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ORIGINAL RESEARCH

Parasitic contamination of soil and vegetable crops irrigated with raw wastewater: A case study from Al-Far'a, Palestine

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Abstract

Purpose Because of the steep shortage in freshwater supply in the Israeli-occupied West Bank, raw wastewater (RWW) has been widely used to irrigate vegetable crops. This study aims to detect the effects of irrigation with raw wastewater on crops cultivated in Wadi Al-Far'a, Palestine.

Method A total of 300 soil, crop, and RWW samples were randomly collected from Wadi al-Far'a, an area with a long history of irrigating crops with raw wastewater. A survey questionnaire was also used to collect data on the parasites-infected farmer.

Results Results showed that percentages of contaminated vegetables, soil, and RWW samples were 10.2%, 27.0%, and 47.5%, respectively. Crops leave indicate contamination with parasite eggs depending on their contact with surface soil, e.g., contamination of zucchini (leaves rest on surface soil) and mallow (upright plant stand) was 19.0% and 2.0%, respectively. The highest and lowest soil contamination with parasites eggs pertained to *A. lumbricoides* (30.0%) and *T. trichiurid* (19.2%).

Conclusion Certain mitigation measures should be used to limit the danger of farmers becoming infected with common parasites, particularly *Ascaris lumbricoides.* Farmers' awareness of the manner of parasite transmission and adherence to safety regulations should be among them.

Keywords Irrigation, Palestine, Parasite contamination, Raw wastewater, Vegetables, Water quality

Introduction

The West Bank is an Israeli-occupied territory. The western slopes of that hilly area represent the natural recharge basin of the coastal groundwater to the west. West Bank has been a relatively water-sufficient area until its occupation in the aftermath of the 1967 Arab-Israeli War. Since then, the Israeli occupation forces have imposed restrictions on Palestinian activities to improve water supply from their resources to meet the ever-increasing demand for freshwater. Such restrictions include the prohibition of digging wells below a given depth and preventing any surface water retention structures (Weinreb 2020). According to the Palestine

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Central Bureau of Statistics (PCBS 2019), available water resources in the 1967 War were 63.3×10^6 m^3. This Fig dropped to $47.2x10^6$ m^3 in 1978 (Weinreb 2020; PCBS 2019). Furthermore, it remained almost constant at $48.0x10^6$ m^3 in 2016 (World Bank 2016). However, the West Bank population from 1967-2020 grew from 6.47×10^5 to more than 3.05×10^6, i.e., the population growth had increased by 4.7 times (Weinreb 2020).

In the meantime, due to the theft of Palestinian water in favor of Jewish colonies, the equivalent per capita allocations of accessible water resources fell even lower, from 98 to 82 m^3 (World Bank 2016; PWA 2013). As a result, the actual per capita drinking water supply remained almost the same during the same period from 1996-2012, i.e., 82 and 80 Li/person/day (PCBS 2019). Shortage in the domestic water supply is usually purchased from Israel. One further detrimental impact of the Israeli policy on the Palestinian population and environment has been the release of wastewater from the isolated settlements to the neighboring Palestinian agricultural lands (PWA 2013). In addition, the significantly underdeveloped infrastructure in the West Bank has reduced management alternatives of the locally produced RWW to direct use in irrigation.

Underdeveloped infrastructure is due to infrastructural challenges, such as the limited sewer network. It resulted from Israeli dissections of Palestinian territory by roads allocated solely to settlers' use and separation walls to keep Palestinian civilians away from the settlements. (Human Right Watch 2010).

All these measures have left the Palestinian communities with no options but to direct the continuous flow of the Jewish settlements-produced RWW away from their homes (Human Right Watch 2010).Apart from the occupied West Bank, the use of RWW in irrigation can also be observed in several developing countries (Gupta et al. 2009) including Mexico (Caucci and Hettiarachchi 2017), Morocco (Amahmid and Bouhoum 2000), and Pakistan (Anwar and McKendry 2012). In these countries, producing low-cost crops is usually a significant factor of such a practice, irrespective of any potential health hazard (Caucci and Hettiarachchi 2017).

