiruchuli, Vembakottai, Virudhunagar, and Watrap. The district has 450 villages with a total population of 1,942,288 (Census, 2011). The climate is generally hot and dry, and the annual temperature ranges between 24 and 40 °C. The region receives an annual rainfall between 724 and 913 mm.

The questionnaire survey is conducted on the farmers of Sivakasi taluk (Figure 1) which is located on the leeward side of the Western Ghats. The taluk receives an annual average rainfall of 812 mm and it is lower than the state's average value of 950 mm. Rainfall is mostly during the northeast monsoon season and occurs in the months of October, November, and December. The topography is almost plain and the soil types are black and red. The total cultivable land area is 6,154 ha and the main crops cultivated are guava, mango, banana, tomato, brinjal, chilli, cotton, and millet. Sivakasi taluk has 52 villages in total. The lists of farmers in each of the villages are collected from the Sivakasi agricultural office. Initially, six to eight farmers from each village are selected to address all the variables mentioned in the questionnaire survey. This process results in a

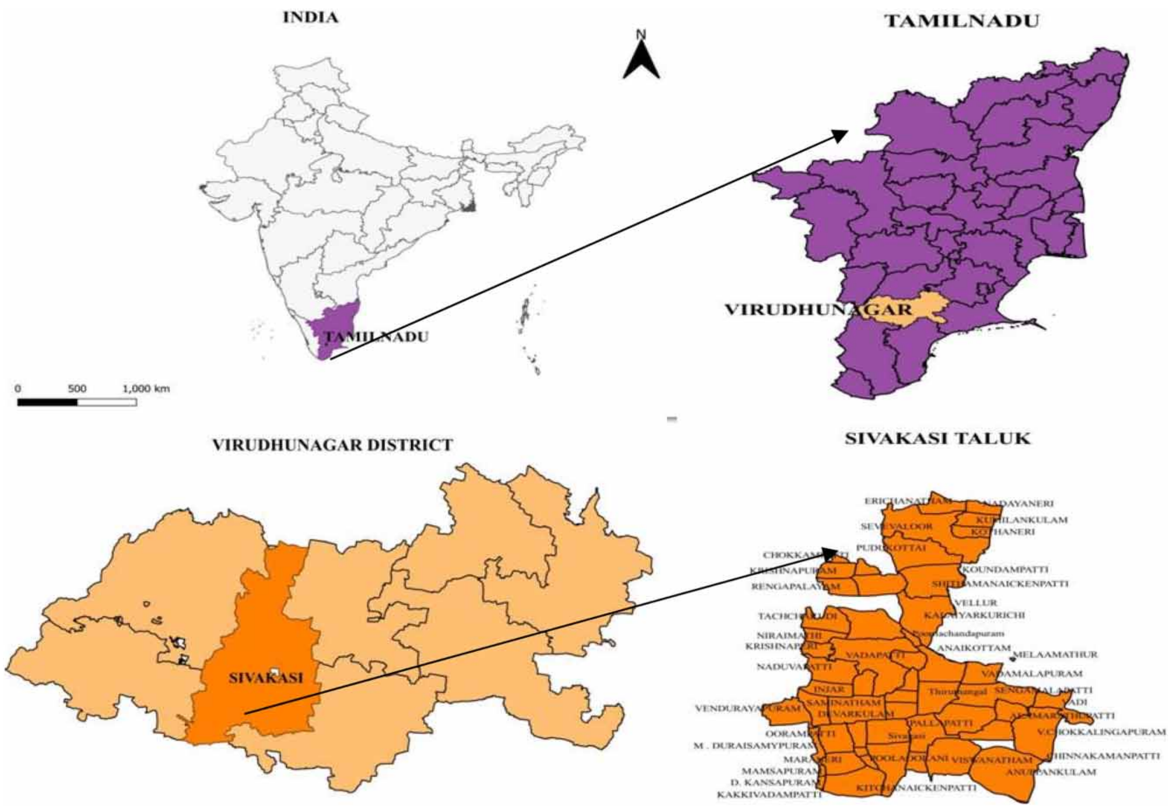


Fig. 1 | Study area map.

sample size of 397, and the farmers are questioned about their WTU, the TWW for agriculture and WTP for the reuse.

