

Article



# Adoption of Sustainable Water Management Practices among Farmers in Saudi Arabia

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**Abstract:** Promoting sustainable water management (SWM) practices among farmers is essential in order to ensure water sustainability. This study aimed to analyze patterns in the adoption of SWM practices by farmers at the farm level, and how their awareness regarding the causes of agricultural water pollution influence SWM adoption. Face-to-face interviews were conducted to collect field data using structured questionnaires from 129 farmers in the Riyadh region, Saudi Arabia. The results indicate that 38.8% of farmers had a high awareness of the causes of water pollution from agriculture. Approximately half of the farmers exhibited a high rate of adoption of SWM practices, most of whom adopted water quality and soil management practices. The findings reveal a positive association (0.37, p < 0.01) between SWM adoption and awareness regarding water pollution from agriculture, whereby the farmers with more awareness regarding the causes of water pollution from agriculture showed a higher level of adoption for 55% of the SWM practices. Multiple regression analysis revealed that the awareness levels regarding the causes of agricultural water pollution and cultivated crops significantly influenced the adoption of SWM by farmers. The findings and implications provide an understanding of the SWM practices of farmers, and offers insights for policymakers aiming to reformulate strategies and policies combatting water scarcity in Saudi Arabia.

**Keywords:** sustainable water management; farmers; awareness; water pollution; adoption; water scarcity; Saudi Arabia

# 1. Introduction

Globally, the agriculture sector consumes about 70% of global freshwater withdrawals [1], and around 90% of global groundwater withdrawals [2]. Irrigated land constitutes about 20% of total cultivated land and contributes 40% of global annual food production [3]. A huge amount of water is lost during its distribution and application, resulting in low water-use efficiency [4,5]. About 35% of irrigation water is lost because of conveyance, farm distribution, and field application losses [6]. Additionally, climate change is expected to exacerbate the existing water-related problems. Evidence suggests that climate change will affect the availability, distribution, and quality of water [7]. On the other hand, polluted water is another example of water with potential future uses being irreparably lost. In many countries, water pollution due to agriculture is of growing concern [8]. It poses serious risks to aquatic ecosystems and human health, and threatens biodiversity [9]. Moreover, about 36 million hectares of land are under wastewater cultivation worldwide [10], and around 10% of the world's population consumes agricultural products produced with wastewater irrigation [11]. Poor quality irrigation water contains pathogens and heavy metals, and can cause potentially harmful environmental and health effects [12].

Sustainable water management can ensure the efficient and equitable allocation of water resources to achieve outcomes that are socially, economically, and environmentally beneficial [8]. In agriculture, sustainable water management refers to the set of all those measures and strategies that aim to improve water-use efficiency and productivity by



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**Copyright:** © 2021 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/). minimizing water losses and negative environmental and health impacts while maintaining agricultural productivity [6]. Sustainable agricultural water management practices can be broadly classified into the following categories: irrigation management practices; soil management practices; agronomic management practices; and water laws and regulations [13]. Irrigation system management practices include: the lining of canals and water networks [6]; the use of drip or sprinkler irrigation [14]; fertigation [15]; the appropriate design and regular maintenance of irrigation systems [16]; irrigation scheduling [6]; regulated deficit irrigation and partial root drying [14]; the use of solar energy for groundwater pumping [17]; the development of surface water storage facilities and rainwater harvesting [18]; and the planned use of treated wastewater [19]. Soil management practices include: conservation tillage [20]; mulching [21]; and the conservation of riparian buffer zones alongside water channels [22]. Agronomic practices consist of: the cultivation of short-duration, drought-resistant, and salt-tolerant crop varieties [23]; agroforestry [5]; integrated nutrients [6]; and pest and weed control [24]. Finally, water laws and regulations include comprehensive policies and frameworks that focus on the sustainable use, protection, and development of water resources at the national level [8].

Sustainable water management practices are important adaptation measures that farmers can use to cope with and resist the potential risks of water scarcity and water pollution [25]. Understanding the drivers shaping sustainable water management adoption is required for the further planning and strategic dissemination of sustainable water management practices [26], allowing water managers and policymakers to know the extent of policy interventions [27]. Farmers tend to adopt water innovations and conservation techniques as long as they can perceive an increase in expected profitability or a reduction in water pollution [28]. A large number of studies conducted in the field regarding the adoption of soil and water conservation practices have shown that farm-specific decisions to adopt new conservation practices are influenced by a wide range of considerations: socioeconomic characteristics (age, gender, education level, etc.) [29,30]; family management characteristics (size of the labor force, the scale of the agricultural operation, income level, etc.) [31,32]; the level of regional economic development; and policy factors (extension system, agricultural technology training, government support, etc.) [33,34]. Furthermore, awareness of water pollution is an important factor influencing the decisions of farmers regarding the adoption of SWM practices. According to [35,36], the low-level diffusion of water conservation practices, and the inability of farmers to adopt them, are mainly due to improper communication regarding the effect of such practices on environmental sustainability.

Saudi Arabia is classified by the United Nations as a water-scarce nation [37]. Overconsumption of water and climate change is expected to intensify the problem of water scarcity in the country [38]. Saudi Arabia has limited freshwater resources, and rainfall is extremely limited [39]. During the 20 years from 1997 to 2016, the country received an average rainfall of around 65 mm per year [40]. The agriculture sector is the largest user of water in the country, accounting for 72% of total water use [41]. Of all the water used for agricultural purposes, 90% is supplied by groundwater aquifers [42]. Different key challenges are facing Saudi Arabia's water sector, including balancing food security and water security [43]; the increasing demand for water from the agricultural sector [44]; low irrigation efficiency [45]; population growth and the high consumption of water [46]; the scarcity of reliable data about ground water resources [47]; climate change [39]; water losses through leakage [43,48]; and the environmental consequences of desalination plants [49]. To overcome these problems, the Ministry of Environment, Water, and Agriculture (MEWA) developed its "Strategic plan 2030" to maintain sustainable water management by increasing water awareness, supporting infrastructure projects in the water sector, reducing the domestic production of water-intensive crops, promoting the adoption of sustainable water management among farmers, and ensuring compliance with water legislation and laws [43,50].