RWW in irrigation has been diagnosed as the primary source of infectious diseases (Sharma et al. 2017). These include viruses, enteric bacteria , and parasitic pathogens (Gerba and Choi 2006), Intestinal parasitic diseases remain the most significant public health problem in developing countries. The most common are *Ascaris lumbricoides*, *Trichuris trichiura*, *Hookworms*, *Giardia lamblia*, *Entamoeba histolytica*, and *Enterobius vermicularis* (Al-Hindi et al. 2013). Vegetables may be contaminated during parasite development, such as eggs and larva. Animal manure, sewage sludge, and RWW are favorable media for flourishing parasites (Pires et al. 2012). Many parasites spend part of their life's cycles in the soil; thus, unwashed and fresh-consumed vegetables can lead to infection and spread of these parasites (Adamu et al. 2012). The spread of intestinal parasites through soil is highly affected by environmental factors such as temperature (optimum 20–30°C), humidity, pH, and soil physicochemical characteristics. Moreover, favorable soil conditions can hasten embryonation, viability, infectivity, and ultimately disease extent (Etewa et al. 2016).

Although not wholly successful, restrictive measures aiming at the safe use of RWW in irrigation were adopted by countries like South Africa and Mexico (Caucci and Hettiarachchi 2017). The purpose of this study was to offer benchmark data on some of the most significant problems to using RWW in irrigation in the occupied West Bank, such as parasite contamination of soil and crops and the most relevant factors that contribute to farmers becoming infected with such parasites.

Materials and methods

Study area

Wadi al-Far'a (~ 340 km^2) is part of the Nablus Governorate in the occupied West Bank. The Wadi descends eastward to The Jordan Valley. The agricultural area of the Wadi approaches 33.9 km^2, of which about 26.0 km^2 are irrigated. The crop structure is olive, almonds, grapes, and vegetables. Because of the shortage in freshwater supply, many fields are irrigated with RWW running in the significant stream bed of the Wadi itself. The RWW originates from a large urban community in the eastern slopes of Nablus city and a nearby refugee camp (Shadeed 2008). Along the descending way to the Jordan Valley, four locations were sampled with the respective coordinates of these sites (Izmut 32°13N,35°18 E, Badhan 32°15N,35°19E, Nassaria 32°09N,35°25E, and Jeftlik 32°14N,35°23E.) as depicted in Fig. 1. The first three sites have respective altitudes of 460, 170, and 24 m ASL, but the last site of Jeftlik has an altitude of 189 m BSL, which makes the weather there very hot in summer but warm and relatively dry in winter.

Samples collection

Thirty composite surface soil samples (0-25 cm) were collected from each study site (a total of 120 samples), 20 RWW samples from each study site (a total of 80 samples, 1 Litre each), and 20 samples from each of the five vegetable crops (5 from each site making a total of 100) were collected randomly at the same time from each site. Selected chemical composition of the saturated paste extracts and soil organic matter were determined following standard methods of soil analysis.

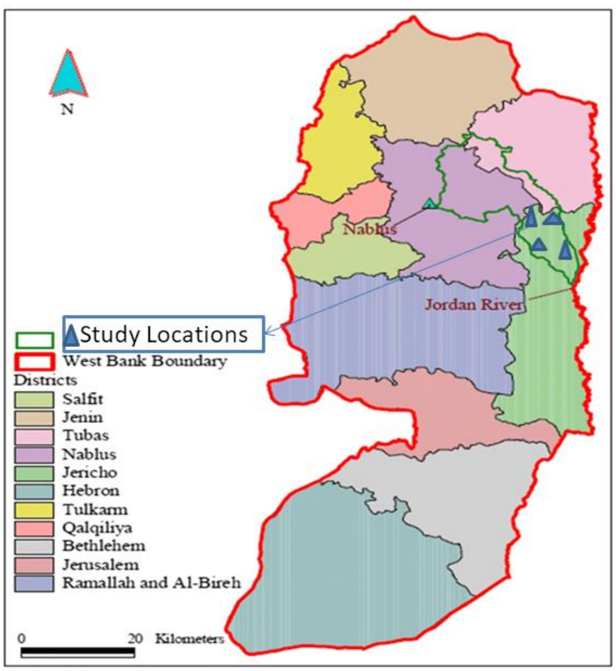

Fig. 1 Locations of the study sites in Wadi Al-Far'a in the Israeli-occupied West Bank
(Source: Google 2021)

Parasites diagnosis

Plant samples were kept in sterile nylon bags and transported to the Palestine National Center for Agricultural