4. DATA COLLECTION

A questionnaire survey on 397 random farmers from all the villages of the Sivakasi taluk is used as a tool for the data collection (Table 1). The survey is carried out by the authors of this paper between August 2021 and December 2021. The questionnaire survey focuses on four components (i) socio-economic profile of the farmers, (ii) satisfaction of water supply, (iii) agricultural factors, and (iv) the WTU the TWW for agriculture and the WTP for the reuse. The farmers confirmed that the variables taken into consideration in the questionnaire (Table 1) are sufficient and significant to cover several issues related to the agricultural water management.

To get the socio-economic profile of the farmers, details on age, gender, educational qualification, and profession are collected. In addition to the satisfaction of household water supply, the data on sources of water for domestic use are also collected. The agricultural factors collected include information on possession of land, type of land, crops cultivated, source of irrigation, method of irrigation, knowledge on smart irrigation, energy for irrigation water pumping, and confirmation of prevailing water scarcity in the region. Finally, along with the WTU the TWW and WTP for the reuse, awareness of possible alternative water solutions, knowledge on water reuse concept, trust in TWW quality, preferred crops for TWW agriculture, and barriers for the reuse if the farmers declined to use the TWW are also collected for comprehension.

Table 1 | Description of variables used in the questionnaire survey.

Variables	Description	Frequency	Percentage
Name	Name of the farmer		
Village name	Name of the village		
Age, years	21–30	17	4.0
	31–40	46	12.0
	41–50	169	42.4
	51–60	151	38.0
	61–70	12	3.1
	71–80	2	0.5
Gender	Male	356	90.0
	Female	41	10.0
Educational qualification	No school	61	15.0
	School	268	68.0
	UG	61	15.0
	PG	7	2.0
Profession	Agriculture alone	135	34.0
	Agriculture + Work	262	66.0
Primary source of household water	Panchayat water	329	83.0
	Panchayat+Bore water	68	17.0
Satisfaction of water supply	Poor	16	4.0
	Moderate	243	61.2
	Satisfied	116	29.2
	Highly satisfied	22	5.5
Possession of land	Own	394	99.2
	Lease	1	0.3
	Own+Lease	2	0.5
Type of land	Rainfed	38	9.6
	Wetland	359	90.4
Crops cultivated	Rainfed	39	9.8
	All crops	318	80.1
	Pulses	6	1.5
	Vegetables	16	4.0
	Flowers	1	0.3
	Vegetables+Fruits	14	3.5
	Fodder crops	2	0.5
	Millet	1	0.3
Source of irrigation	Rainfall	39	9.8
	Rainfall+Well water	294	74.1
	Rainfall+Bore water	43	10.8
	Rainfall+Well water+Bore water	21	5.3
Method of irrigation	Flooding	1	0.3
	Furrow	324	81.6
	Micro-irrigation	34	8.6
	Mixed irrigation	38	9.6

(*Continued*.)

Table 1 | Continued

Variables	Description	Frequency	Percentage
Knowledge on smart irrigation	Yes	28	7.1
	No	316	79.6
	Partially	53	13.4
Energy for pumping	Diesel	32	8.1
	Electricity	363	91.4
	Solar	2	0.5
Water scarcity	Yes	365	91.9
	No	32	8.1
Awareness of alternative water solution	Yes	366	92.2
	No	31	7.8
Knowledge on water reuse concept	Yes	23	5.8
	No	363	91.4
	Partially	11	2.8
Trust on the quality of TWW	Yes	272	68.5
	No	1	0.3
	Report	124	31.2
WTU the TWW for agriculture	Yes/No		
Preferred crops with TWW reuse	Preference of crops		
Barrier for WTU	Reason		
WTP for the TWW reuse	Yes/No		
Barrier for WTP	Reason		

5. ANALYSIS OF FARMERS' RESPONSE

SPSS software is used to analyze the responses of the farmers to the questionnaire survey. The statistical methods such as descriptive analysis, χ^2 test, Mann–Whitney *U* test, and the binary logistic method are used for the analysis. The descriptive analysis is used to get the percentage values of the dependent and independent variables. The χ^2 test is used to check the statistical significance between two nominal variables. The Mann–Whitney *U* test is to analyze the influence of ordinal variables on nominal variables. The binary logistic method is used for simultaneous consideration of all the independent variables and their influence on dependent variables.

