

## Article

# Public Acceptance of Wastewater Reuse: New Evidence from Factor and Regression Analyses

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**Abstract:** The present study attempts to unravel the determinants of public acceptance of Treated Wastewater (TWW) reuse in the United Arab Emirates. A representative sample (1426) of Al-Ain city residents, were interviewed, using a structured questionnaire, on their knowledge and attitudes towards TWW reuse, and other demographic characteristics. Descriptive analysis shows high public acceptance for applications with low contact and lower acceptance for those involving direct or indirect consumption of TWW, and/or skin contact. The Principal Component Analysis (PCA) of acceptance responses identified (Kaiser–Mayer–Olkin test = 0.942;  $p$ -value < 0.001 for Bartlett’s test) five factors/categories of applications that differ in level and type of contact. The five groups of applications are Direct consumption, Indirect Consumption, Non-food Agricultural, Industrial, and Skin Contact. ANOVA analysis ( $p$  < 0.0001) and Spearman’s Rho test validated earlier findings. Another PCA of respondents’ reasons for hesitation towards TWW delivers two factors, attitude toward contamination risk and psychological “yuck” factors. Regression analyses show that both factors are influenced by knowledge and sources of information, and the former is affected by demographic characteristics. PCA and regression analyses provide a robust methodological framework for the study TWW reuse acceptance, and highlight the importance of communication in improving its social sustainability.

**Keywords:** wastewater reuse; public acceptance; questionnaire; principal component analysis

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## 1. Introduction

Water issues have been the focus of international concern because of the growing pressure on freshwater resources resulting from increase in water demand and in some instances, its wasteful use, as well as mounting pollution. Achieving efficient water allocation requires a multidisciplinary approach to managing water resources to maximize economic welfare while guaranteeing social equity and ecological sustainability [1].

Reuse of treated wastewater (TWW hereafter) is widely being researched and recognized as a practical response to the rising demand for water and limited freshwater availability; TWW is gaining importance not just as an alternative source of water but also as means to lessen environmental degradation [2].

As displayed in its regional trends, various factors seem to influence wastewater reuse, including economic and financial considerations, social acceptability, water resources availability, and other environmental aspects. In northern Europe, water reuse is practiced for Environmental and Industrial applications, whereas in southern Europe, agricultural applications dominate TWW reuse [3]. In the Middle East and North Africa region, water reuse is driven by water scarcity, amplified by population growth and climate change effects [4,5].

With very limited rainfall and decreasing groundwater resources, the United Arab Emirates (UAE) is taking steps to tackle its water resources shortage, especially in view of

the high increase in population amplified by the immigration of millions of expatriates to the UAE attracted by the wealth of opportunities [6].

Moreover, the economic growth that the UAE has enjoyed in the last decades has also led to an evolution in the standards of living. Domestic per capita consumption of water in Abu Dhabi reached an average of 629 L a day according to the Environment Agency—Abu Dhabi [7], among the highest rates in the world (around 82 per cent above the global average); when simultaneously UAE's renewable freshwater supply is among the lowest in the world, second only to Bahrain [8].

Indeed, wasteful water use trends, with the use of hundreds of liters at a time in watering gardens, washing cars, etc., suggest a perception of water as an infinite resource, in total conflict with the water scarcity situation in the country [9]. It is critically important that all available water resources in the UAE—namely, Groundwater, Desalinated Water, and Recycled water, be effectively managed to sustainably cater to water needs of all sectors.

In the Emirate of Abu Dhabi, annual production of treated wastewater amounts to 250 cubic hectometers ( $\text{hm}^3$ ), which equates 7.2% of total water production in the Emirate; but only 60% of treated wastewater is reused [10]. Considering the high financial and environmental costs of desalination and the added water stress caused by climate change, the policy makers are moving towards an integrated approach that would include wastewater resources full recycling and reuse [11]. The Abu Dhabi government has developed a Water Conservation Strategy that aims to optimize the use of reclaimed water in the emirate in agriculture, landscaping and forestry [12].

Among the problems that the different reports are emphasizing are questions regarding public acceptance, including farmers' willingness to use the recycled water [13]; indeed, the reuse of treated wastewater might face some hesitation by farmers and consumers even when the risk of contamination is very low. It is important to establish how the different stakeholders perceive this alternative resource, and to understand the factors that affect their attitudes.

The present study aims to fill that gap in providing policy makers in Al Ain—and across country—with accurate, comprehensive, and up-to-date information on the public acceptance of TWW reuse. The city of Al-Ain occupies a choice position, both nationally and throughout the region, it is presented as a model for managing to recycle 100% of its wastewater, but little was done to look into the acceptance of its actual and potential uses. Maraqa and Ghoudi [14] have tackled with the issue but their reporting was limited to Emirati nationals, around 30% of total population in Al Ain and even less at the national level [15], and they mainly concentrated on the descriptive statistics. The study aims to look more thoroughly into the respondents' sources of information, knowledge on water and wastewater, and different demographic factors and how they affect their attitudes toward TWW reuse.

Another main contribution of the present investigation is the use of principal component analysis (PCA) in examining TWW survey data, first to analyze data on the stated reasons of hesitation, then to investigate the respondents' acceptance of TWW reuse in various applications. The results hold some very significant fallouts regarding the psychological traits behind participants' attitude regarding TWW, and the factors that shape their attitude to the reuse of TWW.

## 2. Literature Review

Menegaki et al. [16]. looked into factors affecting social acceptance of recycled water reuse (and farmers' willingness to use TWW in agriculture and to pay for it) on the island of Crete, in Greece; one of the main upshots of the study is that respondents' attitude is owed to their environmental awareness. Alhumoud and Madzikanda [17] surveyed public willingness to use reclaimed water for a variety of purposes in Kuwait, the study showed that the main accepted uses are in agriculture and landscaping, and that education level and knowledge of wastewater reuse are the main factors affecting the respondents' choices, other factors include age, nationality and gender.

Other studies from five US and Australian cities [18], from China [19], and from the Middle East [20], showed a generally high public acceptance for the reuse of treated wastewater for end uses that involve little human contact, in industrial or environmental applications, such as firefighting, landscaping, and irrigating golf courses. However, the tendency is more varied [18], or quite opposite [17,19,21,22] for applications that involve human contact, that are directly connected to human consumption, as irrigation water for edible agricultural products, and even more unpopular, in drinking water supply.

A pilot study [23] in Chalkida, a small city in Greece, showed that the public is reluctant towards wastewater reuse in activities related to food production, the main reasons for their reluctance was tied to their lack of adequate information and lack of trust towards the managing and monitoring agencies. The effect of dissemination of positive information and targeted educational-and-outreach programs in increasing public acceptance was already suggested in previous studies [24,25], however, acceptance of TWW reuse depends also on individuals' trust in authorities and their perceptions on water quality [21].