The development of the agricultural sector in Saudi Arabia requires the adoption of sustainable water management practices in order to ensure the judicious use of the country's limited freshwater resources. Despite the widespread benefits and positive impact of SWM practices in farming, the adoption of these management practices in the context of Saudi Arabia has rarely been covered in the literature. The main aim of this paper is to analyze the adoption of SWM practices by farmers at the farm level. This aim was achieved by the following objectives: (1) to identify the awareness levels of farmers regarding water pollution; (2) to determine the extent of the adoption of SWM practices among farmers; (3) to explore the relationship between the adoption of SWM practices and the awareness of water pollution; and (4) to determine the factors influencing the adoption of sustainable water management by farmers. Thus, the findings of this study can contribute to closing the knowledge gap by providing useful information for the development of awareness campaigns and advisory and extension programs.

# 2. Methodology

# 2.1. Description of the Study Area

The Riyadh region, located in the center of Saudi Arabia, was selected as the study area (24.4116° N, 46.4319° E), as shown in Figure 1. The region is approximately 380,000 square kilometers, which represents around 17% of the total area of the country. The Riyadh region consists of 19 governorates: Al-Deri'yya, Al-Kharj, Al-Dwadmy, Al-Quway'iyah, Wadi Al-Dawaser, Al-Aflaj, Al-Zulfi, Shaqra, Hotat Bani Tameem, Afeef, Al-Saleel, Dharma, Al-Muzahmeya, Rammah, Thadig, Hraymla, Al-Hareeq, and Al-Ghat [51]. The main crops in the region include barley, fodder, winter potatoes, greenhouse tomatoes, and palm trees, with rates of 27.1%, 35.3%, 45%, 47%, and 25% of the total area planted, respectively, in the country [52]. The main source of irrigation in the study area, for about 67.6% of the total irrigated area, is groundwater [45]. More than 20,000 artesian wells, which extract water from deep groundwater aquifers, are distributed in different geographical areas of the region [43]. The second irrigation source used for the remaining irrigated lands is treated wastewater [53]. Wastewater treatment plants in the region produce effluents of acceptable quality according to the Saudi standards issued by the Ministry of Environment, Water and Agriculture (MEWA) [54].

This region was selected because it is characterized by a semi-arid environment with low annual rainfall, high-temperature variability, and limited groundwater reserves [55]. Furthermore, the region is classified as the highest area according to the percentage of water consumption in agriculture in 2017 [43]. In the same context, the quality of groundwater in the region is affected by various types of pollutants because of nonsustainable farming practices. Such pollutants include the accumulation of heavy metals in the soil as a result of the excessive use of pesticides and fertilizers, salinity as a result of the excessive use of groundwater in irrigation, and the use of untreated wastewater in irrigation [43,56].

#### 2.2. Sampling Procedures

Three governorates in the Riyadh region were randomly selected for data collection, namely, Al-Deri'yya, Dharma, and Al-Muzahmeya. Three districts in each governorate were selected purposely based on the abundance of farmers. The study's population consists of all farmers registered in the agricultural directorate databases in these districts during the agricultural season from 2019–2020 (n = 1893). A total of 185 farmers were randomly selected using Yamane's [57] sample size determination formula. These 185 farmers were invited to participate in the study, and among these farmers, 129 farmers completed the paper-based questionnaires, representing a response rate of 70%.



Figure 1. Map of the study area. (source: Mallick, Singh, AlMesfer, Singh, and Alsubih [56]).

# 2.3. Questionnaire Design

Data were collected using a structured questionnaire divided into three parts. The first part of the survey was designed to collect the demographic characteristics of the farmers, including their age, farming experiences, main occupation, level of education, extension contact, and cultivated crops. The second part of the instrument aimed to record the awareness of farmers as to the causes of agricultural water pollution. Five items were developed regarding water pollutants [43,58,59], according to the literature review, including the excessive use of water in irrigation, the use of untreated wastewater in irrigation, the excessive use of fertilizers, the excessive use of pesticides, and the pollution of irrigation water drains and valley estuaries with waste. In the third section, the adoption levels of farmers with regard to sustainable water management practices were assessed. Twenty items were used to measure the adoption of SWM practices among farmers based on the extension recommendations of the MEWA [43]. These items were classified into four groups: water and soil management (five items); water audit (six items); water quality (three items); and water conservation (six items). Validity and reliability were established.

A panel of five experts at King Saud University, Saudi Arabia, reviewed the questionnaire before collecting the data to exam the content validity. The purpose of the experts was to make sure that the items provided information for the study variables. Furthermore, the pilot test of the questionnaire with 30 farmers in the study area, before data collection, also assisted in ensuring content validity. The reliability for the adoption and awareness scales, obtained by applying Cronbach's alpha formula, was 0.81 and 0.86, respectively [60].

# 2.4. Variable Measurement and Data Analysis

The Likert response scale was used to assess the awareness of the farmers regarding the causes of agricultural water pollution. Respondents were asked to indicate their level of awareness on a 5-point Likert-type scale, where 1 = very low, 2 = low, 3 = moderate, 4 =high, and 5 =very high. To classify the farmers' awareness, the overall awareness scores of all items were summed and converted into a percentage. The levels of awareness were classified into three categories: a high level, if the calculated percentage was more than 75%; a medium level, if it was between 50% and 75%; and a low level, if it was less than 50%. In the same sense, farmers were asked to indicate their adoption of SWM practices on a 5-point Likert-type scale, where 1 = never, 2 = seldom, 3 = sometimes, 4 = often, and 5 = always. The total score for each farmer ranged between 20 and 100. The summated scores of adoption were calculated and converted into a percentage to determine the adoption levels of farmers regarding SWM practices. The farmers' adoption levels were classified into three categories, as follows: a high level (>75%), a medium level (50–75%), and a low level (<50%). Six variables, including age, education level, farm size, cultivated crops, extension contact, and awareness of water pollution were used as explanatory determinants in the multivariate regression model.