The WTU and WTP are the dependent variables and are nominal, while the others are independent variables (Table 1). The socio-economic variables such as age, gender, educational qualification, and profession are considered as nominal variables, and among these, age is a categorical variable. Satisfaction with water supply is treated as an ordinal variable and it is also a categorical variable. The agricultural factors such as type of land, crops cultivated, source of irrigation, method of irrigation and knowledge on smart irrigation are also considered as nominal variables.

The probability (p) value represents the relationship between the dependent and independent variables. For the statistical results, the relationship between the dependent variable and independent variable is highly significant if $p \leq 0.001$, significant if $0.001 > p \leq 0.05$, and insignificant if $p > 0.05$.

5.1. Descriptive analysis of socio-economic profile of the farmers

The descriptive analysis is used to obtain the frequency (number of farmers) and percentage values of age group, gender, educational qualification, and profession to understand the socio-economic profile of the farmers

(Table 1). From the analysis on age, it is noted that only a small percentage of the younger generation are involved in agricultural activities. Only 16% of the farmers belong to the age group of 21–40 years and the majority of them are in the age group of 41–60 years. From the analysis on gender, it is observed that the female fraction is low and 90% of the farmers are male.

From the analysis on farmers' educational qualifications, it is identified that only 15% of the farmers are uneducated and the remaining are educated; at least they have school-level education. From the analysis on profession, only 34% of the farmers have agriculture as their full-time profession and the rest are doing it as their part-time job. In addition to agriculture, they are involved in either business or work for daily wages. The fundamental justification behind the part-time profession is that the return benefits from agricultural practices are questionable and scant. Furthermore, agricultural laborers receive low wages and are oftentimes underemployed. They work only 3–4 months out of a year and are idle for the remaining months due to the unavailability of water for irrigation.

5.2. Influence of socio-economic profile of the farmers on the WTU and WTP

The χ^2 test is used to analyze the influence of age, gender, educational qualifications, and profession on the WTU the TWW for agriculture, and the WTP for reuse (Table 2). Irrespective of the age, most of the farmers have WTU the TWW for agriculture, but they are not ready to pay for the reuse. From the analyses on the influence of gender on the WTU and WTP, it is inferred that gender has no influence on the WTU and WTP. Both male and female farmers have higher acceptance towards TWW reuse. This trend is in agreement with Fielding *et al.* (2018). However, like age, irrespective of gender, the farmers are hesitant to pay for the reuse because of their straitened economic conditions.

The analysis on the influence of educational qualification on WTU for TWW reveals that there is a relationship between them. Education has a positive influence on the acceptance of TWW and this is in line with Michetti *et al.* (2019). Analysis on the influence of educational qualification on the WTP shows that there is no relationship between them. Irrespective of their educational qualification, the farmers are reluctant to pay for TWW reuse. During the survey, it is noted that the educated farmers are very keen on the quality of TWW. Thus, the significance between the educational qualification and trust in the quality of TWW is also analyzed. The χ^2 test is used for the analysis and it is inferred that there is a significant relationship between educational qualification and trust in the quality of TWW (Table 2). The farmers who are educated haven't accepted the quality of TWW

Table 2 | Results of χ^2 tests on socio-economic profile of the farmers.

Variables	χ^2	*df*	*p*-value
Age vs. WTU	10.18	5	0.07
Age vs. WTP	9.75	5	0.08
Gender vs. WTU	0.64	1	0.42
Gender vs. WTP	0.00	1	0.94
Education vs. WTU	8.91	3	0.03
Education vs. WTP	1.75	3	0.62
Education vs. trust on quality of TWW	47.60	6	$<$0.001
Profession vs. WTU	0.15	1	0.69
Profession vs. WTP	3.50	1	0.06

df, degrees of freedom; *p*, probability value.

immediately; they seek a report that shows the water quality. They are aware that the quality of water can impact soil and crop productivity.

From the analyses of the influence of profession on the WTU and WTP, it is found that the profession has an influence on neither the WTU nor the WTP. Whether the farmers are taking agriculture as a full-time or part-time profession, they have WTU but are hesitant to pay for the TWW reuse. Relatively, farmers who are taking agriculture as a part-time profession (9%) have more WTP than the other group (1%).

