water

MDPI

Article

Sustainability of a Low-Cost Decentralized Treatment System for Wastewater Reuse: Resident Perception-Based Evaluation for Arid Regions

Mohammad T. Alresheedi [1,*], Husnain Haider [1], Abdulmohsen M. Albuaymi [1], Saleem S. AlSaleem [1], Md. Shafiquzzaman [1], Abdulaziz Alharbi [2] and Amimul Ahsan [3,4]

1 Department of Civil Engineering, College of Engineering, Qassim University, Buraydah 51452, Saudi Arabia; h.chaudhry@qu.edu.sa (H.H.); 411100187@qu.edu.sa (A.M.A.); sa.alsaleem@qu.edu.sa (S.S.A.); m.uzzaman@qu.edu.sa (M.S.)
2 Department of Plant Production and Protection, College of Agriculture and Veterinary Medicine, Qassim University, Buraydah 51452, Saudi Arabia; abb.alharbi@qu.edu.sa
3 Department of Civil and Environmental Engineering, Islamic University of Technology (IUT), Gazipur 1704, Bangladesh; ahsan.upm2@gmail.com
4 Department of Civil and Construction Engineering, Swinburne University of Technology, Melbourne 3122, Australia
* Correspondence: m.alresheedi@qu.edu.sa

Abstract: Small communities and most rural settlements in the Kingdom of Saudi Arabia (KSA) store domestic wastewater in residential septic tanks and transport it to the nearest centralized wastewater treatment plant. Without a sanitary sewerage system, the residents encounter various socioeconomic and environmental challenges related to sewage collection vehicles, the production of objectionable gases, and leaking septic tanks. The present study developed a resident perception-based methodology to appraise the sustainability of a low-cost ceramic filter bioreactor-type decentralized wastewater treatment system (DWWTS) for a small community of 1300 residents (160 households) in Qassim (KSA). In addition to six demographic factors, nine indicators assessed residents' perceptions about existing and proposed wastewater management systems. A hierarchical-based system of sub-indices evaluated the three dimensions of sustainability using four environmental, nine social, and three economic indicators. The indicators translated into dichotomous questions posed to 34 respondents in the study area. The statistical analysis assessed the association of responses with the willingness to accept (WTA) the proposed DWWTS. A subjective rating scheme translated the responses into performance scores, and a fuzzy-based method aggregated the scores into sub- and top-level indices. The top of the hierarchy showed a close agreement between the resident's perception and DWWTS' sustainability. The study found that residents' knowledge about environment and resource conservation resulted in a moderately high willingness to reuse treated effluent and WTA the decentralized system. The study also showed that the economic viability of a DWWTS remained at a moderate performance level due to a low monthly waste disposal cost. The study's findings present a high potential for sustainable community-maintained DWWTS initially supported by the government. The proposed approach facilitates decision-makers working in ministries concerning water resources, environmental protection, and agricultural production in evaluating the sustainability of DWWTS for small communities in arid regions.

Keywords: decentralized wastewater treatment plants; sustainable wastewater treatment systems; wastewater reuse; resident perception; willingness to accept; willingness to pay

check for updates

Citation: Alresheedi, M.T.; Haider, H.; Albuaymi, A.M.; AlSaleem, S.S.; Shafiquzzaman, M.; Alharbi, A.; Ahsan, A. Sustainability of a Low-Cost Decentralized Treatment System for Wastewater Reuse: Resident Perception-Based Evaluation for Arid Regions. *Water* **2023**, *15*, 3458. https://doi.org/10.3390/w15193458

Academic Editors: Anas Ghadouani and Andrea G. Capodaglio

Received: 1 September 2023
Revised: 26 September 2023
Accepted: 28 September 2023
Published: 30 September 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Wastewater reclamation has become a priority in the Kingdom of Saudi Arabia (KSA) due to accelerating urban water demand and the high environmental value of municipal wastewater originating after using the desalinated water supply. Centralized wastewater treatment systems (CWWTSs) treat around 70% of the generated wastewater in the country [1]. The treated effluent is reused for restricted and unrestricted irrigation or discharged into the receiving water bodies, locally called Wadis [2]. CWWTSs serve high-density urban areas to treat large quantities of wastewater sustained by heavy pumping machinery, large sewers, and complex treatment processes. Without a sewerage network, low-density and rural regions rely on unlined or lined septic tanks and subsequent discharge into sewerage systems or wastewater transportation to the nearest CWWTS [3]. Onsite treatment with septic tanks is not a sustainable decentralized wastewater treatment system (DWWTS) due to a lack of maintenance and desludging practices in rural settings [4].

In the water scarcity situation in arid regions, reusing treated wastewater for irrigation or landscape applications and sludge as a soil conditioner is a sustainable wastewater management practice for smaller communities. As the idea of circular economy gains popularity with awareness, even smaller settlements can achieve economic benefits of wastewater treatment byproducts [5,6]. An innovative DWWTS supported with a simplified sewerage system for onsite treatment and reuse is a sustainable solution for smaller communities. Although a DWWTS can effectively treat RST's effluent to protect public health, control groundwater pollution, and preserve water resources, the long-term sustainability of such wastewater management strategies is subject to informed and cooperative residents [7]. In addition, without implementing design standards or guidelines for onsite disposal, wastewater collected in residential septic tanks (RST) infiltrates the soil, posing a groundwater pollution risk [8]. Sometimes, private trucks transport sewage from RST to the nearest CWWTS at a specific cost. In addition to the unavailability of treated wastewater as a useful resource, the residents of such areas face several socioeconomic and environmental challenges, e.g., calling for a collection vehicle and basis, noise of wastewater pumping from RST, and soil and groundwater pollution from seepage from RSTs [9].

Low-cost wastewater treatment processes can change or improve the residents' perception of shifting from the existing RST-based scenario to a more sustainable DWWTS. Membrane bioreactor (MBR) is becoming the technology of choice for municipal and industrial wastewater treatment and reclamation [10–12]. The MBR technology allows for physical separation (through membrane filtration) and biological treatment in the same reactor and has small footprints compared to conventional activated sludge [13]. MBR also produces high-quality effluent with removals of total organic carbon (TOC), chemical oxygen demand (COD), and biological oxygen demand (BOD), exceeding 92%, which makes it an appropriate technology for water reuse or recycling [11,14]. Nevertheless, MBR technology is still costly regarding membrane and maintenance costs and energy consumption. Therefore, a simple, cost-effective, and low-maintenance MBR process would be an ideal DWWTS for smaller and rural communities not connected to the sewerage network of the nearest CWWTS.

Low-cost ceramic filters made of locally available materials (such as clay) can be an economical replacement for membranes in a biological reactor for wastewater treatment. Low-cost ceramic filters have been effectively used for treating artificial greywater as well as wastewater [15], backwash water [16], ablution greywater [17], and stormwater [18]. Authors in their previous work [9] developed a laboratory-scale low-cost ceramic filter bioreactor (CFBR) system to treat residential septic tank (RST) effluent for a small community located in the Qassim Province of KSA. The CFBR was optimized for removing nitrogen compounds through the nitrification/denitrification process and effectively treated the RST effluent to meet the irrigation and landscaping standards set by KSA and the World Health Organization (WHO). Improving residents' participation and establishing a source of funding through a tariff system implementation enhance the sustainability of decentralized systems [19]. For effective implementation, the CFBR system's sustainability (in addition to technical performance) needs to be assessed based on the smaller community residents' perception of DWWTS and willingness to accept and pay.

Demographic factors, awareness of environmental issues, risks associated with the quality of a product, and the product's potential environmental benefits correlate with willingness to pay [20]. Studies also found a higher perception of the product's likely benefits results in higher financial sacrifices that consumers would be willing to make [21]. In the case of a DWWTS, residents' perception is a function of various considerations, for example, knowledge about the existing wastewater treatment and reuse scenario, the inconvenience caused by onsite storage in RST, and awareness about losing treated effluent as a resource. Higher perception due to better knowledge and understanding of DWWTS benefits yields high environmental endurance, social acceptability, and economic viability, consequently leading to a high sustainability score of DWWTS in a smaller community. Multiple indicators are required to assess each dimension of sustainability. For instance, impacts on human health, groundwater, and soil can evaluate environmental endurance brought up by the DWWTS. Likewise, willingness to accept (WTA) a decentralized system in the area and associated positive (reuse of treated effluent) and negative (noise and reduction in land value due to DWWTS operations) impacts can assess social acceptability. Finally, willingness to pay (WTP) can appraise the economic viability of such systems for smaller communities.

Genius et al. [22] analyzed willingness to use and pay for a centralized wastewater treatment facility using the dichotomous choice method in northwest Crete, Greece. They found that the average WTP and monthly water bills were more than the required investment. Byambadorj and Lee [23] investigated WTP to improve water and wastewater systems for smaller communities in Ulaanbaatar City, Mongolia, using the contingent valuation method. They observed a strong correlation between WTP and socioeconomic parameters (residents' education level, monthly water bill, family size, and income level), and knowledge and information about the system improved WTP. Capodaglio [24] reviewed various technologies and found that local issues and operational competency play the most critical roles in the sustainability of DWWT. Therefore, in addition to WTP, resident perception relates to the operations, which is essentially an outcome of acceptance of a DWWTS, as motivated and aware residents can manage the system more effectively. A study on the sustainability of an operational integrated DWWTS for rainwater harvesting and wastewater reclamation in a higher education institution in India used detailed cost data, water demand analysis, and energy utilization [25]. Although the approach provided useful performance indicators for long-term evaluation, detailed data for such analysis is not readily available in rural settlements. Torre et al. [26] found that the feasibility of CWWTS and DWWTS for urban settings depends on many parameters and recommended using life-cycle analysis, cost management techniques, and quantitative tools for site-specific solutions.

Resident perception and knowledge about wastewater treatment technologies, the importance of resource conservation, and environmental issues due to inappropriate wastewater affect their willingness to reuse treatment effluent, WTA, and WTP, critical factors for a sustainable DWWTS in smaller communities within arid regions. To the authors' knowledge, no past study linked resident perception with the sustainability of DWWTS. Therefore, the present study developed a resident perception-based methodology for evaluating the sustainability of DWWTS for smaller communities in arid regions. The core objectives were to (i) develop a set of indicators for social, environmental, and economic dimensions of sustainability, (ii) expand the indicators to multiple-choice questions and conduct in-person interviews with the study area's residents, and (iii) assess the sustainability scores for all the three dimensions using a fuzzy-based method to accommodate subjective data and variations in respondent's opinion.

2. Background of Study Area

The Qassim region in the Center of KSA has five central wastewater treatment plants serving the main cities, including Buraydah, Unayzah, Alrass, and Al Bukayriyah. In addition to high initial and energy costs, a CWWTS imposes extensive technical and management expertise to operate complex infrastructure and, hence, is not a sustainable treatment option for smaller communities which are beyond the proximity of large cities.

A small community of 1300 population and around 160 households called Alqaraa, located approximately 30 km outside Buraydah, the capital of the Qassim Province (KSA), was selected as the study area based on the smaller population, wastewater quantity, and existing collection and disposal practices. Figure 1 presents the location map of the study area. Each household in the Alqaraa community has an independent RST to collect sewage. The sludge settles at the bottom of the tank over time, and some sewage infiltrates through the soil. Subsequently, the RST's effluent is collected and transported by private trucks to the nearest Al-Bukayriyah city's CWWTS. Samples of the RST effluent were collected and used as CFBR influent. The samples were taken from the RST effluent using dark-colored sealed bottles, stored in an ice box, and transported to the Environmental Engineering Laboratory in the College of Engineering, Qassim University. Table 1 presents the RST effluent quality in the study area.