Categorical variables were converted into dummy variables to meet the requirements of regression analysis, as follows: education (high school at least = 1, other = 0), extension contact (contact to whatever degree = 1, no = 0), and cultivated crops (palm and other crops = 1, other = 0). The Statistical Package for Social Sciences was used (IBM SPSS, ver. 25.0, Armonk, NY, USA: IBM Corp.) to analyze the data.

A descriptive analysis using percentages, averages, and standard deviations (SD) was used to address the research objectives. The differences in the adoption levels according to awareness levels were estimated using the Kruskal–Wallis test. Moreover, in case of significant differences, the Dunn's test for multiple pairwise comparisons was performed to determine exactly which groups were different [61]. Pearson's correlation coefficient was used to determine the relationships among SWM practices. To measure the strength and direction of the association between the awareness of farmers regarding the causes of agricultural water pollution and the adoption of SWM practices, Kendall's tau-b was used [62]. Finally, multiple regression analysis was used to assess whether the adoption by farmers of sustainable water management practices was significantly influenced by the independent variables. A significance level of 0.05 was assumed in all data analyses.

#### 3. Results

#### 3.1. Farmers' Profile

A summary of the characteristics of the farmers is shown in Table 1. The results show that more than one-third (38%) of the farmers were in the age category  $\geq$  50 years, with an average age of 44.72 years recorded. Their average experience in agriculture was 16.39 years. Most of the farmers (61.2%) were full-time farmers. Approximately half of the respondents (51.9%) had been to high school or higher, while 20.9% of them were illiterate. The average mean of farm holdings was 3.88 hectares, and more than half of the farmers (58.1%) had farms that occupied between 1–4 hectares. In terms of extension contact, more than half of the farmers (53.5%) had no contact with extension agents. Finally, most farmers (65.9%) were cultivating palm trees and other crops, while the remaining percentage were cultivating only palm trees, in the study area.

| Variable             | Frequency  | Percent                          | Mean   | SD    | Min. | Max. |
|----------------------|------------|----------------------------------|--------|-------|------|------|
|                      | Age        | e (n = 129)                      |        |       |      |      |
| 20–29 years          | 15         | 11.6                             |        |       |      |      |
| 30–39 years          | 34         | 26.4                             | 44.70  | 10    | 20   |      |
| 40–49 year           | 31         | 24                               | 44.72  | 13    | 20   | 11   |
| $\geq$ 50 years      | 49         | 38                               |        |       |      |      |
|                      | Farming ex | perience (n =                    | = 128) |       |      |      |
| <9                   | 45         | 34.9                             |        |       |      |      |
| 19–10                | 33         | 25.6                             | 16.39  | 12.16 | 1    | 50   |
| $\geq 20$            | 51         | 39.5                             |        |       |      |      |
|                      | Farm s     | size (n = 129)                   | 1      |       |      |      |
| 1–4 hectares         | 75         | 58.1                             |        |       |      |      |
| 5–8 hectares         | 40         | 31                               | 3.88   | 2.41  | 1    | 12   |
| More than 8 hectares | 14         | 10.9                             |        |       |      |      |
|                      | Main occu  | pation ( $n = 1$                 | 129)   |       |      |      |
| Part-time farmers    | 50         | 38.8                             |        |       |      |      |
| Full-time farmers    | 79         | 61.2                             |        |       |      |      |
|                      | Education  | n level (n = 1                   | 28)    |       |      |      |
| Uneducated           | 27         | 20.9                             |        |       |      |      |
| Primary              | 14         | 10.9                             |        |       |      |      |
| Middle School        | 21         | 16.3                             |        |       |      |      |
| High School          | 32         | 24.8                             |        |       |      |      |
| College              | 27         | 20.9                             |        |       |      |      |
| Graduate School      | 8          | 6.2                              |        |       |      |      |
|                      | Extension  | contact (n =                     | 128)   |       |      |      |
| No                   | 69         | 53.9                             |        |       |      |      |
| Rarely               | 37         | 28.9                             |        |       |      |      |
| Sometimes            | 16         | 12.5                             |        |       |      |      |
| Always               | 6          | 4.7                              |        |       |      |      |
|                      | Cultivated | $l \operatorname{crops} (n = 1)$ | 126)   |       |      |      |
| Palm                 | 43         | 34.1                             |        |       |      |      |
| Palm and field crops | 24         | 19.1                             |        |       |      |      |
| Palm and vegetables  | 48         | 38.1                             |        |       |      |      |
| Palm and fruits      | 11         | 8.7                              |        |       |      |      |

 Table 1. Demographic profile of farmers.

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# 3.2. Farmers' Awareness about the Causes of Agricultural Water Pollution

The awareness of farmers regarding the causes of agricultural water pollution is presented in Table 2. For all the practices assessed, the farmers recorded a moderate level of awareness. The respondents rated themselves as having the highest level of awareness of the "use of untreated wastewater in irrigation" (mean = 3.47; SD = 1.41), while "excessive use of fertilizers" recorded the lowest level of awareness (mean = 3.08; SD = 1.02).

Table 2. Farmers' awareness of water pollutants.

| Items   | Mean | SD   |
|---|------|------|
| Excessive use of water in irrigation.                                 | 3.35 | 1.52 |
| Use of untreated wastewater in irrigation.                            | 3.47 | 1.41 |
| Excessive use of fertilizers.   | 3.08 | 1.02 |
| Excessive use of pesticides.  | 3.13 | 1.36 |
| Pollution of irrigation water drains and valley estuaries with waste. | 3.23 | 1.32 |

The findings in Figure 2 demonstrate the levels of awareness of farmers regarding water pollution. Most farmers (42.6%) had a moderate level of awareness about the causes of agricultural water pollution, whereas more than one-third (38.8%) had a high level, and only 18.6% of farmers reported having a low level of awareness.



**Figure 2.** Classification of farmers according to their awareness levels regarding the causes of agricultural water pollution.