5.3. Influence of satisfaction of water supply on the WTU and WTP

From the responses of the farmers on the satisfaction with water supply for households, it is found that the primary source is public water supply. The Mann-Whitney test is used to analyze the impact of satisfaction with water supply on the WTU and WTP. It is noted from the results that the satisfaction with water supply has a significant influence on the WTU and a highly significant influence on the WTP (Table 3).

The farmers with a poor level of satisfaction on water supply have higher WTU and WTP for reuse when compared to the others. This is due to inadequate water supply and severe water scarcity in those regions. Farmers who are highly satisfied with the household water supply are found to be the least interested group for both WTU the TWW and WTP for reuse.

5.4. Influence of agricultural factors on the WTU and WTP

During the questionnaire survey, it is observed that the agricultural lands are mostly owned by the farmers. Most of the farmers are marginal and small landholders; they have less than 2 ha of land. About 80% of the farmers cultivate mixed crops using furrow irrigation and use electrical energy for pumping the water. Among the agricultural factors collected, type of land, source of irrigation, and method of irrigation are considered as the primary influential parameters for the WTU the TWW for agriculture and the WTP for the reuse.

The χ^2 test is used to analyze the statistical significance of agricultural factors (type of land, source of irrigation, and method of irrigation) on the WTU and WTP (Table 4). The type of land has no significant influence on WTU. It is noted from the analysis that irrespective of the type of land, whether it is rainfed or wetland, the farmers have WTU the TWW for agriculture. This is due to the fact that almost all the farmers require an alternative source of water for irrigation because of the water scarcity in the area. More than 90% of the farmers confirm the prevailing water scarcity in the area. The farmers prefer to reuse the TWW for agriculture rather than leaving the land barren. However, to date, the farmers are unaware of the potential use of TWW for agriculture.

From the analysis of the WTP, it is found that there is a significant relationship between the type of land and WTP. The farmers who depend only on rainfed agriculture have relatively higher WTP than the other group despite their straitened financial conditions. This is due to the fact that the delay or failure of monsoons reduces agricultural productivity and subsequently income considerably.

From the analyses on the influence of source of irrigation on the WTU and WTP, it is found that source of irrigation has a significant influence. Among the two, the WTP is highly influenced by the source of irrigation. It is

Table 3 | Results of Mann–Whitney *U* tests on satisfaction of water supply.

	Yes		No				
Variables	**No. of farmers**	**Mean rank**	**No. of farmers**	**Mean rank**	**Mann–Whitney *U***	***Z***	***p-value***
Satisfaction vs. WTU	377	195.6	20	256.1	2,629.0	−2.64	0.008
Satisfaction vs. WTP	28	138.7	369	203.6	3,478.5	−3.34	<0.001

U, test statistic; *Z*, *Z* score; *p*, probability value.

Table 4 | Results of χ^2 tests on agricultural factors.

Variables	χ^2	*df*	*p*-value
Type of land vs. WTU	2.22	1	0.13
Type of land vs. WTP	38.56	1	<0.001
Source of irrigation vs. WTU	10.66	3	0.01
Source of irrigation vs. WTP	66.33	3	<0.001
Method of irrigation vs. WTU	3.11	3	0.37
Method of irrigation vs. WTP	62.71	3	<0.001
Knowledge on smart irrigation vs. education	37.94	6	<0.001
Source of irrigation vs. crops cultivated	353.54	21	<0.001
Method of irrigation vs. crops cultivated	374.44	21	<0.001

df, degrees of freedom; *p*, probability value.

identified that the farmers who depend only on rainfall for agriculture are more inclined towards the WTU the TWW and the WTP for the reuse because of the uncertain rainfall conditions.

The method of irrigation is not influencing the WTU. The farmers have WTU the TWW for agriculture regardless of the method of irrigation. On the other hand, there is a significant relationship between the method of irrigation and WTP. It is noted that the farmers who practice mixed irrigation methods have higher WTP than the others. The farmers responded that they are practicing mixed irrigation mainly because of uncertainty in water availability. If TWW is available for agriculture, they can cultivate the crops that yield high returns.

An important observation from the survey is that only 9% of the farmers are adopting micro-irrigation and the remainder are sticking with the conventional methods like flooding and furrow. It is also noted that 10% of the farmers have shifted from micro-irrigation to conventional methods even though governmental subsidies have been provided. The main reasons put forth are: high maintenance cost of micro-irrigation system, reduction in discharge due to salt and slime layer formation in pipes and attack of rodents on pipes. The interesting fact is that the farmers do not show any aversion towards the TWW reuse; they have even shown WTU the TWW for the crops which are cultivated for their own food consumption.