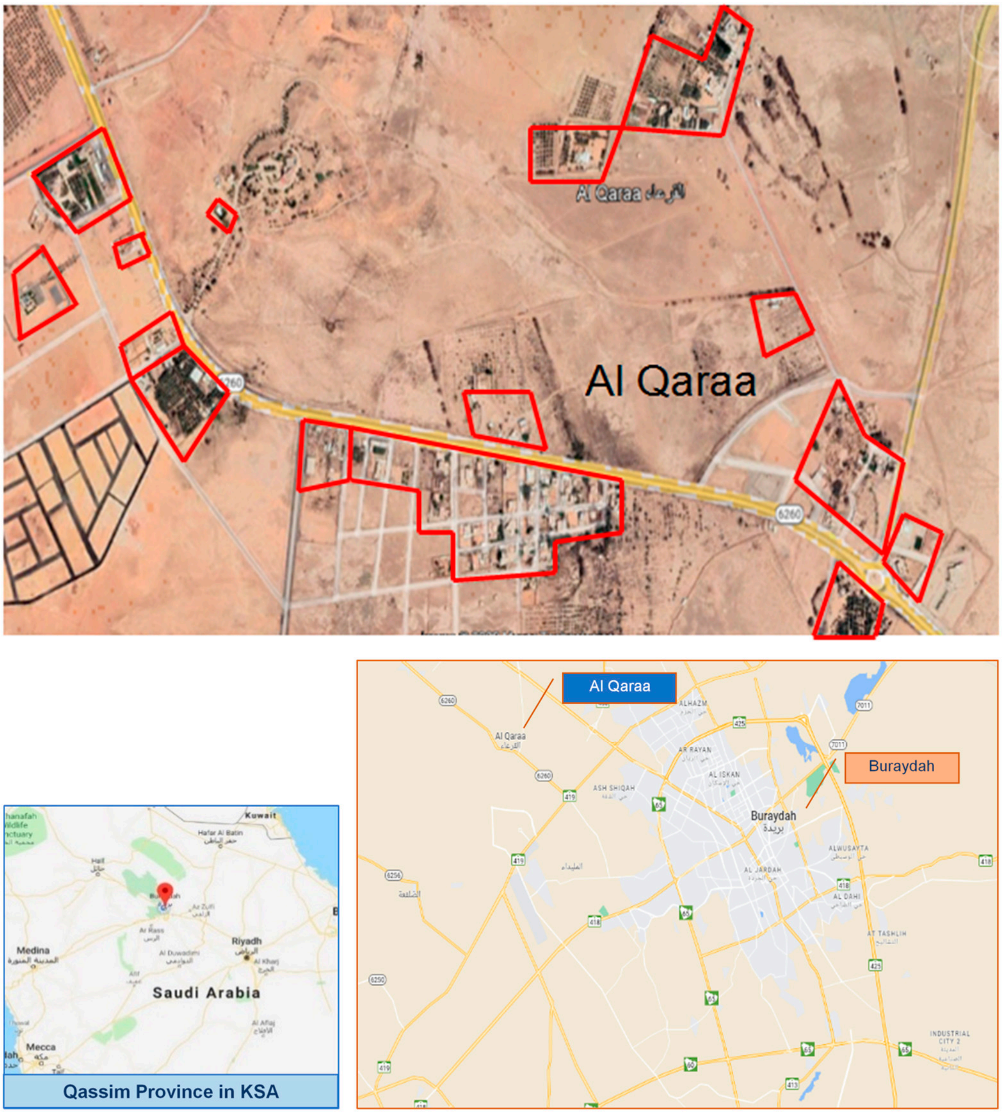

Figure 1. Study area showing the location of Alqaraa village in the Al-Qassim region, KSA.

Table 1. Water quality results of residential septic tanks' effluent in the study area.

No	Parameter	Units	Septic Tank Effluent Concentration	Treated Effluent Using Low-Cost BIOREACTOR [9]	KSA Wastewater Standards for Unrestricted Irrigation [2]
1	pH	-	7.3 ± 0.32	7.8 ± 0.31	6–8.4
2	Electrical conductivity (EC)	µs/cm	1555 ± 48	-	-
3	Dissolved oxygen (DO)	mg/L	8.85 ± 0.64	7.7 ± 0.55	-
4	Ammonia nitrogen (NH_3-N)	mg/L	34 ± 3.55	3.4 ± 0.26	5
5	Biochemical oxygen demand (BOD_5)	mg/L	160 ± 12.31	4.6 ± 2.8	10
6	Chemical oxygen demand (COD)	mg/L	386 ± 14.62	18.1 ± 3.4	50
7	Total suspended solids (TSS)	mg/L	157 ± 22.54	<1	10
8	Phosphate (PO_4)	mg/L	18 ± 2.88	31 ± 3	10

Presently, domestic wastewater collected in the septic tank installed in the household is transported to the nearest CWWTP by a truck to pick up upon a call at a specific cost. Consequently, the residents of the study area face several socioeconomic and environmental challenges, such as (i) calling and waiting for a collection vehicle on a fortnightly basis, (ii) noise and odor (particularly in summer season) nuisance during the pumping of wastewater from the septic tank, (iii) inability to use treated effluent for landscaping or irrigation, (iv) soil and groundwater pollution from seepage from unlined septic tanks and potential leakage from lined ones, and (v) bearing wastewater transportation cost. Figure 2a illustrates the present wastewater collection and disposal scenario in the study area. Figure 2b shows the proposed DWWTS scenario as a sustainable wastewater management system for smaller communities in arid regions.

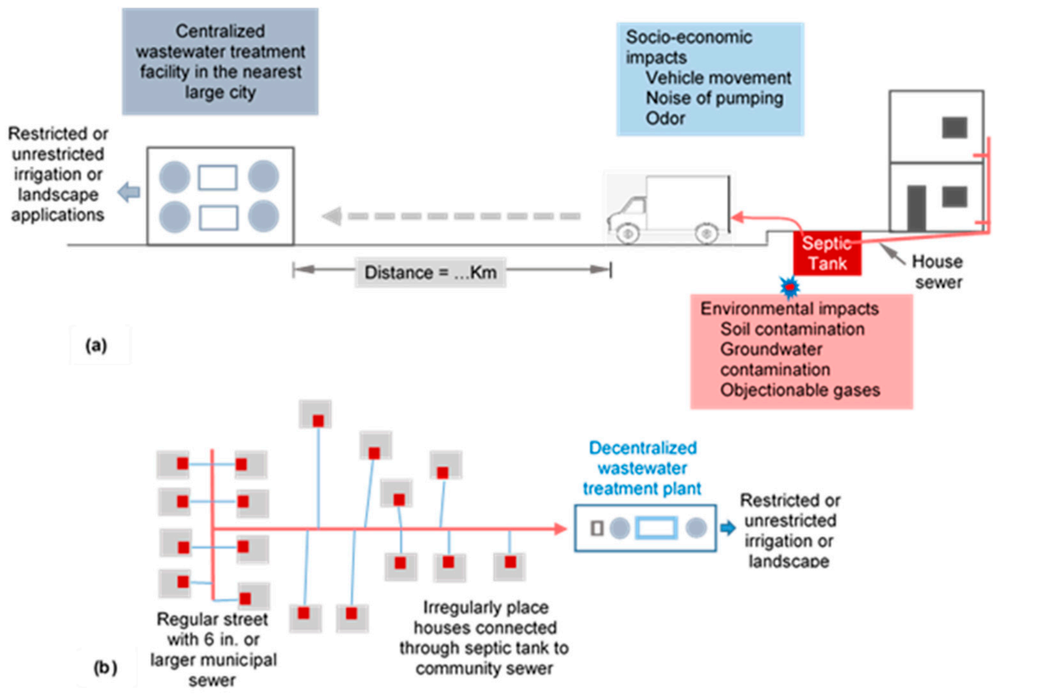

Figure 2. Existing and proposed wastewater management scenarios: (**a**) septic tanks and wastewater transport to the centralized wastewater system, (**b**) simplified sewerage system with a decentralized wastewater treatment facility [9].

The authors' previous work developed a CFBR as a decentralized system to treat RST effluent from the Alqaraa community [9]. The ceramic filter's manufacturing involved low-cost materials, such as local soil (clay) and rice bran. The details of the manufacturing process of the filter and its properties/dimensions are described in previous studies [27]. The lab-scale CFBR treatment unit setup (described in detail in Alresheedi et al. [9]) was used to treat RST effluent under various scenarios of continuous and cyclic aeration modes. The CFBR effectively treated RST effluent to meet irrigation and landscaping application regulations set by KSA and WHO. The CFBR effectively removed nitrogen compounds through an optimized nitrification/denitrification process. The simple operations and cyclic aeration mode reduced the energy requirements due to the reduction of aeration duration, showing the economic and operational sustainability of MBR technology for the Alqaraa community for wastewater reclamation and reuse.

The DWWTS developed in the author's previous work is an energy-saving secondary-level wastewater treatment solution due to cyclic aeration. The treated effluent can be reused for restricted and unrestricted irrigation or landscaping in the service area, such as parks, tree plantations, and greenbelts along roadsides (Table 1). The proposed approach is an economically viable option for the residents, as the resources spent on wastewater disposal (service charges of collection vehicles) can contribute to the DWWT facility's operations. For a practical implementation of the CFBR as DWWTS, the system's sustainability for wastewater treatment and reuse in the small community must be assessed through a comprehensive resident perception-based evaluation.

3. Methodology

3.1. Resident Perception-Based Sustainability Assessment

The present study intended to evaluate sustainability based on the residents' perception of the authors' previously developed low-cost DWWTS for the study area. Figure 3 describes the methodological flow of the research, initiated by defining the study area (Figure 1), followed by an appraisal of the prevailing wastewater management system (Figure 2). We developed and performed a laboratory-scale technical evaluation of a low-cost bioreactor to use as a DWWTS in the study area (see details in Alresheedi et al. [9]). Through several rigorous brainstorming sessions, we developed a list of demographic factors and perception and sustainability indicators. We defined questions to be asked of the residents to assess each sustainability indicator. In the subsequent phase, we interviewed all the households in the study area to capture their responses against each indicator. Statistical analyses checked the significance of each demographic factor and indicator against the willingness to use the proposed low-cost DWWTS. Finally, we used a fuzzy-based method to assess the resident perception index (RPI) and DWWTS sustainability index (DSI). A higher perception yields higher sustainability of DWWTS in the underlying assumption of the present research. The following subsections give details of each step.

3.2. Development of Indicators and Questionnaire Survey

Several small towns and rural settings are similar to the study area in KSA, which rely on onsite storage and subsequent wastewater transport to the nearest CWWTS. The importance of demographics on WTA and WTP of decentralized systems has been well established in past studies [20]. Table 2 presents the criteria for demographics and three dimensions of sustainability. The table also defines the universe of discourse (UoD) for criteria evaluation and the questions posed to the residents in the study area. In addition to gender and age, education level, job type, family size, and monthly water bill were included in the demographic information.