#### 3.3. Adoption of Sustainable Water Management Practices

Table 3 shows the adoption levels of the farmers regarding SWM practices. Overall, the farmers reported moderate adoption levels (mean = 3.49; SD = 1.22). The details of each practice with regard to the SWM categories are provided below.

| No.                       | Items   | Mean | SD   |  |  |  |  |  |  |
|---------------------------|---|------|------|--|--|--|--|--|--|
| Water and soil management |   |      |      |  |  |  |  |  |  |
| WM1                       | Using soil conditioners to reduce water consumption.  | 3.40 | 1.25 |  |  |  |  |  |  |
| WM2                       | Reusing of agricultural residues to improve soil properties.                                    | 3.71 | 1.23 |  |  |  |  |  |  |
| WM3                       | Maintenance of irrigation machines.   | 3.91 | 1.18 |  |  |  |  |  |  |
| WM4                       | Follow up on any leaks in irrigation systems and treat them.                                    | 3.78 | 1.14 |  |  |  |  |  |  |
| WM5                       | Conducting soil tests to measure soil properties.   | 4.04 | 1.16 |  |  |  |  |  |  |
|                           | Water audit   |      |      |  |  |  |  |  |  |
| WA1                       | Monitoring the level of well-water availability.  | 3.94 | 1.16 |  |  |  |  |  |  |
| WA2                       | Using smart meters on wells.  | 2.26 | 1.40 |  |  |  |  |  |  |
| WA3                       | Keeping agricultural records about irrigation.  | 3.07 | 1.38 |  |  |  |  |  |  |
| WA4                       | Calculating water consumption of cultivated crops.  | 3.18 | 1.12 |  |  |  |  |  |  |
| WA5                       | Using new devices for irrigation scheduling and soil moisture monitoring.                       | 2.98 | 1.33 |  |  |  |  |  |  |
| WA6                       | Using weather forecast data for irrigation scheduling.  | 3.18 | 1.25 |  |  |  |  |  |  |
|                           | Water quality   |      |      |  |  |  |  |  |  |
| WQ1                       | Performing tests to measure the quality of irrigation water.                                    | 4.02 | 1.14 |  |  |  |  |  |  |
| WQ2                       | Committing to water legislation and laws.   | 3.73 | 1.21 |  |  |  |  |  |  |
| WQ3                       | Protecting water sources from any pollution.  | 3.61 | 1.21 |  |  |  |  |  |  |
|                           | Water conservation  |      |      |  |  |  |  |  |  |
| WC1                       | Cultivating crops that suit soil characteristics.   | 3.88 | 1.16 |  |  |  |  |  |  |
| WC2                       | Cultivation of crops commensurate with the amount of water available.                           | 3.58 | 1.28 |  |  |  |  |  |  |
| WC3                       | Cultivating crops that are commensurate with the degree of wastewater and industrial treatment. | 3.14 | 1.15 |  |  |  |  |  |  |
| WC4                       | Using irrigation systems that are suitable for crops.   | 3.41 | 1.18 |  |  |  |  |  |  |
| WC5                       | Cultivation of drought-resistant varieties.   | 3.54 | 1.31 |  |  |  |  |  |  |
| WC6                       | Committing to the appropriate periods between irrigations according to the type of crop.        | 3.38 | 1.29 |  |  |  |  |  |  |
|                           | Overall   | 3.49 | 1.22 |  |  |  |  |  |  |

Table 3. Farmers' adoption of sustainable water management practices.

#### 3.3.1. Water and Soil Management

The findings in Figure 3 show that the farmers had moderately adopted these water and soil management practices, with an overall average of 73.35% recorded. For the water and soil management items (Table 3), farmers reported moderate adoptions levels for "using soil conditioners to reduce water consumption" (mean = 3.40; SD = 1.25), and the "reusing of agricultural residues to improve soil properties" (mean = 3.71; SD = 1.23), whereas they reported high adoption levels for other water management practices.



Figure 3. Overall adoption of sustainable water management categories.

#### 3.3.2. Water Audit

In our study, the overall percentage for the adoption of water audit practices was 62.11% (Figure 3). However, as presented in Table 3, the farmers only reported high levels of adoption for the statement of "monitoring the level of water availability in wells". In contrast, for the other water audit practices, the farmers reported moderate adoption levels.

#### 3.3.3. Water Quality

The findings in Figure 3 show that the overall adoption of water quality practices was high, with a percentage of 75.61% recorded. For all three water quality practices assessed in Table 3, the farmers rated their adoption levels as being highest for "performing tests to measure the quality of irrigation water" (mean = 4.02; SD = 1.14), followed by "committing to water legislation and laws" (mean =3.73; SD = 1.21), and "protecting water sources from any pollution" (mean = 3.61; SD = 1.21).

#### 3.3.4. Water Conservation

The results indicate that, overall, more than three-quarters of the farmers (70.40%) had adopted water conservation practices (Figure 3). For all six water conservation practices assessed (Table 3), the levels of adoption ranged from low to moderate adoption levels for all practices. The farmers reported the highest adoption level for "cultivating crops that suit soil characteristics" (Mean = 3.88; SD = 1.16), whereas they reported the lowest level of adoption in this category for "cultivating crops that are commensurate with the degree of wastewater and industrial treatment" (Mean = 3.14; SD = 1.18).

Table 4 shows the percentages for the reported levels of adoption of sustainable water management practices by farmers. The results indicate that approximately half of the respondents were in the high-adoption-level category, 48.8% of the respondents were in the moderate-level category, and only 0.8% of them were in the low-adoption-level category.