Farmers are also questioned about their knowledge on smart irrigation. The significance between educational qualification and knowledge on smart irrigation is analyzed using the χ^2 test (Table 4). From the analysis, it is found that a significant relationship exists between educational qualification and knowledge on smart irrigation. Most of the educated farmers are aware of smart irrigation technologies.

It is observed from the questionnaire survey that the crops cultivated in the field primarily depend on the source of irrigation and the method of irrigation (Table 4). Thus, to identify the significance of the source of irrigation and method of irrigation on crops cultivated, the χ^2 tests are performed. From the analyses, it is inferred that both sources of irrigation and method of irrigation have a highly significant influence on the crops cultivated. The farmers prefer cultivating all kinds of crops using the conventional source and methods of irrigation. On the other hand, the majority of the farmers (41%) prefer cultivating vegetables including green leaves using TWW followed by mixed crops (31%). Also, the farmers who are using micro-irrigation prefer to cultivate fruits using TWW.

5.5. Influence with simultaneous consideration of all the independent variables

The binary logistic method is useful to identify whether the influence of the independent variable on the dependent variable is highly significant, significant or insignificant when ceteris paribus. Here, it is performed to identify the influence of age, gender, educational qualification, profession, satisfaction with water supply, type of land, source of irrigation, and method of irrigation on the WTU the TWW for agriculture and the WTP for the reuse (Table 5). The analysis is done with the simultaneous considerations of all the independent variables against the dependent variable. The subdivisions of categorical variables, age, and profession are treated as dummy variables.

It is observed from the binary logistic analysis on WTU that the independent variables have no significant influence on WTU. It means that regardless of the socio-economic profile, satisfaction with water supply, type of land, source of irrigation and method of irrigation, the farmers have WTU the TWW because of the water scarcity in the region. On the other hand, the binary logistic analysis on the WTP brings out that the profession and level of satisfaction with water supply have a significant influence on the WTP. It is noted that the farmers who undertake

Table 5 | Results of binary logistic analyses on the WTU and WTP.

	WTU		WTP	
Variables	**Wald**	***p*-value**	**Wald**	***p*-value**
Age of farmers, years (71–80)[a]	7.17	0.20	7.25	0.20
21–30	0.00	0.99	0.00	1.00
31–40	0.00	0.99	0.00	0.99
41–50	0.00	0.99	0.00	1.00
51–60	0.00	0.99	0.00	1.00
61–70	0.00	1.00	0.00	0.99
Gender/(Female)[a]	0.04	0.83	0.08	0.77
Educational qualification/(PG)[a]	3.63	0.30	2.49	0.47
No school	0.00	1.00	1.35	0.24
School	0.00	0.99	0.70	0.40
UG	0.00	0.99	0.16	0.68
Profession/(Agriculture+Work)[a]	0.39	0.52	9.64	0.00
Satisfaction of water supply/ (Highly satisfied)[a]	2.77	0.42	8.66	0.03
Poor	0.00	0.99	0.00	0.99
Moderate	2.32	0.12	0.00	0.99
Satisfied	0.54	0.46	0.00	0.99
Types of Land/ (Wetland)[a]	0.00	0.99	0.49	0.48
Source of Irrigation water/ (Rainfall+Well water+Bore water)	6.64	0.08	5.45	0.14
Rainfall	0.00	1.00	0.00	1.00
Rainfall+Well water	0.58	0.44	5.45	0.01
Rainfall+Bore water	0.39	0.52	0.00	0.99
Method of irrigation/(Mixed irrigation)[a]	0.01	1.00	7.52	0.05
Flooding	0.00	1.00	0.00	0.99
Furrow	0.00	1.00	0.00	1.00
Micro-irrigation	0.00	1.00	0.00	1.00

[a]Reference variable.

agriculture as a part-time profession are more likely to pay for TWW reuse than the other categories due to their relatively better economic conditions. It is also observed that the farmers who have a poor level of satisfaction have higher WTP than others, due to severe water scarcity in those regions.