Individual demographics such as gender, age and marital status were correlated with the attitude towards TWW reuse [17], along with other socio-economic factors, such as education, location, and income [16,25,26].

There are two main contributing explanations to the attitudes towards wastewater, a first factor, more rational, stems from the aversion to the risk of contamination, even though there are no known or established health outbreaks or issues generated by TWW reuse [27]. The studies in Beijing [19], Kuwait [17], and Deir Debwan [20] all report that public perception towards TWW reuse is mainly driven by health and environmental reasons.

The second factor is more psychological, prompted by the disgust towards wastewater, and repulsion toward it, it is also described as the "yuck factor" [27,28], and can be influenced by the language used by authorities or the media to talk about wastewater reuse [29]. In the same line, Alhumoud and Madzikanda [17] also points out religious beliefs as a third major concern of the respondents towards use of TWW.

A similar investigation on wastewater reuse acceptance is needed in the United Arab Emirates, to derive the factors affecting public attitudes towards the various uses of TWW and, to evaluate the need for action, including educational tools and communication campaigns to improve the public awareness. The current study also addresses an essential problem in wastewater management: the need for data to guide public decision making; this is a worldwide obstacle to drafting good policies for wastewater management [30]; and the lessons learned will have direct benefits to policy makers, concerned civil society organizations, and other researchers and professionals.

### 3. Materials and Methods

#### 3.1. Al Ain City Water Resources: Water Supply and Wastewater

The city of Al Ain, the geographical area of consideration for this research project, is part of the Emirate of Abu Dhabi, and is ongoing a major restructuring as per the "Plan Al Ain 2030" initiative by the Emirate Urban Planning Commission [31]. This initiative aims at presenting a coherent picture of the future of Al Ain as a modern city with an ancient foundation—environmentally, socially, and economically sustainable.

Based on data from 12. Ministry of Environment and Water [12], it is estimated that Al Ain uses 1250 hm<sup>3</sup> of water annually, most of which is for agriculture and forestry. The demand for water in Al Ain is mostly met through—mostly non-renewable—groundwater sources. Other alternate sources being Desalinated water and TWW.

Desalinated water in the estimates of 297 hm<sup>3</sup> is transported to the region (Table 1) and is primarily used to meet domestic and industrial demands. However, for a sustainable development the desalination process poses a risk, for the desalination technology consumes significant levels of electricity and leads to corresponding levels of greenhouse gas emissions, so it is costly, has an adverse impact on the environment and also affects the marine ecosystem [32].

**Table 1.** Consumption of Desalinated Water in the Region (hm<sup>3</sup>).

	2012	2013	2014	2015	2016
Emirate of Abu Dhabi	1059.2	1083.5	1128.8	1153.6	1116
Al Ain	286.4	293.4	294.4	316.4	296.7

Source: Abu Dhabi Water and Electricity Company & Statistics Centre Abu Dhabi [15].

TWW is a valuable alternative water resource and its potential is still under tapped in the UAE. TWW is increasingly being accepted worldwide in agriculture and other non-potable uses as it helps meet water needs and also helps deal with effluents in discharge water in a more cost effective and environment friendly manner. Data from Abu Dhabi Sewerage Services Company [15] shows that Waste treatment plants in Al Ain are capable of producing 82.4 hm<sup>3</sup> of treated wastewater annually (Table 2). The Zakher treatment plant is the major unit catering to recycling wastewater in the region. The total of 54.8 hm<sup>3</sup> of reused treated water accounts for some 5% of the annual water demand in Al Ain.

**Table 2.** Quantity of Wastewater Produced and Reused in Al Ain (hm<sup>3</sup>).

	2012	2013	2014	2015	2016
Total Capacity of Wastewater Treatment Plants	65.3	112.7	81.7	81.7	82.4
Quantity of Treated Wastewater Generated	55.9	59.1	67.6	67.6	65.3
Quantity of Treated Wastewater Reused	66	64.6	63.7	51.5	54.8

Source: Statistics Centre Abu Dhabi [15].

### 3.2. Questionnaire Design

For the purpose of this research the participants were interviewed based on a structured questionnaire designed to assess their awareness and level of acceptance for various uses of treated wastewater. The questionnaire was drafted to enhance comparability with previous research on treated wastewater acceptance, and compartmented into four sections:

- The first section investigates public acceptance for a wide range of wastewater application items, using a 5-levels Likert scale to measure the disagreement/agreement level (1 for Strongly Disagree, to 5 for Strongly Agree). Consistent and extending on related studies [19–21], 32 questions were used to cover the six main categories of applications: (i) industrial applications, (ii) non-food agriculture applications, (iii) home non-food applications, (iv) in the production of food agriculture, (v) as complement in water supply (for groundwater recharge or as water supply supplement), and, finally, (vi) in direct supply, either as potable water or water for ablution (wudu) for prayer.
- The following section examines participants' knowledge about water use in Al Ain, and wastewater treatment and reuse. It also includes questions on respondents' sources of information. In line with existing literature [19,33], six water and TWW awareness questions were included in the questionnaire, for each question, participants are presented with multiple choices, of which only one is the right answer.
- The third section consisted of a simple "Yes" or "No" question to investigate the respondents' reasons for hesitation towards of wastewater recycling. The question on perceived risk associated with TWW reuse was drafted with careful consideration to the similar concepts reported in previous studies. Six perceived risks associated with TWW reuse were hence considered for the current study: (i) Presence of toxic chemical substances, (ii) Presence of pathogenic microorganisms, (iii) Unpleasant odors, (iv) Disgust by human waste, (v) Religious or ethical reasons, and a final category, (vi) "Others", to specify, for any other reason. The respondents were asked to check all the reasons that influence their attitude.
- The last section collects (in nine questions) the participants' relevant demographic and socio-economic information.

The questionnaire starts off with a short letter addressing the ethical issues and seeking the respondents' agreement to participate in the survey interview, then follows with a quick definition of TWW.

### 3.3. Sampling and Implementation

The instrument of the survey was a structured questionnaire and data were collected through face-to-face interviews. A pilot sample of fifty respondents was run to check for the understandability of the questions by respondents and surveyors. The collected valid questionnaires amounted to 1426.

All the respondents were randomly selected from the city of Al Ain noting the ethnic and gender distributions of the population. Those quotas were determined based on the Statistical Yearbook of Abu Dhabi [15]. Interviews were conducted in public places during the period June to August 2017. Public places included malls, parks, markets, housing complexes, gyms, clinics, educational institutions and others. The actual descriptive statistics of the sample variables are presented in Table 3.