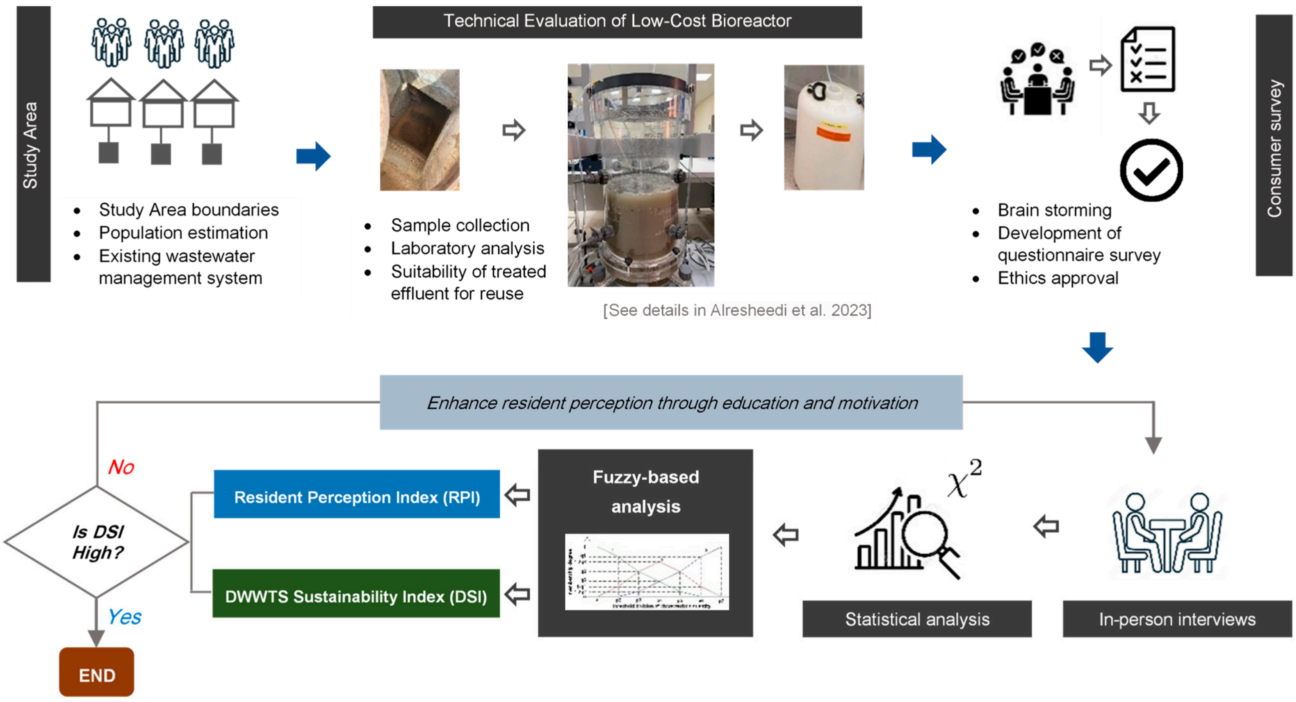

Figure 3. Assessment methodology for the sustainability of a low-cost bioreactor-type decentralized wastewater treatment system for small communities in arid regions.

Table 2. Universe of discourse (UoD) for different criteria influencing the sustainability of DWWTS.

No	Criteria	Low	Medium	High	Questions Asked
1.	**Demographic information**				
Pr1	Gender	-	-	-	-
Pr2	Age	>30 years	30–50 years	<50 years	How old are you?
Pr3	Education level	Pre-high school	High school	University degree or higher	What is your education level?
Pr4	Job type	Government	Private	Personal business	What is your job sector?
Pr5	Family size (Person)	<6	6–10	<10	How many persons live in your house?
Pr6	Monthly water bill (SAR/month)	>100	100–200	<200	How much is your monthly water bill?
2.	**Perception**				
2.1	*Perception of the existing system (PES)*				
Pp 1	Status of wastewater treatment in the area.	Unlikely	Neutral	Likely	Does the municipality treat the wastewater generated from your area?
Pp 2	Wastewater transportation and disposal.	In our area	Do not know	Nearby town	Does the municipality treat wastewater near your area or transport it to a nearby larger town?
Pp 3	Difficulties associated with WW transportation.	Yes	Somehow	No	Do you agree that transporting wastewater is a complicated and expansive task?

Table 2. *Cont.*

No	Criteria	Low	Medium	High	Questions Asked
Pp 4	Loss of wastewater as a resource.	Yes	Somehow	No	Do you agree that the transported wastewater can't be reused in your area; instead, the other site will take advantage of treated wastewater?
2.2	*Perception of DWWTS (PDS)*				
Pp 5	Informed about DWWTS.	Yes	Somehow	No	Do you know that the municipality can install DWWTS in your area to help you reuse the treated wastewater?
Pp 6	Reuse potential for landscaping.	Yes	Somehow	No	Do you know that treated wastewater can be used for landscaping?
Pp 7	Reuse potential for agriculture.	Yes	Somehow	No	Do you know that treated wastewater can be used for agricultural applications?
Pp 8	Reuse potential for road washing.	Yes	Somehow	No	Do you know that treated wastewater can be used for road washing?
Pp 9	Reuse potential for car washing.	Yes	Somehow	No	Do you know that treated wastewater can be used for car washing?
3.	**Environmental Pollution**				
En 1	Impact on human health.	Unlikely	Neutral	Likely	Can untreated wastewater harm human health?
En 2	Impact on the biological environment.	Unlikely	Neutral	Likely	Can untreated wastewater harm the biological environment (plants and animals)?
En 3	Impact on the soil.	Unlikely	Neutral	Likely	Can untreated wastewater contaminate soil?
En 4	Impact on groundwater.	Unlikely	Neutral	Likely	Can the leakage from the septic tank in your house pollute groundwater?
4.	**Social acceptability**				
4.1	*Willingness to accept (WTA)*				
Sc 1	Willingness to accept (WTA) DWWTS.	Unlikely	Neutral	Likely	Are you willing to have a DWWTP in your area?
4.2	*Willingness to use (WTU)*				
Sc 2	WTU for reusing treated wastewater for restricted irrigation.	Unlikely	Neutral	Likely	Would you accept to reuse of treated wastewater for restricted irrigation?
Sc 3	WTU for reusing treated wastewater for unrestricted irrigation.	Unlikely	Neutral	Likely	Would you accept to reuse of treated wastewater for unrestricted irrigation?

Table 2. *Cont.*

No	Criteria	Low	Medium	High	Questions Asked
Sc 4	WTU for reusing treated wastewater for road washing.	Unlikely	Neutral	Likely	Would you accept reusing treated wastewater for road washing?
Sc 5	WTU for reusing treated wastewater for car washing.	Unlikely	Neutral	Likely	Would you accept reusing treated wastewater for car washing?
4.3	*Quality of life*				
Sc 6	Impact of DWWTS on traffic	Yes	Somehow	No	Are you concerned about the location of DWWTS (impact on traffic)?
Sc 7	Impact of DWWTS on land value.	Yes	Somehow	No	Do you have concerns about the impact of DWWTS on land value?
Sc 8	Noise pollution from DWWTS.	Yes	Somehow	No	Do you have concerns about noise pollution from DWWTS operations?
Sc 9	Odour from DWWTS.	Yes	Somehow	No	Do you have concerns about the possible odor from DWWTS operations?
5.	**Economic**				
Ec 1	The monthly cost of wastewater disposal.	100–150	150–200	200–250	How much are you paying per month for wastewater disposal?
Ec 2	Willingness to pay (WTP) the existing expense for DWWTS.	Yes	-	No	Are you willing to share this amount with the DWWTP?
Ec 3	WTP an additional amount for the improvements by DWWTS.	20%	30%	50%	How much additional amount (% of disposal cost mentioned in Ec.1) are you willing to pay to avoid the inconvenience caused by the wastewater disposal process that you must go through regularly?

Studies have shown that the residents' knowledge about water scarcity in arid regions and the safety of reclaimed effluent significantly affect their opinion about wastewater reuse, directly influencing WTA and WTP [28]. Resident perception evaluated how much they were informed about the existing and proposed wastewater management systems using two sub-indices: the perception of the existing system (PES) and DWWTS (PDS). The first two questions assess the residents' perception of existing wastewater management practices in the study area through questions about wastewater treatment (Pp1) and its transport and disposal (Pp2). The third question (Pp3) judges the residents' discomfort when calling and waiting for the transport vehicle. The fourth question (Pp4) assesses whether residents are aware of losing their wastewater as a resource due to disposing it into the CWWTS. Questions Pp5–Pp9 estimate PDS; Pp5 appraises the residents' information about the possibility of a decentralized system in their area. Pp6-Pp9 evaluate the knowledge about applications of reclaimed wastewater, as these are associated with the WTA and WTP. Finally, the responses estimated the RPI using a rational scoring and aggregation scheme (Figure 4).

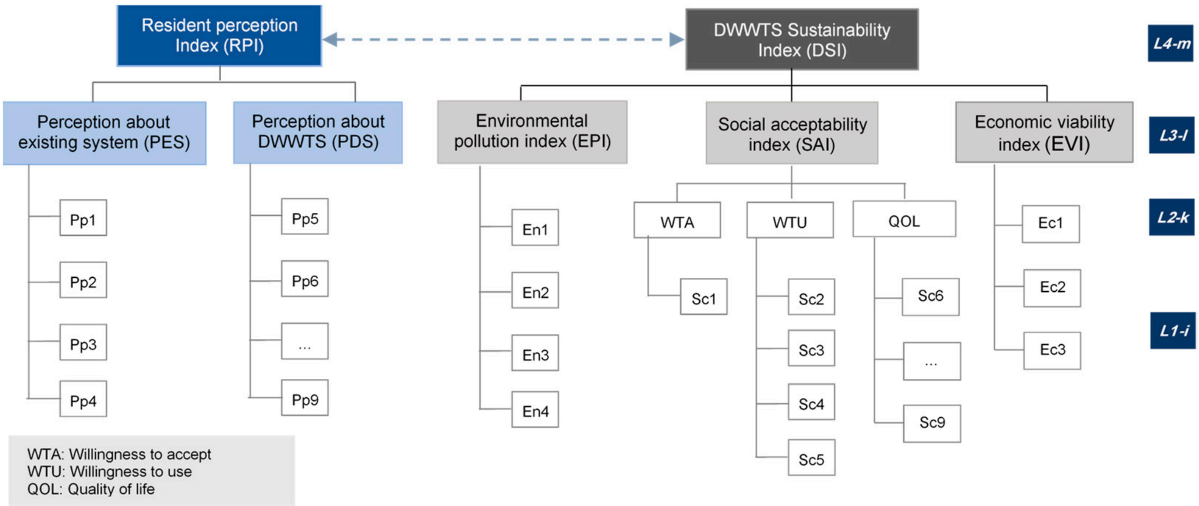

Figure 4. The hierarchical approach used for sustainability and perception indices.

The hierarchical setup shown on the right side of Figure 4, with the help of three indices covering three sustainability dimensions, appraise DWWTS Sustainability Index (DSI). Four indicators (En1–En4) assessed the environmental pollution index (EPI), which essentially encompassed the impact of existing wastewater management practices on human health, biological environment (impacts on aquatic life and terrestrial environment in case of surface water discharge), and physical environment (leakage from RST adversely affecting groundwater and soil). Improved knowledge of residents yields a higher pollution index due to untreated wastewater storage, which enhances WTA, WTP, and the DSI.

The first indicator (Sc1) in social acceptability determines the WTA of the proposed LBR as a DWWTS by the residents of the study area. The following four indicators (Sc2–Sc5) estimate WTU the treated effluent for various intended uses, including restricted and unrestricted irrigation, road cleaning, and car washing. The following four indicators (Sc6–Sc9) assess the potential impacts on quality of life (QOL) due to operations of the proposed DWWTS, such as impacts on traffic due to the movement of sludge collection or maintenance vehicles (Sc6), impacts on land value (Sc7), increase in noise (Sc8), and possible odor issue (Sc9). At the above hierarchy level, SAI was assessed by aggregating the sub-indices (WTA, WTU, and QOL).