Research in Jenin, Palestine. The samples were vigorously shaken with 1 L of saline NaCl solution (0.95% NaCl) then the washing water was left standing still for 12 hours to allow sedimentation of the suspended solids. Afterward, the upper portion of the supernatant solution was discarded before centrifugation at 1800 rpm for 15 min. The supernatant solution was discarded, and sediments were carefully obtained for examination by the direct smear method, i.e., a drop of the sediment was applied to a clean slide, and a coverslip was gently placed on the sample, which was examined under a light microscope at 100X and 400X magnifications. Alternatively, iodine smear analysis was performed, where a drop of the sediment was mixed with a drop of Lugol's iodine solution and examined as an indirect smear. In both analyses, the smears were examined for parasites eggs, cysts, and larvae of *A. lumbricoides, Hookworms, E. vermicularis, T. trichiurid, and Giardia spp.* (Dada 1979). During the parasite detection, soil samples were processed through a modified flotation technique (Horiuchi and Uga 2016). The samples were air-dried for 48 hours, then sifting using a 150 µm sieve. Five grams of the sieved samples were placed in a 10-ml test tube and washed with 10 ml of distilled water using a vortex mixer. The suspension was then centrifuged for 15 min at 1800 RPM. The supernatants were decanted since parasites' eggs have specific gravity exceeding 1g/ml. Eight ml of sucrose solution (1.2 g/ml) were then added, and the mixture was thoroughly mixed using a vortex mixer. The resultant suspension was centrifuged for 15 min at 1800 rpm, and the supernatant solution was discarded. Sucrose solution (1.3 g/ml) was slowly added to the brim of the left sediment using a 10 ml syringe until an upper meniscus layer was formed. A coverslip slide was carefully placed on the meniscus to collect the topmost portion of the suspension. The slides were examined for soil parasite eggs using a compound light microscope at 100X and 400X magnifications (Hatam-Nahavandi et al. 2015). For RWW, the water samples were left standing for 24 hours to allow precipitation of the suspended material. The supernatant solutions were discarded, and the left sediments were recovered (~200 ml) and centrifuged for 15 min at 1200 pm. The obtained sediments were examined under microscopy as described in the case of soil samples. Evaluation of the farmers' infection by parasites was carried out using a two parts questionnaire. The questionnaire was handed to a random sample of 100 farmers from the four study areas. The first part of the questionnaire counted cases of farmers' infection with intestinal parasites (*Giardia spp., A. lumbricoides,* Hookworms, *E. vermicularis, and T. trichiurid*). Infection recognition was identified by referring to the health centers in each site and the associated medical records. The second section of the questionnaire was designed to capture technical and socioeconomic information, such as farmers' age, gender, educational background, and sanitary practices such as wearing boots and gloves while farming and length of farming experience. These data were analyzed using the chi-square method.

Statistical analysis

The mean density of parasite eggs in the studied samples was calculated as the total number of parasite eggs divided by the number of contaminated samples. A t-test was used to compare the contamination level of a given parasite for two crops or soil samples in two sites. Similarly, Chi-square tests were carried out using the SPSS Software, version 20.

Results and discussion

Wastewater production as influenced by the Jewish settlements

Table 1, provides selected statistics on RWW production from the Jewish settlements in the occupied West Bank. The Table shows that a current number of Jewish settlers in the West Bank which approaches 700,000 settler producing wastewater of about 86.6x10^6 m^3 in a year. This volume is extremely high, especially when compared to total wastewater production (75.7x10^6 m^3) by the 3.053x10^6 native Palestinians living in the West bank (PCBS 2019).

Table 1 Selected statistics of the Jewish settlements in the occupied West Bank

West Bank District	Settlers Population (10^3)	Wastewater Production (MCM/year	Number of Industrial Installations [1]	Number of Settlements and RWW Production [2]	
				Untreated [3]	Treated [4]
Hebron	21.2	3.0	3.0	18.0	2.0
Ramallah	137.0	16.4	5.0	25.0	1.0
Bethlehem	89.2	10.4	-	13.0	-
Nablus	20.1	2.2	2.0	13.0	
Jericho	7.4	1.1	3.0	16.0	1.0
Jeneen	3.4	0.3	2.0	5.0	-
Tubas	2.5	0.3	-	7.0	-
Jerusalem	316.2	41.6	-	26.0	-
Toolkarm	4.1	0.4	7.0	3.0	-
Sulfate	47.2	5.2	80.0	12.0	1.0
Qulqeelia	40.0	5.6	-	8.0	-
Total	688.3	86.6	102.0	146.0	5.0

Source: Palestinian Central Bureau of Statistics (PCBS) 2020, Israeli settlements in the West Bank, Annual Statistical Report 2019, Ramallah –Palestine.

[1]Approximate estimates of industrial installations in the Jewish settlements.