**Table 3.** Demographic characteristics of sample (1426).

		Frequency	Percent
Gender	Female	787	55.2
	Male	638	44.7
	Missing	1	0.1
Ethnicity	Non-National	814	57.1
	National	591	41.4
	Missing	21	1.5
Age Group	18–24 Years Old	323	22.7
	25–34 Years Old	527	37.0
	35–44 Years Old	390	27.3
	45–54 Years Old	152	10.7
	55 or Over Years Old	31	2.2
	Missing	3	0.2
Level of Education	Illiterate	27	1.9
	Elementary Diploma	45	3.2
	Middle School Diploma	67	4.7
	High School Diploma	281	19.7
	College Associate Degree	283	19.8
	University Bachelor Degree	574	40.3
	Master or Above Graduate Degree	146	10.2
	Missing	3	0.2
Sector of Employment	Self Employed	139	9.7
	Employed in Private Sector	468	32.8
	Public Sector	382	26.8
	Unemployed	193	13.5
	Student	229	16.1
	Others	12	0.8
Income	Missing	3	0.2
	Less than 2500 Emirati Dirhams (AED)	57	4.0
	2501–5000 AED	154	10.8
	5001–10,000 AED	293	20.5
	10,001–20,000 AED	341	23.9
	20,001–40,000 AED	288	20.2
	40,001–60,000 AED	182	12.8
	More than 60,001 AED	93	6.5
Marital Status	Missing	18	1.3
	Single	550	38.6
	Married	781	54.8
	Divorced	54	3.8
	Widow	27	1.9
Child 5 years or less	Missing	14	1.0
	No	957	67.1
	Yes	469	32.9

It is noteworthy to mention that Chen et al. [19], also conducted face-to-face interviews with sample size 714 respondents. Whereas in case of the study by Maraqa and

Ghoudi [14] the questionnaires were distributed to respondents and the sample size was 1079 respondents.

### 3.4. Data Analysis

The Database for this research was created on Microsoft Excel and was exported to SPSS 25 for statistical analysis. To understand the commonality of attitude towards various types of TWW reuse, PCA was first carried out with varimax rotation. Significant loadings onto this PCA are defined as those with loading factor greater than 0.5 in absolute values. Five components with Eigenvalues above 1.0 emerged and the scree plot also suggested the same.

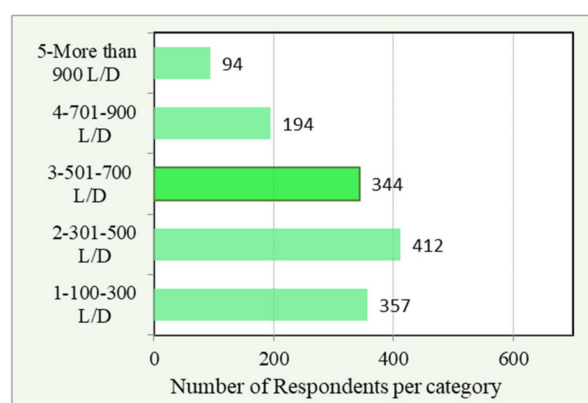
The results from the survey were also analyzed using simple descriptive statistics. Multivariate Regression analysis was performed to get a better understanding of the association between awareness, level of acceptance for various reuses of TWW, reasons for hesitation to use TWW and demographic characteristics. A similar approach was carried for the analysis of US household food waste [34].

This study and its procedures were reviewed and approved by the UAE University Ethical Committee Board.

## 4. Results

### 4.1. Awareness on Water and Wastewater Use & Sources of Information

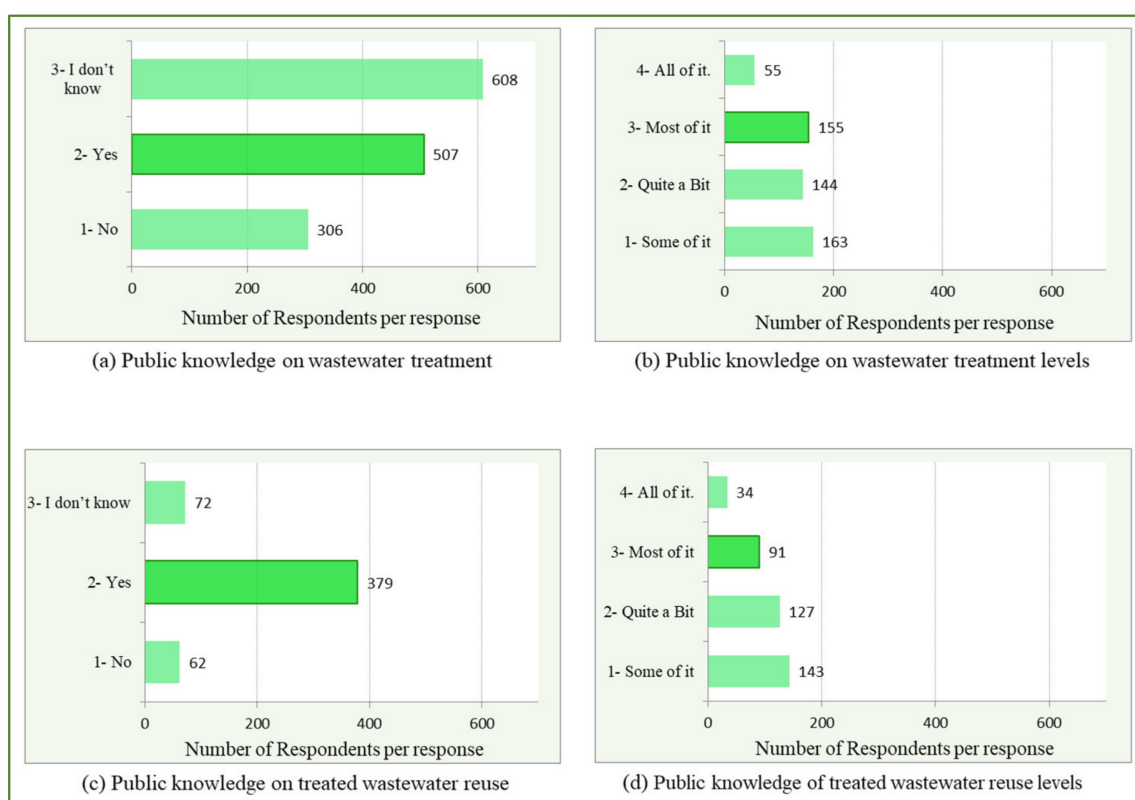
The survey data shows (Figure 1) that 55% of the respondents were not aware of the high per-capita water consumption in the city, 550 Liters/Day (L/D), while another 21% seemed to overestimate the daily consumption. Those results suggest that the public is not well informed about water usage and stresses the need for improved targeted information dissemination in line with improving water management practices in the city.



**Figure 1.** Public knowledge on Per capita Water Consumption (in Liters/Day).

The survey data (Figure 2) also shows that only a third (35.8%) of respondents, are aware of wastewater being treated in Al Ain, most subjects answered that they do not know (42.7%) or that no wastewater is treated (another 21.5%). The reality is that Al Ain generates 71.2 hm<sup>3</sup> of wastewater annually and the three wastewater treatment plants in the city produce together an average of 65 hm<sup>3</sup> of treated wastewater annually. In a follow-up question, limited to the (510) participants who responded “Yes” to the previous question on Al Ain wastewater been treated, only 155 (30.3% of questioned and 10.8% of total sample) responded—correctly—that most wastewater is being treated.