Finally, three indicators (Ec1–Ec3) estimate the financial viability of the DWWTS for smaller communities. The monthly bill (Ec1) tells the usage of a household and indirectly highlights the households with higher water consumption and larger family size. Generally, households with more consumption and large family size have more WTP [23]. The next indicator (Ec2) assesses the WTP, i.e., the amount residents spend on wastewater disposal. The last economic indicator (Ec3) determines the WTP, i.e., the extra amount residents can add to the existing spending to replace the easiness and sustainability the DWWTS brings into the study area.

The ethics committee of the funding organization formally approved the survey questionnaire. Each interview was 30–45 min long, and the total duration of survey collection spanned three weeks. The survey posed questions after a brief introduction of the proposed DWWTS and recorded the responses on hard copies in the presence of respondents.

3.3. Statistical Analysis

The data obtained inform respondents' opinions on both the resident perception and sustainability of DWWTS. The data were statistically analyzed using the Chi-square independence test to ascertain the association level between each factor (or indicator) and WTA, the proposed decentralized wastewater system. The following example defines the null and alternative hypotheses for human health impacts of untreated wastewater (En1) as an example.

H_0: *The null hypothesis: Residents' knowledge about human health impacts of untreated wastewater is a perfectly independent factor and does not affect the willingness to accept DWWTS in their area.*

H_a: *The alternative hypothesis: Residents' knowledge about human health impacts of untreated wastewater is a dependent factor and does affect the willingness to accept DWWTS in their area.*

Similarly, the hypotheses were tested for all demographic factors, resident perception, and sustainability indicators. The Chi-square method centers on anticipated frequencies that retain the null hypothesis. Equation (1) estimates the factors'/indicators' frequencies against the WTA (SPSS Tutorials):

$$e_{ij} = \frac{o_i \times o_j}{N} \quad (1)$$

where e_{ij} represents the expected frequency, o_i is the marginal column, o_j is the marginal row frequencies, and N represents the total number of responses.

Equation (2) estimates the residual for different values of o_i and o_j:

$$r_{ij} = o_{ij} - e_{ij} \quad (2)$$

A considerable absolute value of r_{ij} yields a more significant variance between the perceived responses and the null hypothesis. Equation (3) sums all the residuals to predict the Chi-square (χ^2) test's statistic:

$$\chi^2 = \sum \frac{(o_{ij} - e_{ij})^2}{e_{ij}} \quad (3)$$

Equation (4) estimates the variables' independence (*p*-value) in the given population for a given χ^2 and degree of freedom (d_f):

$$d_f = (i - 1) \times (j - 1) \quad (4)$$

where i denotes the number of rows and j represents the number of columns in the contingency table.

The analysis compared the χ^2, estimated using Equation (3), with the critical values from the χ^2 distribution at $p < 0.05$ to accept or reject the H_0 of independence. For instance, the critical values are 3.84, 5.99, 7.82, 9.49, 11.07, and 12.59, with corresponding d_f of 1, 2, 3, 4, 5, and 6. An H_0 of independence is rejected when the χ^2 value exceeds the critical value.

The χ^2 test's performance is a function of sample size. Therefore, the estimated significances do not confirm the degree of effect. The effect size (ES) of the χ^2 test determines the association strength between the factors (or indicators) and WTA using Cramér's V, Equation (5), a type of Pearson correlation for categorical variables [29]:

$$V = \sqrt{\frac{\chi^2}{n \cdot d_f}} \quad (5)$$

where n represents the number of responses for large UoD (df > 5); ES < 0.04 represents a small association, 0.04 < ES ≤ 0.13 is medium, and ES > 0.22 shows a large association among the factors.

3.4. Fuzzy Synthetic Evaluation

To establish a linkage between resident perception and sustainability of DWWTS, a multilevel hierarchical indicator system was developed, shown in Figure 4. The application of fuzzy synthetic evaluation (FSE) to deal with such multi-criteria and multilevel problems has been proven in the past [30]. Using fuzzy set theory, FSE can effectively deal with variations and uncertainties in respondents' opinions. The present study employed FSE to derive the information from survey responses for the resident perception and sustainability indicators defined in Table 2 and aggregated them to obtain RPI and DSI.

The present study used the following FSE procedure [20,31].

As the responses were recorded for each linguistic term of UoD defined in Table 2, the first step aggregated the distributed responses into a unified score for each indicator. The three-level linguistic rating (Yj = 1, 3, 5) was defined as low (1), medium (3), and high (5). The terms f_{i0}^{P} and f_{i1}^{S} represent the association degree of each perception or sustainability indicator. Equation (6) provides the matrix form for residents' perception assessment:

$$\left(I_i^P\right)_{1\times 3} = \left(f_{i1,}^P f_{i3,}^P f_{i5}^P\right) \tag{6a}$$

$$\left(I_i^S\right)_{1\times 3} = \left(f_{i1,}^S f_{i3,}^S f_{i5}^S\right) \tag{6b}$$

I_i^P represents the resident perception indicator, I_i^S is the sustainability indicator (i = 1, 2, . . ., n), and n is the total number of indicators encompassed in a sub-index.

Equation (7) calculates the overall score for each indicator at level 1 (L1):

$$X_i^P = \sum_{i=1}^{3}\left(Y_j \times I_{ij}^P\right) \tag{7a}$$

$$X_i^S = \sum_{i=1}^{3}\left(Y_j \times I_{ij}^S\right) \tag{7b}$$

Equation (8) estimates the indicators' relative weights under each index:

$$w_{i,}^P = X_i^P / \sum_{i=1}^{n} X_i^P \tag{8a}$$

$$w_{i,}^S = X_i^S / \sum_{i=1}^{n} X_i^S \tag{8b}$$

The next step of FSE estimates the membership functions of indicators through fuzzy decomposition (Z = W × I) of the weighted matrix developed by Equation (8b) and the scoring matrix in Equation (6b) for the sub-indices at level 2 of the hierarchy:

$$\left(Z_{kq}^S\right)_{1*3} = \left(W_i^S\right)_{1\times n} \times \left(I_i^S\right)_{n\times 3} = \left(z_{k1,}^S z_{k3,}^S z_{k5}^S\right) \tag{9}$$

where k denotes the number of sub-indices (k = 3) at level 2 (L2) of the hierarchy, and n is the number of indicators under each sub-index.

Equation (10) estimates XkS—the WTA, WTU, and QOL sub-indices in the next step.

$$X_{kq}^S = \sum\nolimits_{j=1}^{3}\left(Y_j \times Z_{kq}^S\right) \tag{10}$$

Also, the membership functions of resident perception indicators through fuzzy decomposition (Z = W × I) of the weighted matrix developed by Equation (8a) and the scoring matrix in Equation (6a) for the sub-indices at L3 of the hierarchy are as follows:

$$\left(Z_{lr}^P\right)_{1*3} = \left(W_i^P\right)_{1\times n} \times \left(I_i^P\right)_{n\times 3} = \left(z_{l1,}^P z_{l3,}^P z_{l5}^P\right) \tag{11}$$

The resident perception indicators were aggregated at L3 of the hierarchy to calculate PES and PDS sub-indices X_l^P:

$$X_{lr}^P = \sum\nolimits_{j=1}^{3}\left(Y_j \times Z_l^P\right) \tag{12}$$

where l represents the number of indices (l = 1, 2, r) and r = 2.

Likewise, sub-indices EPI and EVI were estimated at L3 using equations

$$\left(\left(Z^{S}_{lr}\right)_{1*3} = \left(W^{S}_{i}\right)_{1\times n} \times \left(I^{S}_{i}\right)_{n\times 3} = \left(z^{P}_{l1,}z^{P}_{l3,}z^{P}_{l5}\right) \tag{13}$$

and

$$X^{S}_{lr} = \sum\nolimits_{j=1}^{3}\left(Y_j \times Z^{S}_{lr}\right) \tag{14}$$

In the case of DSI, there is an intermediate level (i.e., L2), so the weights of sub-indices (X^{S}_{k}) were determined using the following equation:

$$w^{S}_{kq} = X^{S}_{k} / \sum_{i=1}^{q} X^{S}_{kq} \tag{15}$$

where k is the number of sub-indices (k = 1, 2,. . ., q), WTA, WTU, and QOL at L2 and q = 3.

For DSI at L3, the membership functions of the sub-indices (WTA, WTU, and QOL) were estimated as follows:

$$\left(Z^{S}_{lr}\right)_{1\times 3} = \left(W^{S}_{kq}\right)_{1\times n} \times \left(Z^{S}_{kq}\right)_{n\times 3} = \left(z^{S}_{l1,}z^{S}_{l3,}z^{S}_{l5}\right) \tag{16}$$

The subsequent step estimated SAI at level 3 of the hierarchy shown in Figure 4 using Equation (14).

Having FSE results at level 2, Equation (17) estimates the weights of the sub-indices:

$$w^{P}_{lr} = X^{P}_{lr} / \sum_{l=1}^{r} X^{P}_{lr} \tag{17a}$$

$$w^{S}_{lr} = X^{S}_{lr} / \sum_{l=1}^{r} X^{S}_{lr} \tag{17b}$$

where l represents the number of sub-indices (l = 1, 2, . . ., r) at level 2.

Equation (18) establishes the membership functions of the sub-indices at level 2 for RPI and DSI:

$$\left(Z^{P}_{m}\right)_{1*3} = \left(W^{P}_{lm}\right)_{1\times n} \times \left(X^{P}_{lm}\right)_{n\times 3} = \left(z^{P}_{m1,}z^{P}_{m3,}z^{P}_{m5}\right) \tag{18a}$$

$$\left(Z^{S}_{m}\right)_{1*3} = \left(W^{S}_{lm}\right)_{1\times n} \times \left(X^{S}_{lm}\right)_{n\times 3} = \left(z^{S}_{m1,}z^{S}_{m3,}z^{S}_{m5}\right) \tag{18b}$$

Having membership functions of l number of sub-indices, Equation (19) estimates RPI and DSI at the top (L1) of the hierarchy shown in Figure 4:

$$X^{P}_{m} = \sum\nolimits_{j=1}^{3}\left(Y_j \times Z^{P}_{m}\right) \tag{19a}$$

$$X^{S}_{m} = \sum\nolimits_{j=1}^{3}\left(Y_j \times Z^{S}_{m}\right) \tag{19b}$$

In the present study, an indicator or index value less than 2.0 corresponds to 'low', between 2.0 and 3.0 to 'moderate', between 3.0 and 4.0 to 'moderately high', and higher than 4.0 represents 'high' performance index.

4. Results

4.1. Descriptive Statistics of the Residents

With a 95% confidence level and a 10% margin of error, the sample size was 60 for 160 households considered within the study area. An in-person interview survey over three weeks was conducted with 34 households who agreed to participate (56% response rate) in the study area during December 2022. Figures in Appendix A present the descriptive statistics of the respondents. Figure A1a shows that over 50% of respondents are between 30 and 50 years, the age at which the respondents tend to be most interactive [32]. The respondents in this age range were familiar with the study area and were more aware of wastewater management practices. Most (85%) respondents were male (Figure A1b). Figure A1c illustrates that 85% of the respondents were high school graduates, while 44% had university degrees or had completed higher education. As schools and universities in the Arab region have included environmental education in their curriculum [33], around half the participating residents have essential ecological protection and resource conservation knowledge. Figure A1d shows a family size of more than six persons for 97% of the respondents' families, which agrees with the average family size of 5.8 [34]. A past study found higher WTA in larger families with more water consumption and associated concerns about water and wastewater management [23]. More than half (around 53%) of the participants were government employees, 29% had businesses, and 18% worked in the private sector (Figure A1e). Figure A1f shows that the water bill of around 80% of the residents was less than SAR 200 per month, which is less than the global average due to government-subsidized water rates in KSA [35].