[2]Number of Jewish settlements with no linkage to Palestinian municipal sewage system.

[3]Number of settlements that release RWW to neighboring Palestinian fields.

[4]Number of settlements having their WW treatment plants before being released to neighboring Palestinian fields.

Raw wastewater characteristics in the study area

The semi-arid Mediterranean climate predominates Wadi al-Far'a, where winter is a mild, rainy season and lasts for about six months. Summer, on the other hand, is moderately dry and hot. July and August are the hottest months. During that period, the maximum temperature usually reaches up to 35 °C (Table 2). Based on altitude, annual average precipitation ranges between 150 and 660 mm.

Table 2 Monthly maximum and minimum relative humidity and air temperature values during January-September, 2020

Month	Relative Humidity (%)		Air Temperature (°C)	
	Maximum	**Minimum**	**Maximum**	**Minimum**
January	90±5.4	80±5.4	14.2±3.2	7.4±2.3
February	74±3.2	66±4.6	18.9±1.7	9.7±2.1
March	68±4.1	64±6.7	23.5±2.5	12.2±3.1
April	69±4.3	60±3.5	25.4±3.2	13.5±1.7
May	62±4.5	55±8.6	29.5±2.4	18.7±4.2
June	74±7.5	54±7.7	30.9±2.3	19.3±5.3
July	74±8.6	60±6.5	35.0±2.8	20.8±2.3
August	83±6.9	76±3.4	31.7±3.3	21.0±3.6
September	81±6.7	74±3.3	30.7±3.2	20.0±3.2

Source: Reports of Weather Station, Nablus-occupied West Bank.

Data on the monthly discharge of RWW and volumes of RWW and freshwater employed in irrigation in Wadi Al Far'a are given in Table 3.

Table 3 The monthly RWW (m^3) discharge to Wadi al-Far'a and the corresponding estimates of RWW and freshwater applied to agricultural fields

Month	RWW Discharge (m^3)	RWW (m^3/ha)	Freshwater (m^3/ha)
January	138000±400	-	-
February	141000±320	-	-
March	159000±270	2244±681	1696±385
April	160000±150	2500±420	1896±185
May	177000±280	2700±380	1900±210
June	182000±170	3000±250	2100±130
July	178000±120	3400±120	2230±50
August	167000±320	3600±400	2300±210
September	165000±320	3600±400	2300±210

Source: Data were obtained from the Palestine Statistics Center (PCBS 2019).

which shows an increase in these volumes with the advancement of the hot and dry months. Table 4 shows that salinity and organic matter content in the surface soil samples increases and ran almost parallel to the decrease in soil pH. In this regard, the increase in soil organic matter could be used as an indicator of the application of RWW. It is expected to be enriched with soluble salts due to the salt-rich diets of the Palestinians and their limited use of domestic freshwater. On the other hand, aerobic decomposition of the RWW-applied organic matter in the surface soil would enrich this layer with carbonic acid, which could be held responsible for the observed decreases in pH with the increase in soil organic matter content. Izmut soil samples had the lowest pH but the highest EC_e and organic matter (Table 4).

Table 4 The collected soil samples' salinity, pH, and organic matter content

Parameters	Site			
	Izmut	**Badhan**	**Nassaria**	**Jeftlik**
pH	5.60±0.70	6.30±0.43	7.10±0.10	7.20±0.11
EC_e (dS/m)	4.20±0.40	2.40±0.47	3.70±0.30	1.96±0.15
Organic matter (%)	7.70±0.65	6.60±1.20	5.80±0.55	4.73±0.65

Jeftlik soil samples had the lowest organic matter content. The site is close to the Jordan Valley floor of weather conditions favoring organic matter decomposition, as in Fig. 2.