**Table 4.** Classification of farmers according to their adoption levels of sustainable water management practices.

| Adoption Categories | Frequency (n= 129) | %    |
|---------------------|--------------------|------|
| Low                 | 1                  | 0.8  |
| Moderate            | 63                 | 48.8 |
| High                | 65                 | 50.4 |

In order to determine the interrelations in the responses of farmers to SWM practices, a correlation matrix for the different practices investigated was performed, as shown in Table 5.

|     | WM1      | WM2      | WM3      | WM4      | WM5      | WA1      | WA2      | WA3      | WA4      | WA5      | WA6      | WQ1      | WQ2      | WQ3      | WC1      | WC2      | WC3      | WC4      | WC5      | WC6   |
|-----|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-------|
| WM1 | 1.000    |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |       |
| WM2 | 0.364 ** | 1.000    |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |       |
| WM3 | 0.316 ** | 0.111    | 1.000    |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |       |
| WM4 | 0.542 ** | 0.358 ** | 0.396 ** | 1.000    |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |       |
| WM5 | 0.170    | 0.116    | -0.031   | 0.141    | 1.000    |          |          |          |          |          |          |          |          |          |          |          |          |          |          |       |
| WA1 | 0.123    | 0.084    | 0.167    | 0.130    | 0.379 ** | 1.000    |          |          |          |          |          |          |          |          |          |          |          |          |          |       |
| WA2 | 0.280 ** | 0.086    | 0.263 ** | 0.228 ** | 0.333 ** | -0.054   | 1.000    |          |          |          |          |          |          |          |          |          |          |          |          |       |
| WA3 | -0.007   | -0.015   | 0.032    | 0.059    | 0.051    | -0.036   | 0.099    | 1.000    |          |          |          |          |          |          |          |          |          |          |          |       |
| WA4 | 0.307 ** | 0.228 ** | 0.608 ** | 0.324 ** | 0.215 *  | 0.238 ** | 0.325 ** | -0.029   | 1.000    |          |          |          |          |          |          |          |          |          |          |       |
| WA5 | 0.231 ** | 0.235 ** | 0.039    | 0.173 *  | 0.057    | -0.074   | 0.128    | 0.266 ** | 0.104    | 1.000    |          |          |          |          |          |          |          |          |          |       |
| WA6 | 0.293 ** | 0.244 ** | 0.059    | 0.241 ** | 0.115    | -0.002   | 0.159    | 0.327 ** | 0.062    | 0.315 ** | 1.000    |          |          |          |          |          |          |          |          |       |
| WQ1 | 0.207 *  | 0.108    | 0.058    | 0.039    | 0.618 ** | 0.575 ** | 0.173    | 0.044    | 0.312 ** | 0.000    | 0.191 *  | 1.000    |          |          |          |          |          |          |          |       |
| WQ2 | 0.165    | 0.098    | 0.174 *  | 0.278 ** | 0.101    | 0.169    | -0.105   | 0.002    | 0.203 *  | 0.029    | -0.006   | 0.020    | 1.000    |          |          |          |          |          |          |       |
| WQ3 | 0.297 ** | 0.602 ** | 0.222 *  | 0.284 ** | 0.079    | 0.284 ** | 0.022    | 0.133    | 0.132    | 0.283 ** | 0.406 ** | 0.214 *  | 0.090    | 1.000    |          |          |          |          |          |       |
| WC1 | 0.279 ** | 0.262 ** | 0.347 ** | 0.270 ** | 0.360 ** | 0.322 ** | 0.081    | 0.081    | 0.463 ** | 0.029    | 0.075    | 0.392 ** | 0.189 *  | 0.194 *  | 1.000    |          |          |          |          |       |
| WC2 | 0.314 ** | 0.116    | 0.306 ** | 0.238 ** | 0.346 ** | 0.322 ** | 0.143    | 0.005    | 0.507 ** | 0.028    | 0.147    | 0.421 ** | 0.306 ** | 0.103    | 0.576 ** | 1.000    |          |          |          |       |
| WC3 | 0.148    | 0.068    | 0.137    | 0.208 *  | 0.258 ** | 0.148    | 0.157    | 0.305 ** | 0.039    | 0.155    | 0.224 *  | 0.216*   | 0.052    | 0.333 ** | 0.076    | -0.006   | 1.000    |          |          |       |
| WC4 | 0.245 ** | 0.246 ** | 0.060    | 0.287 ** | 0.149    | 0.059    | 0.051    | 0.088    | 0.032    | 0.153    | 0.173    | 0.130    | 0.457 ** | 0.188 *  | 0.114    | 0.188 *  | 0.289 ** | 1.000    |          |       |
| WC5 | 0.320 ** | 0.110    | 0.172    | 0.388 ** | 0.014    | 0.086    | 0.053    | -0.028   | 0.167    | -0.003   | 0.182*   | 0.095    | 0.499 ** | 0.143    | 0.162    | 0.290 ** | 0.161    | 0.573 ** | 1.000    |       |
| WC6 | 0.194 *  | 0.142    | 0.166    | 0.248 ** | 0.029    | -0.007   | -0.109   | 0.008    | 0.160    | -0.022   | 0.144    | -0.018   | 0.703 ** | 0.191 *  | 0.287**  | 0.222 *  | 0.165    | 0.373 ** | 0.463 ** | 1.000 |

**Table 5.** Correlation matrix of the different SWM practices.

Correlation coefficients significant at 5% (\*) and 1% (\*\*), levels are marked in bold.

# 3.4. Relationship between Farmers' Adoption of SWM Practices and Their Levels of Awareness regarding the Causes of Agricultural Water Pollution

The levels of adoption were classified based on the various levels of the farmers regarding awareness of the causes of agricultural water pollution, in each of the categories of sustainable water management practices, to examine the relationship between the two variables, as shown in Table 6. According to the Kruskal–Wallis analysis, the findings reveal that, for the eleven practices examined, highly significant differences existed between all adoption level categories among farmers regarding their awareness of water pollution (55%). Additionally, the Dunn's test results confirmed that there were significant differences between the mean value of the "high adoption" category, and the mean value of the "low adoption" category. The findings show that, in more than half of the practices investigated, the respondents differed in their adoption of sustainable water management practices based on their level of awareness with regard to the causes of agricultural water pollution.