4.2. Descriptive Statistics of the Residents

Analysis for descriptive statistics parameters found a strong association between gender and WTA, with all the female (15%) respondents registering likely or neutral responses towards accepting a DWWTS in their area. Education and job type were moderately associated with WTA, while the monthly bill was also strongly associated with WTA. Figure 5 presents the percentage frequencies for each element of UoD, defined in Table 1, for some critical indicators. In Figure 5a, around 50% (20 out of 34) respondents thought that the wastewater generated from their area was unlikely to be treated; nevertheless, 70% of them would be willing to have or were neutral about having a DWWTS. On the contrary, 30% (10 out of 34) of the respondents who were aware of the wastewater treatment were willing to have a DWWTS. These results show an overall positive response from residents toward having a decentralized facility in their small community. Figure 5b illustrates that half of the respondents indicated a neutral response towards the loss of wastewater as a resource, and most (70%) of the 30% of respondents who agreed with this loss had willingness for a DWWTS. These findings reveal that most (80%) of the residents agreed or somewhat agreed that they were losing their wastewater as a resource.

It can be seen in Figure 5c that around half of the residents did not know about DWWTS; the remaining informed respondents were mostly willing. Most residents concerned about the impact of existing RSTs on human health due to groundwater contamination and odor release also registered their willingness (Figure 5d). More than 75% of the residents either stayed neutral or were interested in reusing treated wastewater for unrestricted irrigation (Figure 5e). Figure 5f shows that around 62% of the residents agreed to share the monthly amount they were presently spending on wastewater transportation and disposal for the operation of a DWWTS.

The detailed statistical analysis summarized in Appendix B shows a moderate or strong association between WTA and most indicators. Interestingly, a strong association between all PES indicators and WTA demonstrates reasonable residents' knowledge about existing RST-based wastewater management practices. Conversely, most (Pp5, Pp6, and Pp8) of the PDS indicators showing weak association with WTA pointed towards a lack of residents' knowledge about DWWTSs. Among the environmental indicators, the impact of RST on soil (En3) showed a weak association. As all the other indicators in this category showed a moderate association, residents seem somewhat aware of environmental issues associated with RST operations. Expecting that further education and awareness could improve their perception, these indicators were included in the sustainability analysis. Residents' perception of impacts on land value and noise due to DWWTS' operation showed a weak association with WTA, so the present study neglected these indicators in the subsequent sustainability analysis.

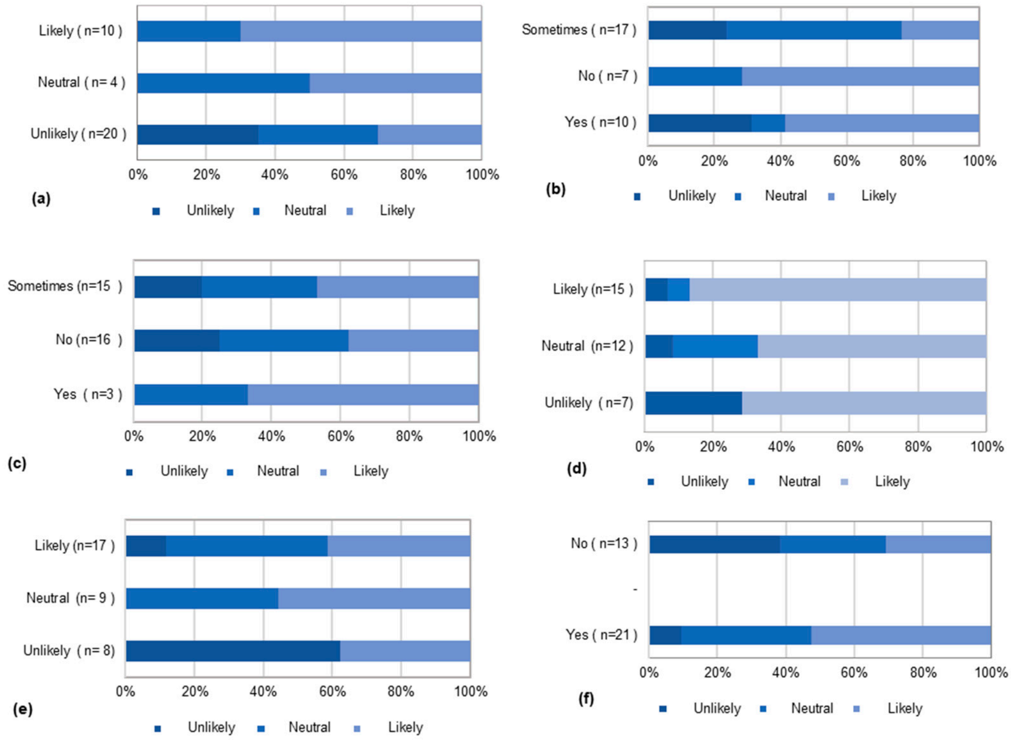

Figure 5. Percentage frequencies for each element of UoD of selected indicators against WTA (Sc1) in the form of stacked bar charts: (**a**) status of wastewater treatment in the area (Pp1), (**b**) loss of wastewater as a resource (Pp4), (**c**) degree of being informed about DWWTS (Pp5), (**d**) impact on human health (En1), (**e**) willingness to use treated wastewater for unrestricted irrigation (Sc3), (**f**) willingness to share monthly bill for operation of DWWTS.

4.3. Sustainability Evaluation of Decentralized System

4.3.1. Resident Perception Index (RPI)

The RPI was derived from two sub-indices, PES and PDS, by using fuzzy-based aggregation of basic inputs indicators developed from residents' perceptions. Equation (6a) calculated the degree of association of each factor to the three-level-rating (Yj = 1, 3, 5), as described in Section 3.4. The term I_i^P for resident perception indicator for the question "Does the municipality treat the wastewater generated from your area?" was calculated as

$$\left(I_1^P\right)_{1\times 3} = \left(z_{i1}^P, z_{i3}^P, z_{i5}^P\right) = (0.588, 0.118, 0.294)$$

where $z_{i1}^P = \frac{20}{34}$, $z_{i3}^P = \frac{4}{34}$, $z_{i1}^P = \frac{10}{34}$ represent response frequencies against the UoD for this indicator, defined as 'unlikely', 'netural', and 'likely', respectively, in Table 2.

The impact of residents' perception of the indicator (Pp1) assessed through the above question, X_1^P, was estimated using Equation (7a) as

$$X_1^P = \sum_{i=1}^{3}\left(Y_j * I_{ij}^P\right) = 1 \times 0.588 + 3 \times 0.118 + 5 \times 0.294 = 2.41$$

Similarly, X_i^P for all questions appraising, PES, and PDS were calculated.

Next, Equation (8a) estimated the relative weight of X_1^P:

$$w_1^P = X_i^P / \sum_{i=1}^{4} X_i^P = \frac{2.41}{(2.41 + 3.47 + 3.29 + 3.18)} = 0.195$$

The weights of all indicators under the sub-index were calculated.

Subsequently, Equation (11) estimated the membership functions Z_l^P for PES:

$$\left(Z_l^P\right)_{1\times 3} = \left(W_i^P\right)_{1\times n} \times \left(I_i^P\right)_{n\times 3} = \left(z_{l1,}^P z_{l3,}^P z_{l5}^P\right)$$

$$\left(Z_{l1}^P\right)_{1\times 3} = \begin{bmatrix}0.195 & 0.281 & 0.267 & 0.257\end{bmatrix} \times \begin{bmatrix}0.588 & 0.118 & 0.294\\ 0.059 & 0.647 & 0.294\\ 0.235 & 0.382 & 0.382\\ 0.206 & 0.500 & 0.294\end{bmatrix}$$

$$\left(Z_{l1}^P\right)_{1\times 3} = \begin{bmatrix}0.267 & 0.413 & 0.320\end{bmatrix}$$

Likewise, the membership functions Z_2^P for PDS were estimated:

$$\left(Z_{l2}^P\right)_{1x3} = \begin{bmatrix}0.315 & 0.388 & 0.297\end{bmatrix}$$

The final values of PES (X_{l1}^P) were estimated using Equation (12) at L3:

$$X_{l1}^P = \sum_{j=1}^{3}\left(Y_j \times Z_{l1}^P\right) = 1\times 0.267 + 3\times 0.413 + 5\times 0.320 = 3.107$$

and, for PDS (X_{l2}^P), as

$$X_{l2}^P = \sum_{j=1}^{3}\left(Y_j \times Z_{l1}^P\right) = 1\times 0.315 + 0.388 + 0.297 = 2.964$$

Finally, to calculate RPI at L4, Equation (17a) estimated that the weights of PES and PDS were w_{l1}^P = 0.491 and w_{l2}^P = 0.509, and Equation (18a) estimated their membership functions:

$$\left(Z_m^P\right)_{1*3} = \left(W_l^P\right)_{1\times n} \times \left(X_l^P\right)_{n\times 3} = \begin{bmatrix}0.491 & 0.509\end{bmatrix} \times \begin{bmatrix}0.267 & 0.413 & 0.320\\ 0.315 & 0.388 & 0.297\end{bmatrix}$$

$$\left(Z_m^P\right)_{1*3} = \begin{bmatrix}0.291 & 0.400 & 0.308\end{bmatrix}$$

Finally, Equation (19a) calculated the RPI (X_m^P):

$$X_m^P = \sum_{j=1}^{3}\left(Y_j \times Z_m^P\right) = 1\times 0.291 + 3\times 0.400 + 5\times 0.308 = 3.034$$

4.3.2. DWWTS Sustainability Index

The perception-driven indicator-based hierarchy described on the right side of Figure 4 appraised the sustainability of the proposed DWWTS. The bottom-up approach began by evaluating the degree of association of the indicators to the rating scheme adopted in the present study. Therefore, Equation (6b) considered the term I_i^S for the sustainability indicator assessed through the question "Are you willing to have a DWWTS in your area?"

$$\left(I_1^S\right)_{1\times 3} = \left(f_{i1,}^S f_{i3,}^S f_{i5}^S\right) = (0.265, 0.382, 0.353)$$

Subsequently, Equation (7b) appraised the willingness to accept the indicator (Sc1):

$$X_1^S = \sum_{i=1}^{3}\left(Y_j \times I_{ij}^S\right) = (1\times 0.265 + 3\times 0.382 + 5\times 0.353) = 3.18$$

As Sc1 was the only indicator assessing WTA, the estimated score of 3.18 represents the level of WTA (X_{k1}^S). Likewise, scores of all the sustainability indicators were calculated. While three sub-indices evaluated social acceptability at L2 of the hierarchy in the case of

DSI (Figure 4), Equation (8b) evaluated the relative weights for the indicators under WTU and QOL:

$$w_2^S = X_i^S / \sum_{i=1}^{n} X_i^S = 3.94/(3.94 + 3.53 + 4.06 + 3.29) = 0.266$$