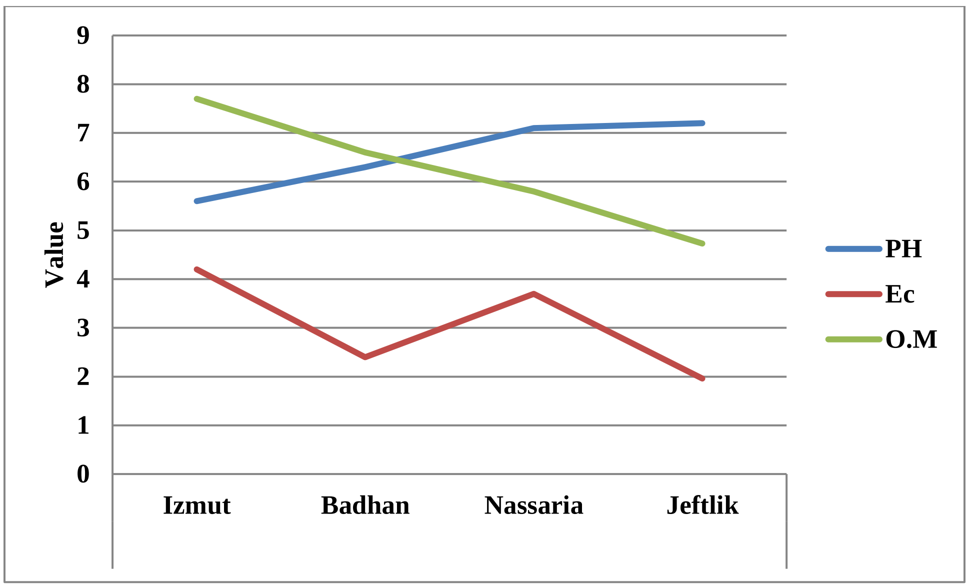

Fig. 2 Content and concentration of soil samples collected

Raw wastewater contaminated parasites

Table 5 shows that *A. lumbricoides* was the most common parasite in the RWW samples (66.3%) to be followed by *E. vermicularis* (47.5%). Maximum contamination with the studied parasites belonged to the Izmut RWW samples, especially for the *Ascaris lumbricoides eggs*, which amounted to 90.0%. This parasite was also predominant in the RWW of Alexandria, Egypt (El-Said 2012).

Table 5 Numbers of parasites-contaminated RWW samples from the four study sites (20 samples each)

Parasite	Izmut	Badhan	Nassaria	Jeftlik	Total
Ascaris lumbricoides	18.0 (90.0%)	16.0 (80.0%)	12.0 (60.0%)	7.0 (35.0%)	53.0 (66.3%)
Hookworms	13.0 (65.0%)	12.0 (60.0%)	5.0 (25.0%)	4.0 (20.0%)	34.0 (42.5%)
Enterobius vermicularis	15.0 (75.0%)	14.0 (70.0%)	6.0 (30.0%)	3.0 (15.0%)	38.0 (47.5%)
Trichuris trichiurid	11.0 (55.0%)	10.0 (50.0%)	6.0 (30.0%)	5.0 (25.0%)	32.0 (40.0%)
Giardia lamblia	12.0 (60.0%)	11.0 (55.0%)	6.0 (30.0%)	4.0 (20.0%)	33.0 (41.3%)

Detection of parasites in the soil samples

The highest parasite density in the soil samples from each site is reported in Table (6). The Table shows that the overall soil contamination by *A. lumbricoides* was 41.7%, with Izmut samples having the highest level and Jeftlik samples being the lowest. The latter observation could be due to the harsh summer condition in that site which is the closest to the Jordan Valley with an altitude of 189 m BSL. Furthermore, Jeftlik is the farthest side away from the point source of RWW generation. Running the longest distance in an open and steep canal can help aerate RWW and decompose its organic load causing a reduction in parasites' survival. On the contrary, Izmut is the closest site to the RWW outlet and, thus, soil organic matter and contamination by all parasites should have been the maximum (Table 4). Notably was the contamination with *T. trichiura*, which showed the lowest among the studied parasites (19.2% for the whole soil samples). The highest level of farmers infection (22%) was reported in July. This month is characterized by high temperature and humidity levels, which foster an ideal breeding ground, rapid growth, and spread of parasites. Pozio (2020) demonstrated that the climate directly impacts parasite distribution and life cycle as increased humidity aids the survival of parasite eggs, larvae, and cysts/ova.

Table 6 Number and percentage of parasite-contaminated soil samples from the four study sites

Parasite	Izmut	Badhan	Nassaria	Jeftlik	Total
Ascaris lumbricoides	22.0 (73.0%)	14.0 (46.0%)	10.0 (33.0%)	4.0 (13.0%)	50.0 (41.7%)
Hookworms	18.0 (60.0%)	10.0 (33.0%)	6.0 (20.0%)	3.0 (10.0%)	37.0 (30.8%)
Enterobius vermicularis	15.0 (50.0%)	6.0 (30.0%)	5.0 (16.0%)	3.0 (10.0%)	29.0 (24.2%)
Trichuris trichiurid	11.0 (36.0%)	6.0 (20.0%)	4.0 (13.0%)	2.0 (6.0%)	23.0 (19.2%)
Giardia lamblia	12.0 (40.0%)	8.0 (26.0%)	5.0 (16.0%)	2.0 (6.0%)	27.0 (22.5%)