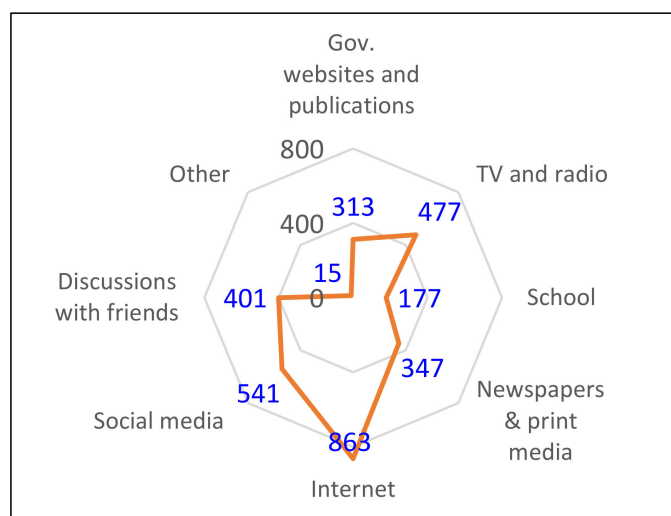


**Figure 2.** Public knowledge on wastewater treatment and reuse: (a) Public knowledge on wastewater treatment; (b) Public knowledge on wastewater treatment; (c) Public knowledge on treated wastewater reuse; (d) Public knowledge on treated wastewater reuse levels.

In another follow up question, participants are asked on the reuse of wastewater after treatment, where 73.8% of respondents (Figure 2) answered correctly that treated wastewater is being reused in the city. However, as revealed in a subsequent question, participants, for the most part, seem to understate the level of reuse, as 77% of them are not aware of the fact that in Al Ain most (84% or 54 hm<sup>3</sup>) of treated wastewater is reused.

A new variable, “total information”, was obtained by summing-up the number of participants’ correct answers to questions regarding their knowledge on water supply and wastewater treatment and reuse in Al Ain (in Figures 1 and 2). The findings suggest that there is room for improving public awareness regarding wastewater treatment and reuse in Al Ain.

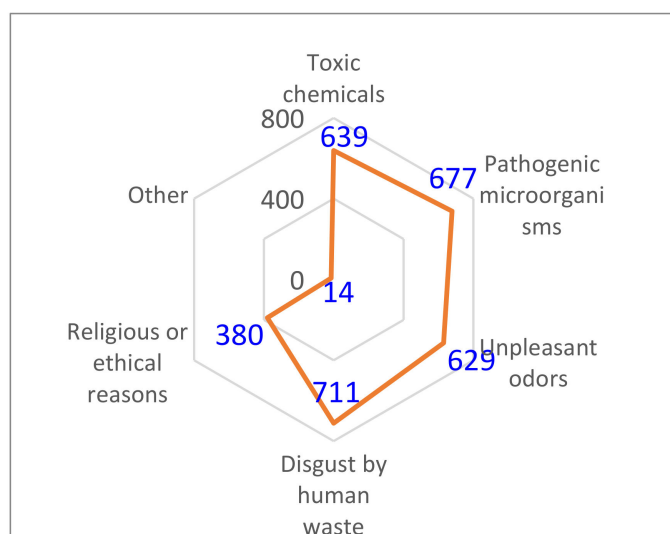
**Sources of information:** Respondents were questioned about their sources of information on water and wastewater (Figure 3). Online sources came as the leading information sources, with “internet” identified by a majority of respondents (61%), followed by Social Media (38%). Traditional—public—media outlets came next where third (33%) of respondents recognized TV and Radio as one of their sources of information, and another 24% for Newspapers and print media. Discussions with family and friends was recognized by a limited share of respondents (28%), but ranked higher than formal sources of information, with only 22% of respondents getting information from Government websites and publications, and another 12% from school and/or university.



**Figure 3.** Public information sources on water and wastewater.

#### 4.2. Reasons for Hesitation Regarding Reuse of TWW: Risk Aversion vs. Yuck Factor

A good share of participants justified their hesitations regarding the reuse of TWW by Disgust by Human Waste (50.1%), Pathogenic Microorganism (47.7%), Chemical Substances (45.1%), and *bad* odor (44.4%), while only 26.8% claim to be hesitant for religious or ethical reasons (Figure 4).



**Figure 4.** Public reasons of hesitations regarding wastewater reuse.

A PCA is then used to obtain a reduced set of core latent factors that sums up the consumers' hesitations reasons. The Kaiser–Mayer–Olkin (KMO) sampling adequacy test was equal to 0.549 which is acceptable for social sciences, and the Bartlett's test of sphericity rejected the null hypothesis (with a  $p$ -value < 0.001), which confirms that it is appropriate to use the PCA to examine the reasons for hesitations [35]. As presented in Table 4 of Varimax rotated factor loadings, the PCA delivered two significant factors with eigenvalues greater than one, that provide explanation for 51.9% of total variance.



**Table 4.** Rotated component matrix on wastewater reuse hesitation.

	Factor 1: Contamination Sensitivity	Factor 2: Disgust Factor
Reasons for hesitation:		
Pathogenic Microorganism	0.804	
Chemical Substances	0.754	
Disgust by Human Waste		0.690
Odor	0.358	0.635
Religious/Ethical Issues		0.602
Initial Eigenvalue	1.355	1.242
% of variance explained	27.11	24.84

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization (Rotation converged in 3 iterations).

All five hesitation reasons had high loadings, greater than 0.60, for one or the other of the two factors. The first factor captures the aversion to contamination by Pathogenic Microorganism and Chemical contaminants in wastewater and the second factor depicts broadly the emotional repulsion toward the reuse of wastewater for due to Disgust by Human Waste, bad Odor, and Religious beliefs and/or Ethical Issues. In line with existing literature [28], the two factors will be referred to as “contamination sensitivity”, for the first one, and “disgust factor”, for the second.

Indeed, previous research has already considered in detail the psychological aspects of wastewater reuse, describing how peoples’ hesitation toward wastewater reuse (and other pollutants and waste) is not totally dictated by an objective aversion towards—the risk of—contamination. In fact, it is also influenced by another factor, more psychological, a more subjective aspect, the “disgust factor”, also referred to as the “yuck factor”. For example, Menegaki et al. [29] show that people can have a more accepting attitude toward TWW when described as “recycled water”.

The PCA analysis of hesitation reasons provides a more empirical evidence on the distinction between the two factors. In addition, it allows to get the constructs for the “contamination sensitivity” and “disgust” factors that are included in later steps of the analysis, this step is especially important as the demographic and all other information that was collected does not show any usefulness in predicting the “disgust factor”.