At the subsequent level, FSE estimated the membership functions of indicators through fuzzy decomposition (Z = W × I) of the weighted matrix developed by Equation (8b) and the scoring matrix in Equation (7b) for the sub-indices (WTU and QOL) at level-2 of the hierarchy:

$$\left(Z_{k2}^S\right)_{1*3} = \left(W_i^S\right)_{1\times n} \times \left(I_i^S\right)_{n\times 3} = \begin{bmatrix} 0.266 & 0.238 & 0.274 & 0.222 \end{bmatrix} \times \begin{bmatrix} 0.118 & 0.294 & 0.588 \\ 0.235 & 0.265 & 0.500 \\ 0.147 & 0.176 & 0.676 \\ 0.294 & 0.265 & 0.441 \end{bmatrix}$$

$$\left(Z_{k2}^S\right)_{1*3} = (0.193, 0.248, 0.559)$$

and

$$\left(Z_{k3}^S\right)_{1*3} = (0.291, 0.235, 0.474)$$

In the next step, Equation (10) estimated X_{kq}^S, the WTA, WTU, and QOL sub-indices:

$$X_{k2}^S = \sum_{j=1}^{3} \left(Y_j \times Z_{k2}^S\right) = 1 \times 0.193 + 3 \times 0.248 + 5 \times 0.559 = 3.732$$

$$X_{k3}^S = \sum_{j=1}^{3} \left(Y_j \times Z_{k3}^S\right) = 1 \times 0.291 + 3 \times 0.235 + 5 \times 474 = 3.368$$

After estimating the weights of WTA $\left(w_{k1}^S = 0.309\right)$, WTU $\left(w_{k2}^S = 0.363\right)$, and QOL $\left(w_{k3}^S = 0.328\right)$, Equation (13) calculated the membership functions for SAI as

$$\left(Z_{l2}^S\right)_{1*3} = \left(W_{kq}^S\right)_{1\times n} \times \left(X_{kq}^S\right)_{n\times 3} = \begin{bmatrix} 0.309 & 0.363 & 0.328 \end{bmatrix} \times \begin{bmatrix} 0.265 & 0.382 & 0.353 \\ 0.193 & 0.248 & 0.559 \\ 0.291 & 0.235 & 0.474 \end{bmatrix}$$

$$\left(Z_{l2}^S\right)_{1*3} = (0.247, 0.285, 0.467)$$

Equation (14) calculated the score for SAI by aggregating the weights and membership functions for the sub-indices at L2:

$$X_{l2}^S = \sum_{j=1}^{3} \left(Y_j \times Z_{l2}^S\right) = 1 \times 0.247 + 3 \times 0.285 + 5 \times 0.467 = 3.441$$

Also, knowing the scores of sub-indices EPI $\left(X_{l1}^S = 3.471\right)$ and EVI $\left(X_{l3}^S = 2.588\right)$ at L3 of the hierarchy shown in Figure 4, Equation (17b) calculated the weights of these indices as $w_{l1}^S = 0.362, w_{l2}^S = 0.365$, and $w_{l3}^S = 0.272$.

For DSI at L3, Equation (18b) estimated the membership functions of the sub-indices (EPI, SAI, and EVI) as

$$\left(Z_m^S\right)_{1\times 3} = \left(W_{lr}^S\right)_{1\times n} \times \left(Z_{lr}^S\right)_{n\times 3} = \begin{bmatrix} 0.362 & 0.365 & 0.272 \end{bmatrix} \times \begin{bmatrix} 0.247 & 0.285 & 0.467 \\ 0.206 & 0.353 & 0.441 \\ 0.543 & 0.121 & 0.0337 \end{bmatrix}$$

$$\left(Z_m^S\right)_{1\times 3} = (0.313, 0.265, 0.422)$$

Finally, Equation (19b) evaluated the score of DSI:

$$X_m^S = \sum_{j=1}^{3} \left(Y_j \times Z_m^S\right) = 1 \times 0313 + 3 \times 0.265 + 5 \times 0.422 = 3.219$$

Figure 6 presents the FSE results for all the indices of the hierarchy shown in Figure 4. The results inform about the perception of the residents of a smaller community in arid regions about the existing wastewater collection and disposal system and the proposed decentralized wastewater treatment and reuse system. In addition, the analysis presents the assessment results of three dimensions of sustainability based on residents' perceptions. Residents were more knowledgeable about the existing system with PES higher than three compared to a value of less than three for PDS. These results show that the residents of the study area are not well-informed about sustainable water management solutions for their smaller community, which reflects sustainability assessment scores between 2.58 and 3.73, with an average score of around 3. However, a higher (3.73) WTU is encouraging and shows improved sustainability of DWWTS as the residents become more aware of the importance of wastewater reuse and resource conservation. The figure also reveals higher performance of environmental and social dimensions compared to the economic dimension of sustainability.

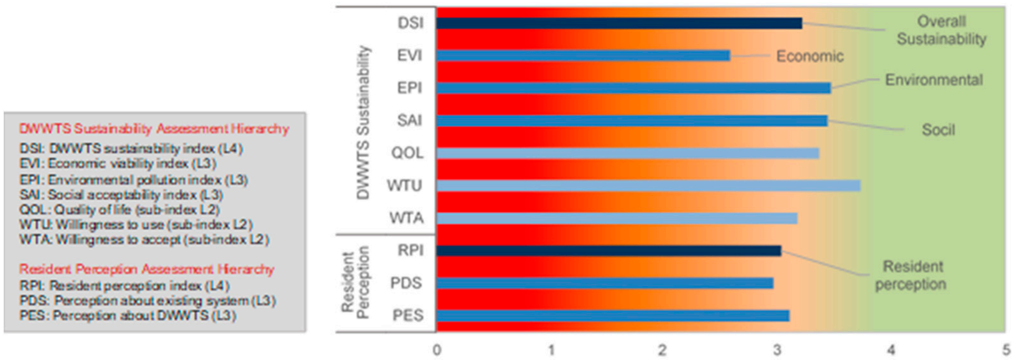

Figure 6. Results of resident perception and sustainability of DWWTS in smaller communities. The figure presents values of all the sub-indices and top-level indicators at the four hierarchy levels shown in Figure 4.

5. Discussion

Governments around the globe have acknowledged the importance of education for sustainable development in local communities, small towns, and rural settlements [36]. Recognizing the United Nations Sustainable Development Goals (SDGs) defined in the 70th UN General Assembly in 2015, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) has emphasized that all countries should instigate efforts to achieve these goals by 2030 [37]. As a signatory to the agreement, the Government of KSA also prepared Vision 2030 for sustainable development, wherein achieving environmental sustainability, emphasizing waste recycling, pollution control, and resource conservation, is one of the primary objectives [38]. Nevertheless, more efforts are needed to include education on sustainable development at the policy and implementation levels in compulsory topics at elementary, secondary, and higher education levels [39,40].

Smaller communities in KSA are not adopting sustainable water management practices due to inadequate infrastructure, lack of skilled personnel, and limited awareness of residents. Consequently, such societies, including towns and rural settlements, rely on onsite storage in residential septic tanks (RSTs) without a sewerage network. In the case of a failure incident, residents face gurgling sounds in the house drains, damp spots around the RST (mainly if covered by soil and grass), odor issues due to releasing objectionable gases, and spongy grass around the tank's area. These conditions commonly occur due to clogging of house drains and blocked inlet or outlet baffles [41]. In addition to these operational problems, leakage of untreated sewage due to structural damage and blocked drains is not uncommon from RSTs. Issues related to inefficient operations of RSTs have been reported in various regions of KSA, including Jeddah and Riyadh [42,43]. As a result, untreated sewage containing pathogens, nutrients, and organics can contaminate soil and groundwater [44].

Some recent studies, which assessed various aspects of sustainable tourism based on users' perceptions, centered on how residents' perceptions and attitudes influence the three dimensions of sustainability [45–48]. The present study was also based on considering residents as the primary stakeholders, as they need to recognize the following aspects for having a sustainable DWWTS in their smaller communities. First are the socioeconomic and environmental challenges they experience from septic tank operations and wastewater transportation to the nearest treatment facility. The local impacts were assessed through residents' knowledge of the existing system using PES and associated impacts on the natural environment with the help of EPI. The study found that the residents have moderate knowledge about the current system and a slightly higher than moderate perception of obvious environmental impacts. A survey on environmental challenges in Nags Head by the Institute for the Environment at the University of North Carolina at Chapel Hill reported that residents preferred septic systems over sewerage systems due to limited awareness about water quality deterioration, treatment systems, and economic concerns [49]. A substantial number of residents observed similar behavior in the present study, as reflected by barely moderate residents' perception, assessed through the PDS index, of the proposed DWWTS.

Gómez-Román et al. [50] identified various perceived costs of decentralized systems that restricted their acceptance among the residents. Libralato et al. [51] found that delayed cost savings after adopting DWWTS disparage residents' enthusiasm. Although the present study found moderately high scores of both WTA and WTU, the analysis revealed a higher value (3.73) of WTU than that of WTA (3.17). This means that the residents, though reluctant to change and accept a DWWTS due to their expected participation in DWWTS operations, are willing to use treated effluent for restricted and unrestricted irrigation. These findings match a past study in Al-Hassa (KSA) reporting a positive attitude toward reusing wastewater for irrigation and public uses due to the existence of a wastewater treatment facility [52]. The present survey revealed that only 17.6% of residents were likely to reuse treated wastewater for car washing and road cleaning. Around 38.2% declared a neutral response towards reusing treated wastewater for road cleaning and 26.5% for car washing. These results also agree with a recent study evaluating WTU for wastewater reuse in the Dammam Metropolitan Area in KSA that reported that only 27.2% of respondents decided to reuse treated wastewater for car washing [53].

Operations of DWWTP may negatively influence QOL due to the movement of staff, transport of chemicals, and driving of desludging vehicles [54]. The residents must comprehend these minor negative impacts and realize that the positive effects are much higher than the existing case. The study found encouraging residents' behavior, as 50% believed there was no impact on land value, around 65% saw no impact on noise levels, and 62% were unconcerned about the smell due to operations of the decentralized facility in the study area. Nevertheless, over 70% of the residents were concerned (likely or neutral) about the impact of the DWWTP's operations on traffic. The performance level of the aggregated QOL index is moderately high.

Around 97% of residents pay less than SAR 200 per month for wastewater disposal. Convincingly, 62% of respondents were willing to share this amount for implementing the proposed DWWTS in their area, which yielded a moderately high WTP. However, in response to WTP, an additional amount in place of the inconvenience caused by the wastewater disposal process, 85.3% of the residents agreed on only 20% more than their current spending. The study found a moderately high WTP by the residents of the study area, and a small monthly waste disposal expenditure (with a negligible additional amount) culminated in a moderate EVI. Rough cost estimates were compared with a past study by Singh and Kazmi [55] in India. They estimated a capital cost of USD 123/pe (population equivalent) and a land requirement of 0.1 m^2/pe. Adopting a public–private partnership (PPP) type of implementation strategy in smaller communities of KSA, land and capital costs are supposed to be managed by the government or a third party under build–operate–transfer (BOT) contracts, as already announced by the Ministry of Environment, Water, and Agriculture for large-scale wastewater treatment systems [56].

In the cases of PPP or BOT, operation and maintenance costs must originate from the residents. The ranges of the monthly cost of wastewater disposal (see Ec1 in Table 1) were averaged as SAR 125 (low), 175 (moderate), and 225 (high). The percentages of respondents for each element of UoD (low, moderate, and high) were found to be 61.8%, 35.3%, and 2.9%. Subsequently, an average monthly cost was calculated as SAR 146 per month. Sixty-two percent of respondents were willing to share this amount for DWWTS' implementation; therefore, SAR 90 per month can be considered reasonable. Likewise, the residents were WTP SAR 12 per month in addition to the existing cost to avoid the inconvenience caused by wastewater disposal (Ec3 in Table 1). Hence, around SAR 102 per month (~USD 27 per month per household) is the total WTP of the study area residents for a DWWTP.

Regarding population equivalent (pe), the monthly WTP was SAR 12.77 per pe (or USD 3.2 per pe), considering 8 persons per household for rural areas in KSA [34]. The annual WTP of USD 38.4 per pe for the study area is much higher than USD 5 per pe for operating and maintaining membrane bioreactor-type decentralized wastewater treatment plants in Northern India, as Singh and Kazmi [55] estimated. As Singh and Kazmi [55] completed their study around six years ago in a low-income country, where the material and labor cost is less than in the study area, the estimated amount seems sufficient to implement a DWWTS in the study area.