It can be noted from the inferences that the results of individual tests carried out to identify the influence of several factors on the WTU and WTP and the results of the test conducted with simultaneous consideration of all the independent variables are different. Thus, it is suggested to test with both individual and simultaneous consideration of independent variables. Such a comprehensive analysis will be helpful to arrive at more practical solutions.

5.6. Descriptive analysis of the WTU and WTP

The descriptive analysis of the WTU and WTP (Table 6) brings to light that about 95% of the farmers have WTU the TWW for agriculture. It is observed that most of the farmers are experiencing severe water scarcity due to dry spells and parchedness in the region, so they have a strong WTU. However, only 7% of the farmers have WTP for the TWW reuse. The response is that the return benefits from agriculture are very low, so it is impossible to pay for TWW reuse. This is further reinforced by the fact that the farmers who are taking agriculture as their part-time profession have relatively higher WTP than the group taking it as a full-time profession.

6. PHYSICOCHEMICAL CHARACTERISTICS OF TWW

The physical, chemical, and microbial characteristics of TWW are analyzed to verify its suitability for agriculture and to examine the extent of reduction in fertilizer application. The TWW sample is collected from the wastewater treatment plant located in the neighboring district, Madurai, and its physicochemical characteristics are analyzed. The results of the TWW analysis are compared against the FAO standards for irrigation water quality (FAO, 1985) and found to be within acceptable limits (Table 7).

7. POSSIBLE FERTILIZER REDUCTION AND COST SAVINGS

The Nitrogen (N), Phosphorus (P) and Potassium (K) values of the TWW sample are 53, 1.2, and 11.5 mg/l, respectively (NPK=53.0:1.2:11.5 mg/l). A sample farm that has one acre (1 acre=0.405 ha) of guava cultivation with 110 plants in total is considered for estimating the possible fertilizer reduction. The crop water requirement of guava is taken as 25 l/day. The recommended NPK fertilizer dose for guava is 1.0:1.0:1.0 kg per plant/year. Thus, the required NPK dose for the sample farm is 110.0:110.0:110.0 kg/acre. This has to be applied in two split doses per year.

The volume of water requirement for guava is 0.55 ml/acre (Number of plants [110]×number of months of irrigation [10]×number of irrigation per month [20]×crop water requirement [25/l/day/plant]). The amount of NPK that can be supplemented through the TWW is 29.1:0.6:6.3 kg/acre. The fertilizer to be applied when cultivating with TWW is the difference between the recommended dose and the amount of NPK that can be supplemented by the TWW (Urbano *et al.*, 2017). In this way, the percentage of quantity of fertilizer reduction in guava cultivation using the TWW is found to be 26.5:0.6:5.8%. This fertilizer reduction could save around ₹300 of the total fertilizer application cost of ₹5,000 (NHB.gov.in).

The possible fertilizer reductions and cost savings for other major crops cultivated in the study area are also computed (Table 8). For mango and chilli, the amount of nitrogen required can be supplemented by the TWW itself. In addition to these macronutrients, TWW also supplements micronutrients such as zinc and iron to the plants, which in turn can increase the crop yield. However, it is necessary to have the proper treatment and monitoring of TWW quality to ensure the required irrigation water quality standards.

Table 6 | Descriptive analysis of WTU and WTP.

Variables	Description	WTU (%)	WTP (%)
Age, years	21–30	94.0	0.0
	31–40	96.0	1.0
	41–50	98.0	1.0
	51–60	91.0	3.0
	61–70	100.0	0.0
	71–80	100.0	0.0
Gender	Male	95.0	6.0
	Female	98.0	5.0
Educational qualification	No school	100.0	2.0
	School	95.0	1.0
	UG	90.0	1.0
	PG	90.0	0.0
Profession	Agriculture alone	96.0	1.0
	Agriculture+Work	95.0	9.0
Primary source of household water	Panchayat water	92.5	6.9
	Panchayat+Bore water	91.1	6.7
Satisfaction of water supply	Poor	100.0	31.0
	Moderate	97.0	7.0
	Satisfied	92.0	5.0
	Highly satisfied	86.0	0.0
Possession of land	Own	91.0	5.5
	Lease	100	0.0
	Own+Lease	100	0.5
Types of land	Rainfed	100	18.0
	Wetland	95	6.0
Crops cultivated	Rainfed	100	28.0
	All crops	93.7	2.2
	Pulses	100.0	3.3
	Vegetables	100.0	18.8
	Flowers	100.0	0.0
	Vegetables+Fruits	100.0	35.7
	Fodder crops	100.0	0.0
	Millets	100.0	0.0
Source of irrigation	Rainfall	100.0	33.0
	Rainfall+Well water	96.0	4.0
	Rainfall+Bore water	90.0	10.0
	Rainfall+Well water+Bore water	86.0	9.0
Method of irrigation	Flooding	100.0	0.0
	Furrow	95.0	2.5
	Micro-irrigation	100.0	21.0
	Mixed irrigation	100.0	34.0