**Table 6.** Differences in the adoption of sustainable water management practices by farmers according to their awareness with regard to the causes of agricultural water pollution.

|           | Awareness of Water P |         |           |       |      |      | Kruskal–Wa | allis Test      | Dunn's Test |            |            |                 |  |
|-----------|----------------------|---------|-----------|-------|------|------|------------|-----------------|-------------|------------|------------|-----------------|--|
| Practices | Lo                   | w       | Mode      | erate | Hig  | gh   | ~          |                 |             |            |            |                 |  |
|           | Mean                 | SD      | Mean      | SD    | Mean | SD   | Chi-Square | <i>p</i> -Value | Mean        | Difference | Std. Error | <i>p</i> -Value |  |
| WM1       | 3.09                 | 1.3     | 3.35      | 1.23  | 3.66 | 1.22 | 4.11       | 0.12            |             |            |            |                 |  |
| WM2       | 3.36                 | 1.41    | 3.83      | 1.03  | 3.82 | 1.25 | 2.5        | 0.28            |             |            |            |                 |  |
|           |                      |         |           |       |      |      |            |                 | L-M         | -25.46 **  | 8.67       | 0.00            |  |
| WM3       | 3.13                 | 1.36    | 4.05      | 1.06  | 4.14 | 1.08 | 11.76      | 0.00            | L-H         | -29.07 **  | 8.80       | 0.00            |  |
|           |                      |         |           |       |      |      |            |                 | M-H         | -3.61      | 6.92       | 0.60            |  |
|           |                      |         |           |       |      |      |            |                 | L-M         | -20.44 *   | 8.79       | 0.02            |  |
| WM4       | 3.08                 | 1.17    | 3.75      | 1.17  | 4.14 | 0.92 | 12.89      | 0.00            | L–H         | -32.01 **  | 8.92       | 0.00            |  |
|           |                      |         |           |       |      |      |            |                 | M-H         | -11.57     | 7.02       | 0.09            |  |
| WM5       | 4.09                 | 0.98    | 3.89      | 1.08  | 4.14 | 1.35 | 3.43       | 0.17            |             |            |            |                 |  |
| WA1       | 3.82                 | 1.15    | 3.91      | 1.17  | 4.30 | 1.12 | 5.65       | 0.06            |             |            |            |                 |  |
| WA2       | 3.48                 | 1.48    | 3.43      | 1.27  | 2.96 | 1.42 | 4.02       | 0.13            |             |            |            |                 |  |
| WA3       | 3.03                 | 1.26    | 2.98      | 1.49  | 3.18 | 1.38 | 0.53       | 0.76            |             |            |            |                 |  |
|           |                      |         |           |       |      |      |            |                 | L-M         | -21.93 **  | 8.88       | 0.01            |  |
| WA4       | 3.13                 | 1.36    | 4.05      | 1.06  | 3.88 | 1.25 | 8.29       | 0.001           | L-H         | -24.28 **  | 8.75       | 0.00            |  |
|           |                      |         |           |       |      |      |            |                 | M-H         | -2.34      | 6.99       | 0.73            |  |
| WA5       | 3.39                 | 1.45    | 3.35      | 1.28  | 3.82 | 1.27 | 3.83       | 0.14            |             |            |            |                 |  |
| WA6       | 3.27                 | 1.12    | 3.35      | 1.26  | 3.74 | 1.29 | 4.49       | 0.11            |             |            |            |                 |  |
| WQ1       | 3.97                 | 0.91    | 4.09      | 1.00  | 3.98 | 1.39 | 0.93       | 0.63            |             |            |            |                 |  |
|           |                      |         |           |       |      |      |            |                 | L-M         | -8.75      | 8.80       | 0.32            |  |
| WQ2       | 3.17                 | 1.43    | 3.55      | 1.21  | 4.20 | 0.90 | 12.43      | 0.00            | L–H         | -28.10 **  | 8.94       | 0.00            |  |
|           |                      |         |           |       |      |      |            |                 | M-H         | -19.35 **  | 7.03       | 0.00            |  |
|           |                      |         |           |       |      |      |            |                 | L-M         | 7.19       | 8.65       | 0.40            |  |
| WQ3       | 3.79                 | 1.44    | 3.73      | 1.14  | 4.18 | 1.15 | 6.44       | 0.004           | L–H         | -17.51 **  | 6.91       | 0.01            |  |
|           |                      |         |           |       |      |      |            |                 | M-H         | -10.32     | 8.78       | 0.24            |  |
|           |                      |         |           |       |      |      |            |                 | L-M         | -10.11     | 8.55       | 0.23            |  |
| WC1       | 3.46                 | 1.41    | 1.41 3.98 | 1.06  | 4.36 | 1.04 | 10.45      | 0.00            | L–H         | -26.06 **  | 8.68       | 0.00            |  |
|           |                      |         |           |       |      |      |            |                 | M-H         | -15.95 *   | 6.83       | 0.02            |  |
|           |                      |         |           |       |      |      |            |                 | L-M         | -15.65     | 8.65       | 0.07            |  |
| WC2       | 3.29                 | .9 1.26 | 1.26 3.87 | 1.21  | 4.18 | 1.28 | 10.92      | 0.00            | L-H         | -28.58 **  | 8.78       | 0.00            |  |
|           |                      |         |           |       |      |      |            |                 | M-H         | -12.93 *   | 6.91       | 0.05            |  |

|           |      | Aware  | ness of V | Vater Po | ollution |      | Kruskal–Wa  | Kruskal–Wallis Test |                 |           | unn's Test |                 |      |
|-----------|------|--------|-----------|----------|----------|------|-------------|---------------------|-----------------|-----------|------------|-----------------|------|
| Practices | Low  |        | Moderate  |          | High     |      | 01:0        | X7 1                |                 |           |            |                 |      |
|           | Mean | SD     | Mean      | SD       | Mean     | SD   | CIII-Square | <i>p</i> -value     | Mean Difference |           | Std. Error | <i>p</i> -value |      |
|           |      |        |           |          |          |      |             |                     | L-M             | -17.06 *  | 8.80       | 0.05            |      |
| WC3       | 3.25 | 0.94   | 3.64      | 1.28     | 4.04     | 1.00 | 10.22       | 0.00                | L-H             | -28.42 ** | 8.93       | 0.00            |      |
|           |      |        |           |          |          |      |             |                     | M-H             | -11.35    | 7.03       | 0.10            |      |
|           | 3.38 |        |           | 1.15     | 4.06     | 1.05 | 7.71        | 0.002               | L-M             | -2.77     | 8.81       | 0.75            |      |
| WC4       |      | 1.37   | 3.55      |          |          |      |             |                     | L-H             | -19.89 *  | 8.94       | 0.02            |      |
|           |      |        |           |          |          |      |             |                     | M-H             | -17.11 ** | 7.04       | 0.01            |      |
|           |      |        |           |          |          |      |             |                     | L-M             | -13.10    | 8.66       | 0.13            |      |
| WC5       | 3.13 | 1.42   | 3.69      | 1.27     | 4.34     | 1.09 | 16.20       | 0.00                | L-H             | -32.99 ** | 8.79       | 0.00            |      |
|           |      |        |           |          |          |      |             |                     | M-H             | -19.89 ** | 6.92       | 0.00            |      |
| WC6       |      |        |           |          |          |      |             |                     | L-M             | -17.86 *  | 8.80       | 0.04            |      |
|           | 2.88 | 1.29 3 | 3.55      | 1.25     | 4.22     | 1.09 | 19.26       | 0.00                | L-H             | -37.75 ** | 8.93       | 0.00            |      |
|           |      |        | 2.00      |          |          |      |             |                     |                 |           | M-H        | -19.88 **       | 7.03 |