#### 4.3. Attitude and Level of Acceptance for Various TWW Reuse Categories

Respondents level of acceptance for the 32 reuse applications of TWW were recorded and the responses are listed in Table 5.

A majority of respondents stated their acceptance for the reuse of treated wastewater in industrial applications; firefighting is the most accepted reuse (89%) of all suggested applications, with 35% of respondents opting for the “Agree” choice and 54% for “Strongly agree”. More than three quarters of respondents are accepting of TWW reuse in Construction (81%), Offices toilet flushing (79%), and Street cleaning (77%). Reuse in Commercial car-wash received a slightly lower approval (71%), while only few units above the average (54%) showed acceptance for TWW reuse in Commercial laundrettes.

Similar to industrial applications, reuse of treated wastewater was highly accepted in environmental uses, indeed, Forest irrigation (83%) and Landscape/sidewalks irrigation (82%) were respectively second and third most accepted reuse applications. Applications in public recreational facilities were slightly less favored, around three quarters of respondents approved of TWW reuse in the irrigation of Urban parks (77%), Sport fields (74%), Groundwater recharge for agricultural Reuse (72%) and Industrial crops irrigation (70%), and two thirds in Play grounds (66%).

**Table 5.** Public acceptance of TWW reuse in various applications.

	N	S-D <sup>1</sup> (1)	D <sup>1</sup> (2)	NA-ND <sup>1</sup> (3)	Ag <sup>1</sup> (4)	S-Ag <sup>1</sup> (5)	Average	Total Ap- proval
<b>Industrial applications</b>								
1. Firefighting	1418	2%	5%	4%	35%	54%	4.34	89%
2. Offices toilet flushing	1418	4%	9%	8%	39%	40%	4.03	79%
3. Construction	1418	2%	8%	9%	39%	43%	4.12	81%
4. Commercial car-wash	1411	4%	12%	13%	38%	33%	3.85	71%
5. Street cleaning	1414	3%	8%	12%	37%	40%	4.05	77%
6. Commercial laundrettes	1413	13%	18%	15%	28%	26%	3.36	54%
<b>Non Food Agriculture</b>								
1. Groundwater recharge agricultural Reuse	1417	5%	12%	11%	37%	35%	3.85	72%
2. Forest irrigation	1411	3%	7%	7%	45%	38%	4.07	83%
3. Landscape/sidewalks irrigation	1414	3%	6%	8%	45%	37%	4.07	82%
4. Urban parks	1418	3%	8%	12%	44%	33%	3.94	77%
5. Sport fields	1413	3%	10%	13%	40%	34%	3.92	74%
6. Playgrounds	1421	5%	15%	14%	35%	31%	3.71	66%
7. Industrial crops irrigation	1419	5%	11%	14%	37%	34%	3.83	70%
<b>Domestic</b>								
1. Home toilet flushing	1419	6%	16%	12%	30%	36%	3.74	66%
2. Home washing machine/laundry	1422	16%	26%	18%	23%	17%	2.98	40%
3. Recreational lake/swimming pool	1416	20%	28%	19%	20%	14%	2.79	33%
4. Bathing	1416	26%	29%	16%	17%	11%	2.57	28%
5. General cleaning	1417	15%	21%	25%	24%	16%	3.05	40%
<b>Food and Agricultural</b>								
1. Animal feed crops	1414	9%	18%	11%	37%	25%	3.50	62%
2. Vegetables irrigation (edible)	1419	17%	25%	12%	27%	19%	3.06	46%
3. Private garden irrigation	1414	8%	14%	14%	42%	21%	3.53	63%
4. Orchard irrigation	1415	9%	16%	15%	40%	21%	3.47	60%
5. Field crops irrigation	1409	11%	19%	13%	35%	21%	3.36	56%
6. Date palm trees irrigation	1409	12%	18%	12%	36%	21%	3.37	58%
7. Use in food processing industry	1414	22%	28%	18%	19%	13%	2.72	32%
8. Domestic cooking purposes	1414	28%	29%	16%	15%	11%	2.51	26%
9. Aquaculture/fish farms	1413	16%	25%	24%	22%	13%	2.92	35%
10. For drinking by farm animals/pets	1415	16%	25%	23%	21%	15%	2.94	36%
<b>Water Supply Supplement</b>								
1. Groundwater recharge (drinking water)	1420	24%	23%	19%	19%	15%	2.79	35%
2. Supplementing drinking water supply	1417	28%	22%	22%	17%	11%	2.62	28%
<b>Direct Supply and Wudu Application</b>								
1. Potable (drinkable) use	1415	33%	22%	18%	13%	14%	2.54	27%
2. Ablution (wudu) for prayer	1412	28%	20%	22%	17%	13%	2.66	30%

<sup>1</sup> S-D: Strongly Disagree; D: Disagree; NA-ND: Nor Agree nor Disagree; Ag.: Agree; S-Ag.: Strongly Agree.

Home applications show a higher variability; a majority of respondents was accepting of TWW reuse in Home toilet flushing (66%), but less favorable to all other TWW home applications. Reuse in General cleaning and in Home washing machine (and laundry) were favored by forty percent of interviewees, while only the third of respondents displayed acceptance for the reuse in Recreational lake/swimming pool (33%), since it involves more skin contact. Reuse in Bathing (28% acceptance) was even more rejected (55% when adding disagree and strongly disagree), as it entails further contact, including the possibility of digestion of TWW.

For food and agricultural applications, one can distinguish two main categories. For reuse in agriculture, the respondents generally expressed moderate acceptance for reuse in Animal feed crops (62%), Orchard irrigation (60%), Date palm trees irrigation (58%) and Field crops irrigation (56%). However, for freshly edible vegetables, acceptance was much lower (46%), which might reflect their perception of higher risk of contamination by fresh

products. This might also be the justification for respondents' relatively higher acceptance for TWW reuse in Private garden irrigation (63%), as the products are generally consumed by the private growers and their relatives, and, in doing so, do not pose a clear public safety problem. The second category of agricultural applications showed a significantly lower acceptability of TWW reuse, as it involves potential or perceived direct risks for human health. Only a third of respondents would approve of TWW reuse in fish farming (35%), as drinking water for farm animals (36%), or in human food preparation in the food processing industry (32%); the acceptance is even lower for Domestic cooking purposes (26%), interestingly, lower than TWW reuse in water supply.

The public does not generally favor the use of TWW in water supply, only (28%) of respondents thought that it was acceptable (agreed or strongly agreed) to use TWW as a supplement for drinking water supply (and 50% rejected it); the direct use of TWW as potable water was rejected by a slightly higher majority (55% while 27% approved). Less than third (30%) were in favor of TWW use for ablution (wudu) for prayer, which might be explained by the cultural and psychological aspects of ablution water, but also, by the attitude toward use of TWW to wash body parts including face and mouth.