Parasites contaminated crops

Intestinal parasites were detected in 10.2% of the examined crops samples. This Fig increased to 27% of the collected soil samples and 47.5% of the RWW samples, as shown in Fig. 3. The highest and lowest cases of the contaminated samples were reported as in Table 7, the zucchini (19.0%), and the mallow crops (2.0%). All differences were significant ($P < 0.05$). The *Ascaris and hookworms* were the most prevalent parasites (19% each), but *T. trichiuri* was the least (2%). The edible leaves of the mallow crop are located slightly above the soil surface and, thus, these were the least contaminated.

Moreover, the mallow plant's smooth leaves and upright growth patterns could have caused the parasite's eggs to be least likely attached. On the contrary, zucchini fruits were the most contaminated by all parasites (19 cases), particularly with *Ascaris eggs* (7 cases), as shown in Table 7. A similar infection order was reported by (Adanir and Tasci 2013). The high percentage of zucchini contamination could be attributed to their coarse leaves, which are usually in direct contact with the soil surface (Javanmard et al. 2018). Ascaris eggs are thought to be firmly adhered to eggplant leaves after irrigation with RWW (Hassan et al. 2012). As for *hookworms*, a widespread crops contamination was 19%. Eggplants showed the highest contamination of 30%. Possibly is due to the strong adhesive properties of that crop leaves (Bethony et al. 2006). On the other hand, hookworm spores can survive wastewater treatment and present in sewage sludge or runoff wastewater (Kumar et al. 2014). Unspecified spore hookworm species were detected in Zucchini, Eggplant, and Parsley crops (Al-Nahhas and Aboualchamat 2020). In our study, the overall crop contamination with *Giardia spp*. was 15%

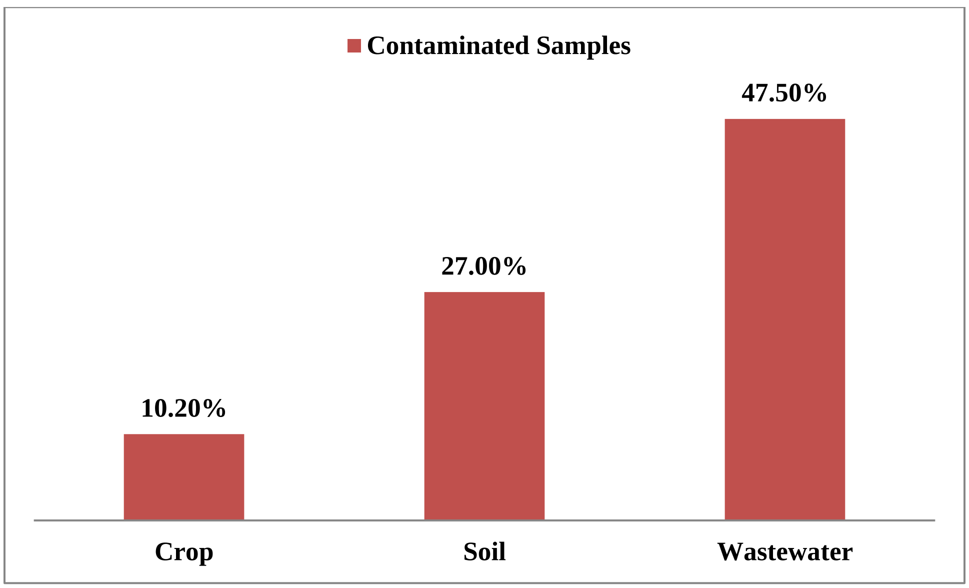

Fig. 3 Percentage of selected parasites-contaminated soil, crop, and Wastewater samples were collected from four different areas within Wadi Al Far'a With onion came first

Such findings conform to data from Iran (Shahnazi and Jafari-Sabet 2010).

Parasites-infected farmers

Table 8 presents a summary of infection sources and symptoms. Moreover, the Table shows that 22.0% of the farmers in the study area had symptoms associated with at least one of the surveyed parasites. These symptoms included anemia, diarrhea, abdominal pain, weight loss, and vomiting. According to Dhanabal et al. (2014), the worldwide highest and lowest infection rates belonged to *Ascaris lumbricoides* infects a billion person while *T. trichiura* infects 795 million people. Hookworms infect a comparable around of 740 million, but *Giardia lamblia* infects only 2.8 million. Infection rates usually spike during the hot months, optimal for parasites' growth and development. It is also noted that most sources of infection occur through uncooked food and that most rates of disease transmission occur through parasites' eggs.