The use of TWW can expand the cultivable land area; otherwise, they will remain as barren lands because of water scarcity. If the wastewater generated is properly treated and reused for agriculture, the untreated wastewater discharge into the freshwater bodies will reduce. Thus, the TWW reuse not only increases the economic

Table 7 | Physicochemical properties of the TWW.

Parameter	Unit	Concentration	FAO standards		
			None	Slight to moderate	Severe
TDS	mg/l	1,310.00	<450	450–2,000	>2,000
EC	ds/cm	0.9	<0.7	0.7–3.0	>3.0
Calcium	mg/l	56.00	–	–	–
Magnesium	mg/l	6.80	–	–	–
Sodium	me/l	3.73	<3	3–9	9
Chloride	mg/l	13.98	<4	4–10	>10
Sulphate	mg/l	178.00	–		
Nitrate	mg/l	12.50	–		
Ammonia	mg/l	2.00	–		
Phosphate	mg/l	1.20	–		
Potassium	mg/l	11.50	–		
SAR	mg/l	2.88	–		
pH	mg/l	8.20	6.5–8.4		
BOD	mg/l	12.00	–		
COD	mg/l	45.00	–		
Total Nitrogen	mg/l	53.00	–		
Zinc	mg/l	1.20	2.0		
Manganese	mg/l	<0.10	0.2		
Iron	mg/l	0.20	5.0		
Borates	mg/l	<0.10	–		
Copper	mg/l	0.05	0.2		
E. coli	CFU/ml	80.00	–		
Coliform	CFU/ml	650.00	–		
Salmonella	CFU/ml	Absent	–		

Table 8 | Possible fertilizer reduction and cost savings through TWW reuse.

Crop	Recommended dose of NPK (kg/acre)	NPK supplemented through TWW (kg/acre)	NPK to be applied (kg/acre)	NPK reduction quantity (%)	Possible cost savings	
					(₹)	(%)
Guava	110.0:110.0:110.0	029.1:0.60:06.3	80.9:109.4:103.7	027.0:0.60:05.8	300	6
Banana	197.1:616.0:480.5	187.2:4.20:40.6	09.9:611.8:440.0	095.0:0.70:08.4	1,900	20
Tomato	080.0:100.0:100.0	051.4:1.20:11.2	28.6:098.8:088.8	064.0:01.2:11.2	500	10
Mango	012.6:012.6:018.9	024.0:0.54:05.2	00.0:011.5:012.8	100.0:09.0:32.0	200	4
Chilly	048.0:032.0:032.0	058.9:1.30:12.5	00.0:030.7:019.6	100.0:04.1:38.8	500	9

₹, Indian rupees.

benefit but also benefits the environment. The use of TWW can also reduce the pumping cost in addition to the reduction of overexploitation of freshwater resources. However, TWW needs to be pumped to farms; either the government or farmers have to bear the cost.

8. EFFECT OF EDUCATING THE FARMERS ABOUT THE BENEFITS OF TWW REUSE ON THE WTP

After the fertilizer quantity and possible cost reduction analysis, about 25% of the sample size, i.e. 100 farmers who are unwilling to pay for the TWW reuse earlier, are chosen randomly. The selection is carried out in such a way that they represent all the villages and are able to address all the influencing factors. They are questioned again about their WTP after explaining the TWW quality and associated cost benefits. The respondents are positively convinced about the findings of TWW characteristics and savings in the cost of fertilizer application. The environmental benefits of TWW reuse are also explained to the farmers.