Finally, a bit more (35%) were accepting for TWW use to recharge groundwater resources used in drinking water supply. This result reflects the perception that—infiltration in—groundwater can present a buffer to different risks related to TWW.

#### 4.4. Principal Components Analysis of TWW Acceptance of and Multilevel Regressions

##### 4.4.1. Principal Components Analysis of Acceptance of TWW Reuse

A PCA was carried to obtain a reduced set of principal components (PCs) that captures the consumers' acceptance of TWW reuse in various applications. The KMO test of sampling adequacy was equal to 0.942 confirming that correlations among the 32 items were appropriate for factor analysis, and the Bartlett's test of sphericity rejected the null hypothesis (with a  $p$ -value  $< 0.001$ ), which confirms that it is appropriate to use the PCA to examine consumers' acceptance [35].

As presented in Figure 5 of Varimax rotated factor loadings, the PCA delivered five significant factors with eigenvalues greater than one, that provide explanation for 69.6% of the total variance. Most items had high loadings, 28 (out of 32) greater than 0.60, for one of the five PCs. The five PCs replicate to a certain degree the classification of applications as outlined in the questionnaire, and are as follows:

1. Direct consumption acceptance: This factor summarizes the attitude toward the reuse of TWW in applications closely linked to human consumption, this applies to uses in water supply or direct uses as drinkable or ablution water, it also includes uses in food preparation, in aquaculture or for consumption by farm animals and pets.
2. Indirect Consumption acceptance: This factor summarizes the attitude toward the use in six applications in food agriculture, as irrigation water to grow products destined for human consumption or animal feed.
3. Non-food Agriculture acceptance: This factor summarizes the attitude toward all seven applications in non-food agriculture.
4. Industrial acceptance: This factor summarizes the attitude toward the reuse of TWW in industrial applications, it includes all listed applications except commercial laundries.
5. Skin Contact acceptance: This factor relates the attitude toward the reuse of TWW in most applications that involve skin or bodily contact; it includes all home applications, in addition to commercial laundries.

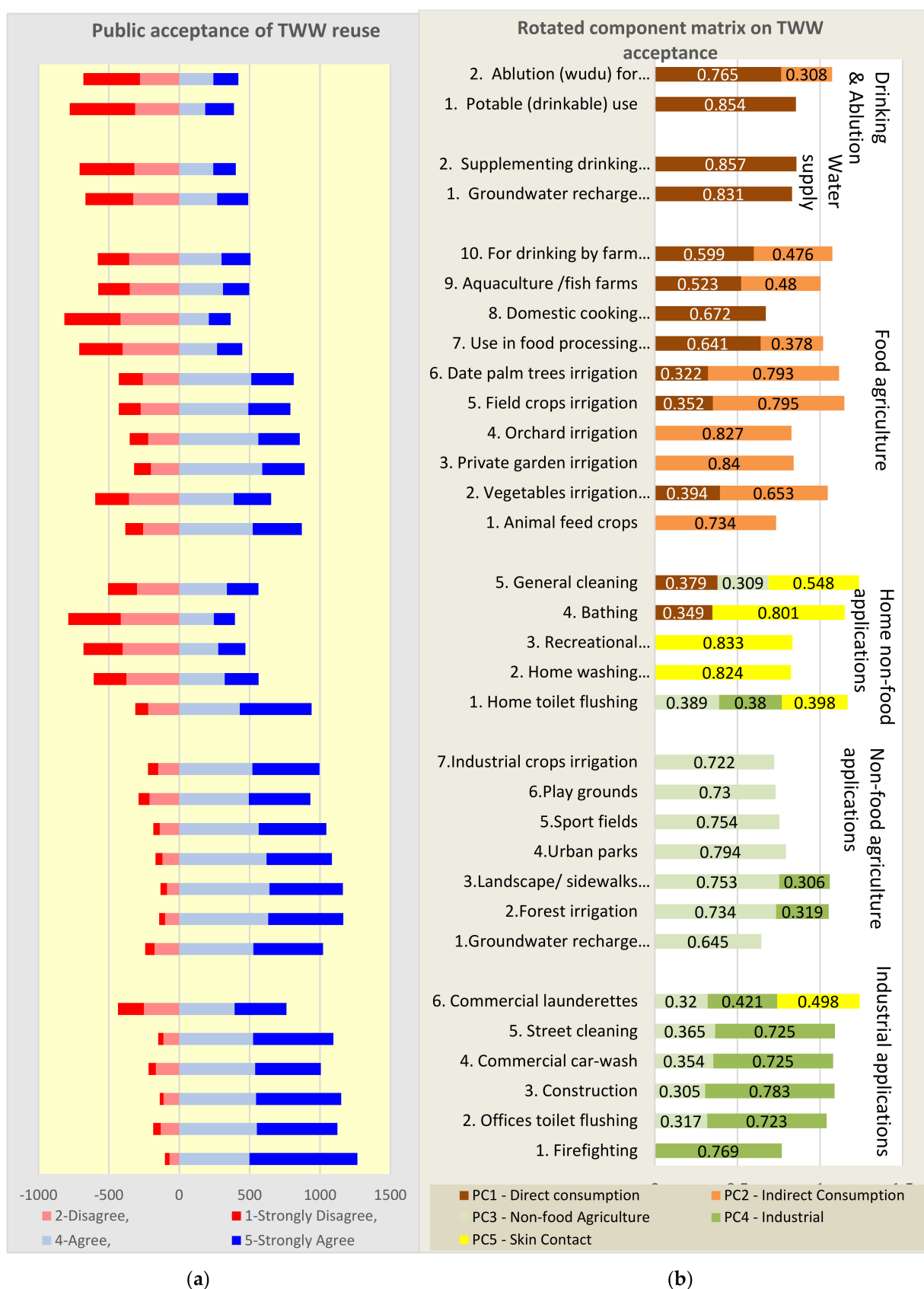


Figure 5. (a) Public acceptance of TWW reuse; (b) Results of PCA analysis of TWW acceptance data.

Table 6a depicts the average (weighted) acceptance of all applications by factor, it shows that the more accepted applications are those associated with the Industrial and the Non-food Agriculture factors. Indirect Consumption is associated with moderate acceptance levels. The levels of acceptance are lower for applications that involve skin contact and even lower with direct consumption.

**Table 6.** (a) Average acceptance by principal component; (b) One-Way ANOVA for the association between TWW applications' main factor and application average acceptance.