Table 7 Numbers of the parasites-contaminated crop samples collected from the four study sites

Parasite	Eggplant	Mallow	Corn	Zucchini	Onion	Total
Ascaris lumbri-coides	3.0 (15.0%)	2.0 (10.0%)	2.0 (10.0%)	7.0 (35.0%)	5.0 (25.0%)	19.0 (19.0%)
Hookworms	6.0 (30.0%)	0.0 (0.0%)	4.0 (20.0%)	4.0 (20.0%)	5.0 (25.0%)	19.0 (19.0%)
Enterobius vermicu-laris	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	3.0 (15.0%)	2.0 (10.0%)	5.0 (5.0%)
Trichuris trichiurid	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	2.0 (10.0%)	0.0 (0.0%)	2.0 (2.0%)
Giardia lamblia	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	3.0 (15.0%)	3.0 (15.0%)	6.0 (6.0%)
Total Cases	9.0	2.0	6.0	19.0	15.0	51.0

Table 8 Summary of parasites infection rates as documented by the Health Centers in the study sites and their potential sources, transmission method, and infection symptoms*

Parasites	Infection	Source	Transmis-sion	Recorded symptoms
Giardia spp.	4.0 (4.0%)	Uncooked foods	Cysts ingestion	Anemia, diarrhea, abdominal pain, nausea, weight loss, vomiting.
E. vermicularis	4.0 (4.0%)	Uncooked foods	Eggs ingestion	Loss of appetite, weight loss, bed-wet-ting, irritability, itching in the anal area, emotional instability.
A. lumbricoides	6.0 (6.0%)	Contaminated food and soil	Eggs ingestion	Reduction of food intake capacity.
T. trichiura	3.0 (3.0%)	Contaminated food and soil	Eggs ingestion	Dysentery and rectal prolapse.
Hookworms	5.0 (5.0%)	Contaminated soil	Skin penetration	Iron deficiency and anemia.

*Source: Braz et al. (2015) and Thome and Wen (2012).

Relation between infection and socioeconomic conditions of the farmers is presented in Table 9. The Table shows that 82% of the farmers were under 40 years old and had less than five years of work experience.

Of these farmers, 13% worked bare feet, only 22% wore gloves, but 73% used hygiene regularly. Of the bare feet-farmers, 61.5% suffered from recurrent contractions due to intestinal parasite infection. This Fig was sharply reduced (16%) among those wearing boots. Only 18.1% of those who wore gloves experienced parasites infection compared to 23.0% of those who did not. The farmers who had contact with soil during farming had a more significant infection rate (23.3%) than those who had no contact (10%). Unawareness of the risk of intestinal parasites transmission through soil could significantly caused higher rate of infection. Al-Hindi et al. (2013) reported that most males work bare feet, but females use boots. Although not significant, the rate of intestinal parasites infections among females was 27.7%, but males had a 20.7%. In addition, there was a similarity in the intestinal parasite's infection among family members, which could have been explained that those individuals were exposed to the same sources of infection such as water, food, and soil but not to the same working conditions.

Table 9 Numbers of parasites-infected farmers as influenced by selected socioeconomic factors

Parameter		**Infection (%)**	**No infection**	***P-value***
Age	≥40 (n=26)	2.0 (7.6%)	24.0 (92.4%)	0.040
	<40 (n=74)	20.0 (27.0%)	54.0 (73.0%)	
Gender	Male (n=82)	17.0 (20.7%)	65.0 (79.3%)	0.510
	Female (n=18)	5.0 (27.7%)	13.0 (72.3%)	
Experience	≤5 year (n=19)	9.9 (47.3%)	10.0 (52.7%)	0.003
	>5 year (n=81)	13.0 (16.0%)	68.0 (84%)	
Work bare feet	Yes (n=13)	8.0 (61.5%)	5.0 (38.5%)	0.001
	No (n=87)	14.0 (16.0%)	73.0 (84.0%)	
Wear gloves	Yes (n=22)	4.0 (18.1%)	18.0 (82.0%)	0.620
	No (n=78)	18.0 (23.0%)	60.0 (77.0%)	
Sanitation type	Hygienic (n=73)	6.0 (8.2%)	67.0 (91.8%)	0.001
	Non-hygienic (n=27)	16.0 (59.2%)	11.0 (39.8%)	
Direct contact with soil	Yes (n=90)	21.0 (23.3%)	69.0 (76.6%)	0.310
	No (n=10)	1.0 (10.0%)	9.0 (90.0%)	
Education	> secondary (n= 72)	13.0 (18.0%)	59.0 (82.0%)	0.127
	< secondary (n= 28)	9.0 (32.0%)	19.0 (81.0%)	