In the post-survey, 74 out of 100 farmers said 'yes' to the WTP for the TWW reuse but only at a subsidized cost. The response was that it is not possible to pay the entire cost incurred for treating and transporting the wastewater due to their unstable financial conditions; only a fraction of the cost can be shared by them and the rest has to be borne by the government. The cost of treatment being high, if farmers pay for the transportation of TWW from the treatment plant to farms, it is remarkable progress. The analysis brings out that educating the farmers about the possibility of fertilizer reduction and subsequent cost savings when using TWW can have a significant and positive influence on the WTP for reuse. Farmers are inclined to pay for the reuse due to reasons such as reduction in fertilizer inputs and cost savings, retaining the land productivity, reduction in dependency on conventional irrigation water and sustenance of livelihoods.

9. SUMMARY AND CONCLUSIONS

Public acceptance and participation are essential for the success of sustainable water reuse projects. Treated wastewater reuse is one of the viable and long-term solutions for ever-increasing water demand. It has to be seen holistically and seriously in a country like India, where the employment and livelihood is primarily due to agriculture and its allied sectors.

This study has created a platform to understand the farmers' perception willingness to use the TWW for agriculture and the willingness to pay for the reuse. The socio-economic profile of the farmers, level of satisfaction with household water supply, type of land, source of irrigation and method of irrigation were considered as the prime influencing parameters of WTU and WTP. It was found from the analysis that more than 90% of the farmers have the willingness to use the TWW as an alternative source of irrigation as they are facing severe water scarcity.

When considering the socio-economic profile, irrespective of their age, gender, educational qualifications, and profession, around 95% of the farmers have WTU the TWW for agriculture. However, educated farmers demanded a report that shows the characteristics of TWW quality for reuse though they are interested in the reuse. It is observed that regardless of the level of satisfaction with water supply, around 93% of the farmers prefer TWW reuse for agriculture. The percentage of WTU gradually increases from the highly satisfied category (86%) to the poor satisfaction category (100%). Like socio-economic profile and satisfaction with water supply, irrespective of the agricultural factors such as type of land, source of irrigation and method of irrigation, around 96% of the farmers have WTU the TWW. Relatively, the source of irrigation has more influence on WTU and the farmers who depend only on rainfall for agriculture are highly interested in reuse.

Though the percentage of the farmers having WTU the TWW for agriculture is very high, the acceptance percentage for the WTP is only 7%. This is because of their straitened economic conditions. This is reinforced by the fact that when considering the socio-economic profile, the farmers who have taken agriculture as a part-time profession are relatively more interested in paying for the reuse because of their additional income. The satisfaction with water supply has a highly significant influence on the WTP for the reuse. Similar to WTU, the percentage of WTP increases from the highly satisfied category (0%) to the poor satisfaction category (31%). All the agricultural factors such as type of land, source of irrigation and method of irrigation have a highly significant influence on the WTP. Farmers who possess a rainfed type of land depend only on rainfall as the source of irrigation and practicing the mixed method of irrigation (flooding, furrow, micro-irrigation) are more inclined to pay for TWW reuse despite unstable financial conditions.

The study presented in this paper also investigated the suitability of TWW for agriculture by analyzing its physicochemical characteristics. It was found that the physicochemical characteristics of the properly treated wastewater are within the acceptable limits of irrigation water quality standards. Possible fertilizer reduction and subsequent cost savings are also analyzed and it was found that a significant percentage reduction of NPK fertilizer application can be achieved by using TWW for agriculture which in turn saves up to 20% in costs.

The benefits, such as the possibility of cultivation with TWW as an alternate source of irrigation, characteristics of TWW, associated environmental benefits, the possibility of fertilizer reduction and cost savings were explained to the farmers. About 25% of the farmers who are not interested in paying earlier were questioned again about their WTP for TWW reuse after being educated on the benefits of using TWW for agriculture. Interestingly, 74% of the farmers accepted paying for the TWW reuse but at a subsidized cost. The outcome of this study clearly brings to light that it is necessary to educate the farmers about the benefits of TWW reuse.

The wastewater has to be treated properly before being put into use for irrigation. The treatment plant requires operation and maintenance costs in addition to the capital cost. Also, TWW has to be transported from the treatment plant to farms and it requires transportation costs. The total treatment and transportation cost is high and the farmers cannot bear the entire amount. The government has to establish an appropriate policy to charge for TWW irrigation accounting cost of wastewater treatment and transportation as well as the economic conditions of farmers. The cost of water for irrigation is not quantified in the present study. The quantification and comparison between the cost of conventional irrigation and irrigation using TWW can be done in the future.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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