(a)					
Factor	Average Acceptance	Number of Applications	Std. Deviation	Rank of Interaction	
Direct consumption (PC1)	2.67	8	0.17	5	
Indirect Consumption (PC2)	3.37	6	0.18	3	
Non-food Agriculture (PC3)	3.92	7	0.14	2	
Industrial (PC4)	4.09	5	0.18	1	
Skin Contact (PC5)	3.06	6	0.43	4	
Total	3.37	32	0.59		
(b)					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.156	4	2.289	40.645	0.000
Within Groups	1.521	27	0.056		
Total	10.677	31			

The results of one-way ANOVA analysis (Table 6b) confirm the high level of association between the of wastewater applications' main factor and their average acceptance ( $F(4,27) = 40.64, p < 0.0001$ ). This relationship is reinforced and refined through Spearman's Rho test showing the strong negative correlation between the "rank of interaction" of main factor of wastewater applications (provided in Table 6a, lowest at 1 for Industrial and highest at 5 for Direct Consumption) and their respective average acceptance ( $r_s = -0.914, p < 0.0001$ ).

#### 4.4.2. Multilevel Regressions

Multiple linear regression models were utilized to determine the statistical significance of the independent variables in explaining the variability in the explained variables. Model 1 in Table 7 regresses the dependent variable Risk Factor on the listed independent variables. The variable Risk Factor or Contamination Sensitivity is a composite—using PCA factor loading in Table 4—of the respondents' answers to the question about their reasons of hesitation regarding usage of TWW (Figure 4). Most of the information sources are statistically significant. Specifically, respondents' source of information regarding TWW from government websites and publications, newspapers, social media, and social discussions seem to partially shape their motives for hesitation in using TWW.

Ethnicity and marital status are both statistically significant and positively related to Risk Factor. On the other hand, age group and number of children under the age of five are negatively related to Risk Factor and statistically significant. Therefore, Emiratis and singles are expected to be less risk averse with respect to contamination sensitivity whereas older respondents and having five-year-old children or younger seem to be more cautious to the risk factors represented by concerns for contamination from TWW.

**Table 7.** Regression results on wastewater recycling hesitation and acceptance factors.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
	Risk Factor		Disgust Factor		Direct Consumption		Indirect Consumption		Non-Food Ag		Industrial		Skin Contact	
	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.	B	Sig.
(Constant)	0.422	0.029	0.727	0.000	0.520	0.006	0.164	0.423	−0.182	0.370	−0.236	0.265	0.379	0.061
Gov. Websites and Publ.	−0.264	0.000	−0.209	0.001	0.186	0.004	0.104	0.135	−0.110	0.110	−0.104	0.148	0.069	0.315
TV and Radio	−0.006	0.918	−0.270	0.000	0.003	0.964	0.193	0.002	−0.069	0.262	−0.007	0.912	−0.008	0.893
School	−0.060	0.472	−0.126	0.121	0.066	0.422	−0.047	0.596	−0.088	0.324	−0.025	0.783	−0.050	0.573
Newspaper	−0.182	0.004	−0.275	0.000	−0.070	0.261	−0.047	0.483	0.082	0.221	0.004	0.952	−0.054	0.413
Internet	−0.084	0.132	−0.144	0.009	0.005	0.928	0.156	0.009	0.009	0.877	−0.012	0.845	0.006	0.920
Social Media	−0.172	0.002	−0.362	0.000	−0.009	0.875	−0.076	0.193	0.218	0.000	0.063	0.295	−0.010	0.867
Social Discussions	−0.167	0.004	−0.360	0.000	−0.112	0.051	0.003	0.964	−0.061	0.323	−0.079	0.223	−0.009	0.889
Gender	−0.052	0.355	0.072	0.193	0.250	0.000	−0.147	0.013	−0.019	0.748	0.010	0.874	0.097	0.100
Ethnicity	0.451	0.000	−0.245	0.000	0.474	0.000	−0.244	0.001	0.127	0.073	−0.075	0.308	0.255	0.000
Age Group	−0.139	0.000	0.010	0.742	−0.090	0.005	−0.016	0.636	0.117	0.001	0.042	0.238	−0.006	0.873
Education	−0.038	0.098	−0.032	0.149	−0.105	0.000	−0.017	0.494	0.040	0.099	0.023	0.360	−0.090	0.000
Sector of Employment	−0.003	0.900	−0.008	0.719	−0.042	0.070	−0.022	0.371	0.032	0.207	−0.049	0.061	−0.029	0.251
Income	−0.006	0.769	0.015	0.461	−0.039	0.064	−0.015	0.496	−0.065	0.004	0.058	0.013	0.010	0.668
Marital Status	0.147	0.007	−0.039	0.464	0.079	0.139	−0.013	0.816	−0.118	0.040	−0.017	0.771	0.002	0.971
Child_5_Or_Less	−0.122	0.050	0.063	0.298	−0.122	0.045	0.055	0.405	0.119	0.070	0.075	0.268	−0.001	0.984
Tot_Info_level	0.036	0.083	0.038	0.062	0.122	0.000	0.132	0.000	−0.015	0.483	−0.018	0.413	0.015	0.490
Risk factor					0.080	0.002	0.080	0.005	−0.066	0.021	−0.051	0.084	0.172	0.000
Disgust factor					0.159	0.000	0.113	0.000	−0.020	0.502	0.020	0.508	0.040	0.166

Model 2 regresses Disgust Factor on the same explanatory variables in Model 1. The source of information variables were all statistically significant and positively related to Disgust factor except for the variable Schools. However, all the demographic variables were statistically insignificant except for ethnicity, which is negatively related to Disgust Factor. Those results imply that the respondents' disgust from TWW is mainly due to information received from different sources and Emiratis are more likely to be disgusted than other nationality although Emiratis were shown to be less sensitive to contamination (Model 1).

Risk Factor and Disgust Factor in Models 3 to 7 were used as regressors in addition to the explanatory variables used in Models 1 and 2. The dependent variables in Models 3 to 7 were adopted from the PCA results presented above. Unlike in Models 1 and 2, sources of information seem to play a lesser role in explaining the respondents' acceptance of TWW. That is evident from the insignificance of any of those sources of information in Models 6 and 7. In addition, in Model 5 only Social Media is statistically significant from all information sources. It implies that Social Media is positively related to respondents' acceptance of TWW usage for non-food agricultural purposes. Internet and TV and Radio were statistically significant with respect to their positive relation to the respondents' acceptance of TWW for use in indirect consumption applications. In the case of Model 3, Government Websites and Publications is statistically significant and positively related to direct consumption of TWW. However, Social Discussions as a source of information seem to be statistically significant but negatively related to direct consumption of TWW.

The demographic variables play a major role in explaining the variation in Model 3 where five of the eight variables were statistically significant. Gender and Ethnicity were statistically significant implying that male and Emirati respondents were more accepting of TWW use for direct consumption. On the other hand, older, better educated, and having children of five years old or younger respondents seemed less accepting of TWW usage for direct consumption. In Model 4, TV and Radio and Internet as sources of information increase the acceptance of respondents to the usage of TWW for indirect consumption. However, opposite to their role in Model 3, Gender and Ethnicity seem to reduce the respondents' acceptance of TWW for use in indirect consumption in Model 4.