Table 6. Cont.

\* *p* < 0.05; \*\* *p* < 0.01; L (Low); M (Medium); H (High); Sig. = level of significance.

In order to examine the strength of the association between the adoption of sustainable water management practices and the farmers' awareness of water pollution caused by agriculture, Kendall's tau-b was applied (Table 7). The results depict a significant positive correlation between the adoption levels of SWM practices for farmers and their awareness regarding the causes of agricultural water pollution: p < 0.01. The value of Kendall's tau-b (0.37) reflects the strength of the association between adoption and awareness. This indicates that farmers with a higher level of awareness about the causes of agricultural water pollution scored higher on the items related to SWM adoption.

**Table 7.** Association between the adoption of water sustainable management practices by farmers and their awareness of the causes of agricultural water pollution.

| Awareness of     |       |      | Adoptic | on Level |       |     | _     |      |                    |                 |  |  |  |
|------------------|-------|------|---------|----------|-------|-----|-------|------|--------------------|-----------------|--|--|--|
|                  | Lo    | w    | Mod     | erate    | Hi    | gh  | - 10  | tal  | Kendall's<br>Tau-b | <i>p</i> -Value |  |  |  |
| viace i officion | Freq. | %    | Freq.   | %        | Freq. | %   | Freq. | %    | iuu D              |                 |  |  |  |
| Low              | 0     | 0.00 | 0       | 0.00     | 1     | 2   | 1     | 0.7  |                    |                 |  |  |  |
| Moderate         | 17    | 70.8 | 31      | 56.4     | 15    | 30  | 63    | 48.8 | 0 271 **           | 0.001           |  |  |  |
| High             | 7     | 29.2 | 24      | 43.6     | 34    | 68  | 65    | 50.4 | 0.371              |                 |  |  |  |
| Total            | 24    | 100  | 55      | 100      | 50    | 100 | 129   | 100  |                    |                 |  |  |  |

\*\* *p* < 0.01; Freq. = frequency.

# 3.5. Factors Influencing Adoption of SWM Practices

A multiple regression analysis was performed to identify the independent variables that accounted for the variations in the adoption of SWM practices by farmers, as shown in Table 8. The results show that the awareness of farmers regarding the causes of agricultural water pollution contributed positively and significantly to adoption, at a 1% level of probability, while the cultivated crops variable contributed negatively and significantly to adoption, at a 5% level of probability. The coefficient of determination (R<sup>2</sup> value) was 0.23, which indicates that 23.00% of the variation in the adoption of SWM practices was accounted for by these five explanatory variables selected for the study. Furthermore, the results show that the independent variables explained only 26.8% of the variability in the adoption of SWM practices by farmers.

| Variable                     | Coefficient (b) | Standard Error | t       | <i>p</i> -Value |
|------------------------------|-----------------|----------------|---------|-----------------|
| Age                          | 0.04            | 0.08           | 0.51    | 0.60            |
| Awareness of water pollution | 0.62            | 0.17           | 3.64 ** | 0.00            |
| Education level              | -1.54           | 2.69           | -0.57   | 0.56            |
| Farm size                    | 0.98            | 0.81           | 0.63    | 0.69            |
| Cultivated crops             | -4.34           | 2.15           | -2.01 * | 0.04            |
| Extension contact            | -2.15           | 2.10           | -1.03   | 0.30            |

**Table 8.** Summary of multiple regression analysis for variables predicting the adoption of sustainable water management practices by farmers.

\* p < 0.05; \*\* p < 0.01; R<sup>2</sup> = 0.26.8; F = 9.66 \*\*.

# 4. Discussion

This study examined the adoption of SWM practices as a strategy for farmers in Saudi Arabia to adapt to the current agro-climatic conditions and water scarcity in the study area. This article provides deeper insight into the varied and dynamic nature of SWM adoption, examining the factors that drove adoption in the study area, and how adoption varied according to the awareness of farmers as to the causes of water pollution. This approach provides a series of valuable policy guidelines to stimulate adoption at the farm level and, in turn, to achieve one of the main objectives of the country's 2030 vision for the water sector.

Awareness of water pollution issues caused by agriculture is the first step towards overall SWM adoption. Our results found that the awareness levels of most farmers surveyed in this study regarding water pollution was moderate. This means that farmers still have insufficient knowledge about the drivers of water pollution. This might be because farmers lack sufficient understanding of the negative consequences of incompliance with water conservation practices, particularly in arid and semi-arid regions. According to Okumah et al. [63], an understanding of the awareness–behavioral change–water quality pathway is critical in mitigating diffuse water pollution. Such an understanding would offer an opportunity to design "tailored" diffuse water pollution reduction measures and implement effective policy interventions to influence an uptake in SWM practices [63,64]. In this regard, agricultural extension services could play a critical role in raising the awareness of water pollution, influencing the behavior of farmers in order to promote the adoption of SWM practices, and facilitating the networking of farmers with other stakeholders in order to solve water issues. These activities could be conducted by a range of individual, group, and mass advisory methods [65–67].