Work experience had a significant effect on farmers' infection rates. Table 9 shows a more significant intestinal infection among those who had less than five years of work experience (47.3%) as compared to those who had more than that period (16.0%). In this regard, Al-zain and AL-Hindi (2005) reported a decreasing infection rate with increasing educational levels. For example, Al-Jawabreh et al. (2019) reported a 36.0% infection rate by *A. lumbricoides* in marginal rural areas of Palestine compared to 6.0% in our study cites. Table 9 also shows that the most vulnerable age group was the less than 40 years old farmers (27.0%) who supposedly were less aware of the parasite's health risk. Krstin et al. (2018) argued that the frequent use of onion and garlic in the daily diets of farmers using RWW in irrigation might reduce infection risk by providing an anti-helminthic property. This may explain why the prevalence of parasitic infection was low among older farmers. According to official records of the health centers in the four study sites, the number of intestinal-infected patients was 210, of a total of 1095 patients (19.1%) who visited these centers at the same period of May- September 2020 (Table 10). Unwashed vegetables intake and improper cooking were associated with high infection rates (Damen et al. 2007). Poor health services and underdeveloped infrastructures also contribute to parasite infection in rural communities. For example, during the past decades, about 55 million Nigerians were infected with *Ascariasis*, 38 million with Hookworms, and 34 million with *Trichuriasis* (Hotez and Kamath 2009).

Table 10 Numbers of parasite-infected farmers documented by Health Centers in the study sites during May-September 2020

	Number of Patient Farmers					Number of Parasite-Infected Farmers					
Month	**Izmut**	**Badhan**	**Nassaria**	**Jeftlik**	**Total**	**Izmut**	**Badhan**	**Nassaria**	**Jeftlik**	**Total**	**Infction %**
May	55.0	32.0	35.0	34.0	156.0	7.0	5.0	6.0	5.0	23.0	14.7
Jun	82.0	57.0	45.0	40.0	224.0	14.0	7.0	11.0	9.0	41.0	18.3
Jul	107.0	82.0	78.0	58.0	325.0	24.0	16.0	14. o	18.0	72.0	22.1
Aug	91.0	21.0	33.0	35.0	180.0	8.0	7.0	10.0	7.0	32.0	17.7
Sept	73.0	65.0	50.0	22.0	210.0	13.0	9.0	9.0	11.0	42.0	20.0
Total	408.0	257.0	241.0	189.0	1095	66.0	44.0	50.0	50.0	210.0	19.1

Conclusion

The results of this study clearly illustrate the need for sanitary and reduced environmental risk associated with parasitic contamination from the reuse of RWW for irrigating vegetable crops such as (eggplant, zucchini, onion, mallow, corn) in Wadi Al Far'a, Palestine. The health concerns are even more profound, knowing that some crops are consumed directly. Prevention measures to control parasitic contamination associated with RWW should be considered, including prohibiting their reuse in the raw state or installing RWW treatment plants and restrictions to use RWW for irrigating crops. The findings of this study are an indicator for the spread of contamination with intestinal parasites (Ascaris spp., Trichiuri spp., Enterobius vermicularis, Hookworm, and Giardia spp), on vegetables which is a significant threat to the general public health and food safety among growing populations. Contamination of vegetables in the Wadi AlFar'a with intestinal parasites increases disease risk in local communities, mainly depending on the infectious doses of contaminant. Percentages of the observed intestinal parasites in the examined vegetable, soil, and RWW samples increased in the same sequence, i.e., 10.2%, 27.0%, and 47.5%, respectively. Total 19.2% farmers were aware of intestinal parasites and their transmission mode to avoid infection. Further measurements are needed to regularly evaluate farmers' compliance with safety standards and implement a comprehensive farmer awareness program to educate farmers and their families about the hazards of parasite infection. The Ministry of Health and environmental protection institutions should also educate citizens and the authorities to establish treatment plants for RWW and their disposal of biological pollutants. Our findings suggest the need for legally enforced precautions to ensure the purity of both natural water sources and food products.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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