The present study supports the findings reported in the literature. For instance, a lack of awareness of water resource challenges was also identified as a significant factor affecting WTA for decentralized systems [49,50]. In addition, facilitation by the governments for the implementation of decentralized systems improves residents' perception and WTA [57]. Informing residents about the environmental issues and benefits of the conservation of water resources can significantly improve the residents' perception and participation in the installation and operations of decentralized systems. A comprehensive planning framework including all relevant authorities and stakeholders is needed to benefit from the present research and facilitate the implementation of DWWTS in arid regions.

6. Conclusions

Residents of smaller communities in KSA depend on onsite wastewater collection and storage systems, followed by transportation to the nearest centralized wastewater treatment facility. The existing practices raise various socioeconomic and environmental problems. The residents' knowledge about environmental degradation and resource conservation influences their perception of decentralized systems and, consequently, their willingness to accept a decentralized wastewater treatment facility. The residents of small communities in KSA are more aware of the existing wastewater management scenarios than the proposed decentralized treatment supported with a simplified sewer network.

Sub-indices of the social dimension, willingness to reuse treated effluent, willingness to accept a decentralized system, and impact of DWWTS' operations on quality of life were moderately high, yielding the same social acceptability index performance level. Knowledge of general environmental awareness produced a moderately high environmental pollution index. The economic viability of a decentralized system remained at a moderate performance level based on residents' perception due to a low monthly waste disposal cost. The comparison of WTP with the operation and maintenance cost of low-cost membrane type of DWWTS reported in the literature revealed that a small community can generate enough financial resources.

The construction of such systems needs a detailed policy framework to involve all relevant authorities and stakeholders effectively. The results of the present study will help decision-makers working in ministries concerning water resources, environment protection, and agricultural production in evaluating the sustainability of DWWTS for small communities in arid regions. Further research can affirm the usefulness of the developed approach by applying it to different rural settings, small towns, and agricultural areas in arid regions.

Author Contributions: Conceptualization, resources, supervision, M.T.A.; conceptualization, methodology, writing—original draft, H.H.; data collection and analysis, A.M.A.; validation, writing—review and editing, S.S.A. and M.S.; writing—review and editing, A.A. (Amimul Ahsan) and A.A. (Abdulaziz Alharbi). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Deanship of Scientific Research, Qassim University Grant no. 10249-qec-2020-1-3-I.

Data Availability Statement: Detailed data from the survey cannot be shared due to confidentiality issues.

Acknowledgments: The author(s) gratefully acknowledge Qassim University, represented by the Deanship of Scientific Research, on the financial support for this research under the number (10249-qec-2020-1-3-I) during the academic year 1441 AH/2020 AD. The authors also acknowledge all the participants who shared their opinion on our proposed wastewater treatment process.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

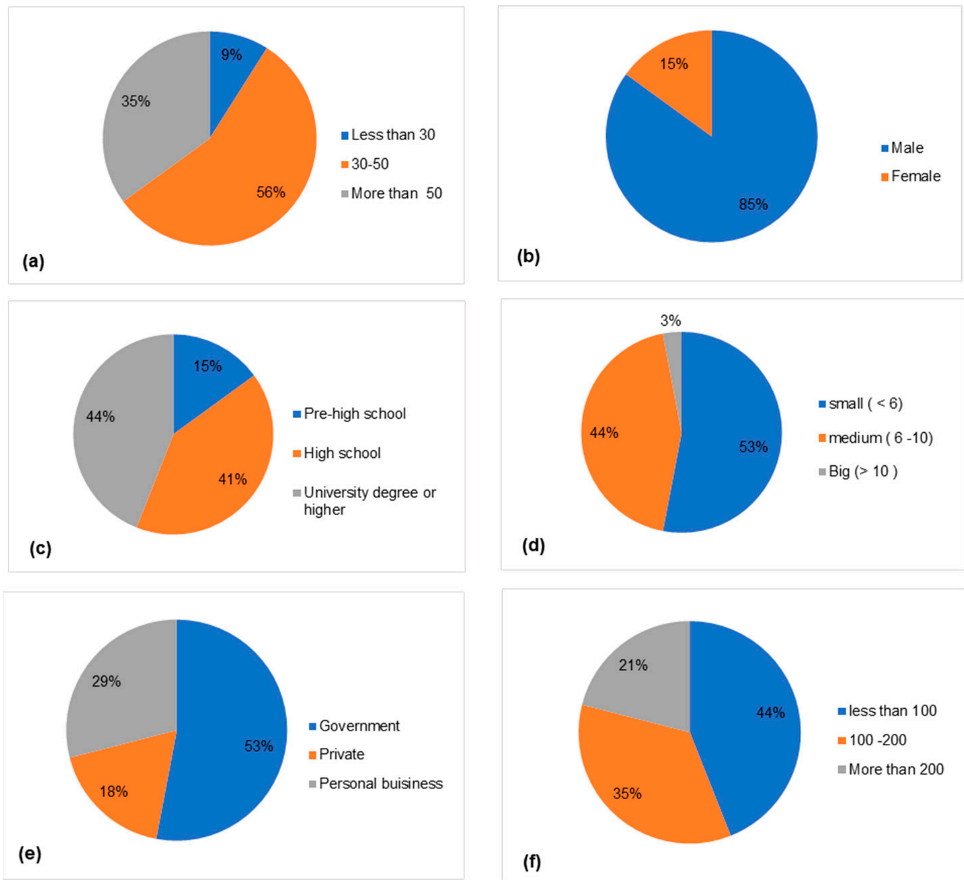

Figure A1. Descriptive statistics of respondents: (**a**) age, (**b**) gender, (**c**) education level, (**d**) family size, (**e**) job type, (**f**) monthly water bill (SAR/month).

Appendix B

Table A1. Summary of statistical analysis using Chi-square and Cramer's V tests.

No	Factors	Chi-Square (χ^2)	Significance at $p < 0.05$	Cramer's V	Association
1.	**Demographic information**				
Pr1	Gender	27	No	0.63	Strong
Pr2	Age	2.5	No	0.19	Weak
Pr3	Education level	4.6	No	0.26	Moderate
Pr4	Job type	5.9	No	0.29	Moderate
Pr5	Family size (Person)	2.5	No	0.19	Weak
Pr6	Monthly water bill (SAR/month)	9.3	No	0.37	Strong
2.	**Perception**				
2.1	*Perception of existing system (PES)*				
Pp 1	Status of wastewater treatment in the area.	66.7	Yes	0.99	Strong
Pp 2	Wastewater transportation and disposal.	67.5	Yes	1.0	Strong
Pp 3	Difficulties associated with WW transportation.	72.8	Yes	1.03	Strong
Pp 4	Loss of wastewater as a resource.	131.6	Yes	1.39	Strong
2.2	*Perception of DWWTS (PDS)*				
Pp 5	Informed about DWWTS.	13	No	0.14	Weak
Pp 6	Reuse potential for landscaping.	2.6	No	0.19	Weak
Pp 7	Reuse potential for agriculture.	3.1	No	0.21	Moderate
Pp 8	Reuse potential for road washing.	2.4	No	0.19	Weak
Pp 9	Reuse potential for car washing.	3	No	0.21	Moderate
3.	**Environmental Pollution**				
En 1	Impact on human health.	5.5	No	0.28	Moderate
En 2	Impact on the biological environment.	5.4	No	0.28	Moderate
En 3	Impact on the soil.	2.6	No	0.20	Weak
En 4	Impact on groundwater.	5	No	0.27	Moderate
4.	**Social acceptability**				
4.1	*Willingness to accept (WTA)*				
Sc 1	Willingness to accept (WTA) DWWTS.	68	Yes	1.0	Strong
4.2	*Willingness to use (WTU)*				
Sc 2	WTU for reusing treated wastewater for restricted irrigation.	11.2	Yes	0.41	Moderate
Sc 3	WTU for reusing treated wastewater for unrestricted irrigation.	13.4	Yes	0.44	Moderate
Sc 4	WTU for reusing treated wastewater for road washing.	12.8	Yes	0.43	Moderate
Sc 5	WTU for reusing treated wastewater for car washing.	18.2	Yes	0.52	Moderate
4.3	*Quality of life*				

Table A1. *Cont.*

No	Factors	Chi-Square (χ^2)	Significance at $p < 0.05$	Cramer's V	Association
Sc 6	Impact of DWWTS on traffic	9.2	No	0.37	Moderate
Sc 7	Impact of DWWTS on land value.	2.2	No	0.18	Weak
Sc 8	Noise pollution from DWWTS.	4.7	No	0.26	Weak
Sc 9	Odour from DWWTS.	8.6	No	0.36	Moderate
5.	**Economic**				
Ec 1	The monthly cost of wastewater disposal.	122.6	Yes	1.34	Strong
Ec 2	Willingness to pay (WTP) the existing expense for DWWTS.	74.5	Yes	1.05	Strong
Ec 3	WTP an additional amount for the improvements by DWWTS.	15.8	No	0.48	Moderate