Model 5 fits the data for Non-food Agricultural use of TWW. The variables Age Group, Income, and Marital Status were found to be statistically significant implying that respondents with a higher income and not being single seem to accept less of TWW use



in non-food agricultural applications; however, older respondents seemed to favor this type of usage. The only statistically significant variable in Model 6 was Income where higher income respondents were more accepting of using TWW for industrial purposes. Ethnicity and Education were the only statistically significant variables in Skin Contact Model. Emiratis seemed more accepting while more educated less accepting of TWW to get in contact with their own skin.

The variable Total Information Level was composed of the answers of the respondents to the questions related to their knowledge about the water situation in Al Ain. This variable showed statistical significance in Models 3 and 4 related to direct and indirect consumption of TWW. In both models, the increments in the knowledge of the respondents about the water situation in Al Ain seemed to enhance their acceptance of usage of TWW in both applications of direct and indirect consumption.

The variables Risk Factor and Disgust Factor were both statistically significant in Models 3 and 4. Respondents with higher sensitivity to contamination and with negative attitude of disgust towards TWW seemed to be less accepting of utilizing TWW in direct and indirect consumption. In addition, the disgust factor did not seem to play a role in the non-food agricultural use of TWW model while Risk Factor was statistically significant implying more acceptance of use of TWW in non-food agricultural applications by respondents with higher sensitivity to contamination from TWW. Model 7 showed less acceptance on the part of respondents to TWW contact with skin when the sensitivity towards contamination is high. The goodness of fit of the models seem low as shown by the values of the coefficients of determination  $R^2$  and adjusted  $R^2$ . However, this should not be surprising since the data fitted was cross sectional. Amongst all the seven models, Models 3 showed the best fit and the highest number of statistically significant variables.

## 5. Discussion

The present study considers a wide range of applications for TWW reuse. For comparison, Chen et al. [19] analyzed two broad categories of applications for acceptance of TWW responses, namely, Non-Body Contact/Non-Potable reuses and Potentially potable Reuses, for a total of 13 reuse applications. Similarly, seven reuse applications were considered by Maraqa and Ghoudi [14], with only “Yes” or “No” responses. Po et al. [21] considered 12 reuse applications and the levels of acceptance were marked on a five-point scale. In the study by Menegaki et al. [16], the final value of the stated likelihood of using recycled is computed as the sum of 10 items, each representing one particular water use. The 10 alternative uses were: watering the garden (flowers, trees, and shrubs), washing clothes/doing laundry, cooking, showering/taking a bath, drinking, brushing teeth, toilet flushing, cleaning (the house, windows, and driveways), watering the garden (vegetables, and herbs to be eaten raw), and washing the cars.

Research studies in Australia [33] and China [19] provide evidence that respondents' knowledge about treated wastewater is a key factor in their attitudes to TWW reuse, along with demographic and socio-economic characteristics. Unlike figures from the current study, about 90% of respondents in the Beijing [19] survey are aware of TWW reclamation and reuse. Their study also reports that 75% of the respondents realize the city is facing a severe water shortage; this has not been included in the present study. In contrast to the current study, 70% of the respondents in the Beijing study are aware of the waste treatment facilities in the city. Alhumoud and Madzikanda [17] report that 38% of Kuwait study respondents are not aware at all about TWW and its reuse, they have not reported any other awareness question in their article.

The obtained results regarding low-contact applications are in line with the previous studies in Beijing [19] and Deir Debwan in Jordan [20], where a large majority of the public (more than 80% in both cases) support the use of recycled water for non-potable, agricultural, and industrial uses. Similarly, Alhumoud and Madzikanda [17] report that Agriculture/Landscaping and House Washing as the most accepted reuse application for TWW in Kuwait.

Similar research in Perth [21] indicated that it becomes less fair to ask people to use treated wastewater as the uses move closer to human contact, most of participants (62.7%) thought it was unfair or extremely unfair to ask people to use treated wastewater for drinking or cooking. The acceptance of wastewater reuse in cooking and or as drinking water is even lower in Kuwait [17], respectively, at 8% and 5%.

The multiple regression results showed that most sources of information about TWW were significantly important in explaining the respondents' sensitivity and hesitation to using TWW. However, those information sources were less important in explaining the respondents' acceptance of using TWW in different applications. The demographic variables were instrumental in explaining the variabilities in the hesitation model due to contamination sensitivity and the acceptance model related to direct consumption. The statistically significant demographic variable in Models 1 and 3 share the same signage. That is perhaps an indication of a relation between the psychological factors related to hesitation in using TWW and the acceptance, or lack of, of using TWW in application connected with direct consumption. In addition, the results showed that hesitation could be decomposed into two factors, namely, contamination sensitivity and disgust factors. Those two factors intuitively separated the psychological factors from the disgust factors effectively when explaining reasons for hesitation in using TWW. Respondents' knowledge about the water situation in Al Ain was found to be of importance only in explaining the acceptance of using TWW in direct and indirect consumption uses. Disgust factor seemed to explain part of the respondents' acceptance of using TWW only in the two cases of direct and indirect consumption. However, contamination sensitivity appeared statistically significant all acceptance models except for industrial use (Model 6). It also carried a negative sign in models related to use of TWW in consumption related application or uses that have to do with skin contacts. Intuitively, the connection here was evident between TWW use and the risk factor associated with hesitation in using TWW.

## 6. Conclusions

The UAE is an arid country that relies heavily on energy intensive desalination for the supply of its growing agglomerations; at the same time, at over 500 Liter/Day, the country's per-capita water use is one of the highest in the world. The reuse of treated wastewater presents therefore the ideal solution for increasing water supplies while easing the economic and environmental costs of seawater desalination and the pressure on groundwater resources.

The study main objective is to assess public acceptance of TWW reuse in Al Ain city and identify the factors that influence public attitudes towards TWW reuse. The results show a high acceptance for low human contact applications, while applications involving direct and indirect consumption, or skin contact, are less accepted. Five core categories of applications are delivered through PCA analysis, and applications' levels of acceptance are shown significantly correlated with their category "rank of interaction".

The hesitation reasons are attributed to the attitude toward a perceived risk of contamination by TWW and another psychological yuck factor related to disgust of wastewater. Both factors are negatively affected by the provision of good information through various sources and media outlets, including social media, newspapers, and government websites and publications.

To increase public support for TWW reuse, policy makers can rely on these findings to improve their communication on the subject and on water conservation in general, using the right mix of messaging, communication medium, and information content, to provide clear and accurate information to the most reluctant and/or uninformed demographics.

Finally, the study is but a modest first step that highlights the potential benefit for future research on social acceptance from adopting appropriate econometric models. In the case of the UAE, future research on TWW acceptance should also consider questions related to environmental attitudes and trust in media and government, to better advice

government efforts to communicate on the topic and bring more awareness on water security issues.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The dataset will be shared by the authors if requested. The data analysis only required basic statistical manipulations on SPSS, the output file will be shared if requested.

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