Given the adoption rates among the respondents, it is more relevant to discuss the extent to which respondents were practicing SWM rather than how to increase adoption in general. Our results report that most farmers had moderately adopted SWM practices. This result is in agreement with those of previous studies in the field of soil and water conservation [67–71]. For all SWM categories, variations in adoption rates were observed for water audit practices, specifically with regard to using smart meters on wells and using new devices for irrigation scheduling and soil moisture monitoring. This might be attributed to the lack of positive attitudes among farmers toward the effects of such practices on water efficiency consumption. Other possible explanations for this result could be attributed to the negative attitudes of farmers towards applying such practices. Farmers perceive that water audit practices are a method of monitoring water consumption and applying water pricing and water quota policies. The results also reveal, among conservation practices, that the rate of adopting cultivating crops that are commensurate with the degree of wastewater and industrial treatment was low compared to the other practices. This might be attributed to the lack of knowledge among farmers about the safe use of wastewater in agriculture because of irregular contact with extension services, as presented in Table 1. In this sense, it is worth noting that some farmers, on purpose, grow some crops that are not suitable for the level of wastewater treatment. Accordingly, implementing inspection campaigns that monitor the compliance of famers with wastewater legislation, and apply

penalties to violators, is critical for enhancing the adoption by farmers of wastewater use in irrigation. In general, the adoption of SWM practices can be stimulated when farmers discover the advantages and disadvantages of different practices and have the opportunity to experiment on their own land [72].

The findings highlight an interrelationship between the awareness of farmers regarding the causes of agricultural water pollution and their adoption of SWM practices. In other words, farmers with a higher awareness of the levels of water pollution exhibit higher adoption rates. In this regard, the results clarify that knowledge of the adverse consequences of incompliance with the correct usage of water resources creates the motivation for acquiring knowledge about best management practices. Correctly diagnosing water challenges and problems is the first step in identifying possible solutions to cope with water scarcity. Consequently, policies and strategies should be targeted towards developing integrated extension messages that explain the environmental risks associated with noncompliance, and the penalties related to it, and provide information about SWM practices and how to adopt them at the farm level [64,66,73]. This finding is aligned with other studies that have reported a positive relationship between the awareness of water issues and the adoption of soil and water conservation practices [70,74–76].

However, despite some recent studies that have indicated the importance of intercropping in maintaining high crop yields, effectively decreasing water consumption in semi-arid and arid climates, providing better coverage on the soil surface, reducing the direct impact of raindrops, and protecting soil from erosion [77–79], the results show that cultivated crops had a negative and significant effect on the adoption of SWM practices. This means that farmers who specialized in cultivating palm trees scored higher in adoption compared to farmers who cultivated palm and other crops. In other words, mono-cropping will accelerate the adoption of SWM practices, whereas intercropping may discourage farmers from adopting SWM practices in Saudi Arabia. A probable explanation for this result might be that farmers have insufficient knowledge of the management of limited water resources under intercropping systems.

Moreover, most farmers in the study area specialized in the production and exporting of dates. According to the observations during field data collection, several farmers mentioned that they had encountered some difficulties in implementing integrated pest management programs for red palm weevils within the context of intercropping, programs which are critical for ensuring the livelihoods of palm farmers in the study area. This result is consistent with the results of Zhang, Fu, Wang, and Zhang [69], who found that the diversity of agricultural activities had a negative effect on the adoption of water-saving irrigation technologies by farmers in China. On the contrary, another study, conducted by He et al. [80] in China, reported that the diversity of crops grown resulted in an increase in the probability of rainwater harvesting and supplementary irrigation technology adoption.

Surprisingly, among the explanatory variables, extension contact did not have a significant effect on the adoption of SWM practices. One explanation could be that Saudi agricultural extension services are inactive in providing effective services, particularly in the field of soil and water conservation, or they use inactive extension methods. This conclusion is supported by the findings of several studies conducted in Saudi Arabia [66,81–84] that confirm the weak role of extension services in changing the knowledge, attitudes, and behaviors of farmers regarding the adoption of agricultural innovations. This result is in line with the findings of Gebru et al. [85], who argue that access to extension services was not statistically significant in explaining the adoption of water harvesting practices by farmers in a semi-arid region of Ethiopia. In contrast, some studies [86,87] have shown that access to extension services has a negative significant association with the adoption of SWM practices, while a large number of previous studies [29,64,71,88–92] have found that extension access significantly influences the adoption of SWM practices.

### 5. Conclusions

This paper attempted to develop an understanding of the adoption of SWM practices by Saudi farmers. As this topic is rarely covered in the literature within the context of Saudi Arabia, this study contributes to the existing body of knowledge by highlighting the relationship between the awareness of farmers concerning the causes of agricultural water pollution and the adoption of SWM practices, as well as the factors influencing adoption. The results conclude that farmers need support to enhance their knowledge regarding the causes of agricultural water pollution. It was also found that the levels of adoption by farmers of SWM categories (i.e., soil and water conservation, water quality, water audit, and water conservation) ranged between medium and high rates for all practices. Furthermore, our results confirm an interesting interplay between the adoption and knowledge levels of farmers regarding agricultural water pollution, indicating that farmers with more knowledge about the causes of agricultural water adoption were more likely to adopt SWM.

The results also show that the variable of cultivated crops is significantly influenced by the adoption of SWM practices. The SWM practices developed in this study have implications in both theory and practice. This study offers a relatively simple view of the adoption patterns of SWM practices at the farm level. This scale of practices offers a practical guide, with a tested and reliable rating scale, to assist future researchers who want to research the adoption of SWM practices. Practically, this scale provides insights into the adoption gaps that need to be filled by farmers, particularly water audit practices. The results also provide useful implications for policymakers for developing extension programs and providing incentives to stimulate adoption at the farm level. Due to the scarcity of research on the adoption of SWM practices in Saudi Arabia, more comprehensive empirical research on the impact of SWM practices may be influenced by the attitudes of farmers toward environmental sustainability and governmental incentives would be beneficial to investigate.

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