References

1. Alkhudhiri, A.; Darwish, N.B.; Hilal, N. Analytical and forecasting study for wastewater treatment and water resources in Saudi Arabia. *J. Water Proc. Eng.* **2019**, *32*, 100915. [CrossRef]
2. Al-Hetari, M.; Haider, H.; Ghumman, A.R.; Al-Salamah, I.S.; Thabit, H.; Shafiquzzaman, M. Development of a Water Quality Management Model for Dry Rivers in Arid Regions: Application on Wadi Rumah, Saudi Arabia. *Ecosyst. Health Sustain.* **2023**, *9*, 0001. [CrossRef]
3. Alahdal, H.M.; AlYahya, S.; Ameen, F.; Sonbol, H.; Alomary, M.N. A review on Saudi Arabian wastewater treatment facilities and available disinfection methods: Implications to SARS-CoV-2 control. *J. King Saud Univ. Sci.* **2021**, *33*, 101574. [CrossRef] [PubMed]
4. Kazora, A.S.; Mourad, K.A. Assessing the sustainability of decentralized wastewater treatment systems in Rwanda. *Sustainability* **2018**, *10*, 4617. [CrossRef]
5. Arista, N.I.D.; Handayani, D.; Ernawati, N. Is It Possible to Implement the Same Circular-Economy Concept in Rural and Urban Areas? Study on Willingness to Pay for Household Waste. *Sustainability* **2023**, *15*, 5843. [CrossRef]
6. Brault, J.M.; Buchauer, K.; Gambrill, M. *Wastewater Treatment and Reuse, A Guide to Help Small Towns Select Appropriate Options*; World Bank Group: Washington, DC, USA, 2022.
7. Chopra, V.; Das, S. Estimating willingness to pay for wastewater treatment in New Delhi: Contingent valuation approach. *Ecol. Econ. Soc. -INSEE J.* **2019**, *2*, 75–108. [CrossRef]
8. Alsalah, D.; Al-Jassim, N.; Timraz, K.; Hong, P.Y. Assessing the groundwater quality at a Saudi Arabian agricultural site and the occurrence of opportunistic pathogens on irrigated food produce. *Int. J. Environ. Res. Public Health* **2015**, *12*, 12391–12411. [CrossRef]
9. Alresheedi, M.T.; Albuaymi, A.M.; AlSaleem, S.S.; Haider, H.; Shafiquzzaman, M.; AlHarbi, A.; Ahsan, A. Low-cost ceramic filter bioreactor for treatment and reuse of residential septic tank effluent: A decentralized approach for small communities. *Environ. Technol. Innov.* **2023**, *31*, 103213. [CrossRef]
10. Friha, I.; Karray, F.; Feki, F.; Jlaiel, L.; Sayadi, S. Treatment of cosmetic industry wastewater by submerged MBR with consideration of microbial community dynamics. *Int. Biodeterior. Biodegrad.* **2014**, *88*, 125–133. [CrossRef]
11. Chang, J.; Chang, C.; Chen, A.; Erdi, L.; Vigneswaran, S.; Brindle, K.; Stephenson, T. The application of membrane biological reactors for the treatment of wastewaters. *Biotechnol. Bioeng.* **2006**, *49*, 601–610.
12. Iorhemen, O.; Hamza, R.; Tay, J. Membrane bioreactor (MBR) technology for wastewater treatment and reclamation: Membrane fouling. *Membranes* **2016**, *6*, 33. [CrossRef] [PubMed]
13. Mutamim, N.; Noor, Z.; Hassan, M.; Yuniarto, A.; Olsson, G. Membrane bioreactor: Applications and limitations in treating high strength industrial wastewater. *Chem. Eng. J.* **2013**, *225*, 109–119. [CrossRef]
14. Mutamim, N.; Noor, Z.; Hassan, M.; Olsson, G. Application of membrane bioreactor technology in treating high strength industrial wastewater: A performance review. *Desalination* **2012**, *305*, 1–11. [CrossRef]
15. Hasan, M.M.; Shafiquzzaman, M.; Nakajima, J.; Ahmed, A.K.T.; Azam, M.S. Application of a Low-Cost Ceramic Filter to a Membrane Bioreactor for Greywater Treatment. *Water Environ. Res.* **2015**, *87*, 233–241. [CrossRef] [PubMed]
16. Shafiquzzaman, M.; Al- Mahmoud, A.; Al-Saleem, S.S.; Haider, H. Application of a Low Cost Ceramic Filter for Recycling Sand Filter Backwash Water. *Water* **2018**, *10*, 150. [CrossRef]
17. Shafiquzzaman, M.; Haider, H.; Ghazaw, Y.; Alharbi, F.; AlSaleem, S.S.; Almoshaogeh, M. Evaluation of a low-Cost ceramic filter for sustainable reuse of urban stormwater in arid environments. *Water* **2020**, *12*, 460. [CrossRef]
18. Shafiquzzaman, M.; Alharbi, S.; Haider, H.; AlSaleem, S.S.; Ghumman, A.R. Development and evaluation of treatment options for recycling ablution greywater. *Int. J. Environ. Sci. Technol.* **2020**, *17*, 1225–1238. [CrossRef]

19. Maryati, S.; Firman, T.; Humaira, A.N.S. A sustainability assessment of decentralized water supply systems in Bandung City, Indonesia. *Util. Policy* **2022**, *76*, 101373. [CrossRef]
20. Chen, Y.; Wang, J.; Yu, Y. A study on consumers' willingness to pay for remanufactured products: A study based on hierarchical regression method. *Front. Psychol.* **2019**, *10*, 2044. [CrossRef]
21. Lopes, A.B.; Galletta, D.F. Consumer perceptions and willingness to pay for intrinsically motivated online content. *J. Manag. Inf. Syst.* **2006**, *23*, 203–231. [CrossRef]
22. Genius, M.; Manioudaki, M.; Mokas, E.; Pantagakis, E.; Tampakakis, D.; Tsagarakis, K.P. Estimation of willingness to pay for wastewater treatment. *Water Sci. Technol. Water Supply* **2005**, *5*, 105–113. [CrossRef]
23. Byambadorj, A.; Lee, H.S. Household willingness to pay for wastewater treatment and water supply system improvement in a Ger area in Ulaanbaatar City, Mongolia. *Water* **2019**, *11*, 1856. [CrossRef]
24. Capodaglio, A.G. Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas. *Resources* **2017**, *6*, 22. [CrossRef]
25. Zang, J.; Kumar, M.; Werner, D. Real-world sustainability analysis of an innovative decentralized water system with rainwater harvesting and wastewater reclamation. *J. Environ. Manag.* **2021**, *280*, 111639. [CrossRef]
26. Torre, A.; Vázquez-Rowe, I.; Parodi, E.; Kahhat, R. Wastewater treatment decentralization: Is this the right direction for megacities in the Global South? *Sci. Total Environ.* **2021**, *778*, 146227. [CrossRef]
27. Shafiquzzaman, M.; Hasan, M.; Nakajima, J.; Mishima, I. Development of a simple and effective arsenic removal filter based on ceramic filtration. *J. Water Environ. Technol.* **2011**, *9*, 333–347. [CrossRef]
28. Dolnicar, S.; Saunders, C. Recycled water for consumer markets—A marketing research review and agenda. *Desalination* **2006**, *187*, 203–214. [CrossRef]
29. Cohen, A.D. *Strategies in Learning and Using a Second Language*; Longman: London, UK, 1998.
30. Alinizzi, M.; Haider, H.; Alresheedi, M. Assessing Traffic Congestion Hazard Period due to Commuters' Home-to-Shopping Center Departures after COVID-19 Curfew Timings. *Computation* **2022**, *10*, 132. [CrossRef]
31. Zhao, X.; Hwang, B.G.; Gao, Y. A fuzzy synthetic evaluation approach for risk assessment: A case of Singapore's green projects. *J. Clean. Prod.* **2016**, *115*, 203–213. [CrossRef]
32. Beullens, K.; Loosveldt, G.; Vandenplas, C. Interviewer effects among older respondents in the European Social Survey. *Int. J. Public Opin. Res.* **2019**, *31*, 609–625. [CrossRef]
33. Saab, N.; Badran, A.; Sadik, A.K. Environmental Education for Sustainable Development in Arab Countries. In *Annual Report of Arab Forum for Environment and Development*; Arab Forum for Environment and Development: Beirut, Lebanon, 2019.
34. Salam, A.A.; Elsegaey, I.; Khraif, R.; Al-Mutairi, A. Population distribution and household conditions in Saudi Arabia: Reflections from the 2010 Census. *SpringerPlus* **2014**, *3*, 530. [CrossRef] [PubMed]
35. Ouda, O.K. Review of Saudi Arabia municipal water tariff. *World Environ.* **2013**, *3*, 66–70.
36. Leicht, A.; Heiss, J.; Byun, W.J. *Issues and Trends in Education for Sustainable Development*; UNESCO Publishing: Paris, France, 2018; Volume 5.
37. United Nations Educational, Scientific and Cultural Organization (UNESCO). UNESCO and Sustainable Development Goals. 2015. Available online: https://en.unesco.org/sustainabledevelopmentgoals (accessed on 24 July 2023).
38. KSA Vision 2030. Available online: https://www.vision2030.gov.sa/ (accessed on 15 June 2023).
39. Essa, S.; Harvey, B. Education for sustainable development in Saudi Arabia: A critical discourse analysis of media and government policy documents. *Interdiscip. J. Environ. Sci. Educ.* **2022**, *18*, 2266. [CrossRef]
40. Al-Dosary, R. Waqi' attarbiah fi atta'alim ela'am fil mamlakah [The reality of environmental education in public education in the Kingdom of Saudi Arabia]. *Educ. J. Al-Azhar Univ.* **2016**, *2*, 391–420.
41. Washington State Department of Health. Signs of Septic System Failure. 2023. Available online: https://doh.wa.gov/community-and-environment/wastewater-management/septic-system/signs-failure#:~:text=Gurgling%20sounds%20in%20the%20plumbing,drainfield%2C%20even%20during%20dry%20weather (accessed on 1 August 2023).
42. Alhamid, A.A.; Alfayzi, S.A.; Hamadto, M.A. A sustainable water resources management plan for Wadi Hanifa in Saudi Arabia. *J. King Saud Univ. -Eng. Sci.* **2007**, *19*, 209–221. [CrossRef]
43. Elfeki, A.M.; Bahrawi, J. A fully distributed spreadsheet modeling as a tool for analyzing groundwater level rise problem in Jeddah city. *Arab. J. Geosci.* **2015**, *8*, 2313–2325. [CrossRef]
44. USEPA. Septic System Impacts on Water Sources. Available online: https://www.epa.gov/septic/septic-system-impacts-water-sources#:~:text=A%20failing%20septic%20system%20likely,ground%20and%20into%20surface%20waters (accessed on 25 July 2023).
45. Magadán-Díaz, M.; Rivas-García, J.I. Residents' perception of sustainable tourism in protected mountain areas: The case of Asturias. *J. Mt. Sci.* **2022**, *19*, 3597–3614. [CrossRef]
46. Lin, Y.H.; Lee, T.H. Does the perception of sustainability matter for environmentally responsible behavior? Empirical evidence from national park residents. *Int. J. Tour. Res.* **2022**, *24*, 593–609. [CrossRef]
47. Song, H.; Zhu, C.; Fong, L.H.N. Exploring residents' perceptions and attitudes towards sustainable tourism development in traditional villages: The lens of stakeholder theory. *Sustainability* **2021**, *13*, 13032. [CrossRef]
48. Lee, T.H.; Jan, F.H. Can community-based tourism contribute to sustainable development? Evidence from residents' perceptions of the sustainability. *Tour. Manag.* **2019**, *70*, 368–380. [CrossRef]

49. UNC. Environmental Change and Septic Systems in Nags Head: Local Perspectives and Impacts on Water Quality and Quantity, Capstone Report, University of North Carolina at Chapel Hill Institute for the Environment Outer Banks Field Site. 2018. Available online: https://ie.unc.edu/wp-content/uploads/sites/277/2019/03/Fall2018_ENEC698_OBXFSCapstone_final_report.pdf (accessed on 31 August 2023).
50. Gómez-Román, C.; Lima, L.; Vila-Tojo, S.; Correa-Chica, A.; Lema, J.; Sabucedo, J.M. "Who Cares?": The acceptance of decentralized wastewater systems in regions without water problems. *Int. J. Environ. Res. Public Health* **2020**, *17*, 9060. [CrossRef]
51. Libralato, G.; Volpi Ghirardini, A.; Avezzù, F. To centralize or to decentralize: An overview of the most recent trends in wastewater treatment management. *J. Environ. Manag.* **2012**, *94*, 61–68. [CrossRef] [PubMed]
52. Alataway, A.A.; Ness, M.R.; Gowing, J.W. Public attitude towards wastewater reuse for irrigated agriculture in Saudi Arabia. *WIT Trans. Ecol. Environ.* **2011**, *145*, 759–767.
53. Mu'azu, N.D.; Abubakar, I.R.; Blaisi, N.I. Public acceptability of treated wastewater reuse in Saudi Arabia: Implications for water management policy. *Sci. Total Environ.* **2020**, *721*, 137659. [CrossRef] [PubMed]
54. Bąk, J.; Barbusiński, K.; Thomas, M. Review of methods for assessing the impact of WWTPs on the natural environment. *Clean Technol.* **2021**, *3*, 98–122. [CrossRef]
55. Singh, N.K.; Kazmi, A.A. Performance and cost analysis of decentralized wastewater treatment plants in Northern India: Case study. *J. Water Resour. Plan. Manag.* **2018**, *144*, 05017024. [CrossRef]
56. ZAYWA. Saudi Arabia Offers 6 PPP Wastewater Projects. Available online: https://www.zawya.com/en/projects/utilities/saudi-arabia-offers-6-ppp-wastewater-projects-fovuru4t (accessed on 6 August 2023).
57. Mankad, A.; Tapsuwan, S. Review of socioeconomic drivers of community acceptance and adoption of decentralised water systems. *J. Environ. Manag.* **2011**, *92*, 380–391. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.