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Evaluation of Sparta's municipal wastewater treatment plant's effluent as an irrigation water source according to Greek Legislation

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ABSTRACT

A project co-funded by the Greek Ministry of Rural Development and Food and by the Prefecture of Laconia has been undertaken aiming at the investigation of the influence of irrigating olive orchards with treated municipal wastewater (TMWW) on crop productivity and the quality of olive oil produced as well as on the soil chemical and physical characteristics, bearing its influence on the environment in general. According to this project, a two-year experiment was conducted in a 0.5 ha olive orchard with two different irrigation water sources. The first source was a water borehole and the second source was the Sparta's municipal wastewater treatment plant. As regards the aim of the project, comparisons between the effects of these two sources had to be made concerning olive trees productivity and nutritional status, olive oil quantity and quality, soil chemical and physical properties, etc. In the summers of 2011 and 2012, we irrigated the olive trees 7 and 12 times, respectively. At the same time we conducted all the statutory chemical analysis of both fresh water and TMWW at every irrigation event, excluding the microbial analysis for technical reasons. In this paper, we present the chemical analysis results concerning both irrigation water sources and their characterization according to the Greek legislation. Furthermore, we discuss issues concerning the possibility of reusing the Sparta's TMWW plant effluent for irrigation based on the analysis of the data and the Greek legislation.

Keywords: Sparta's treated municipal wastewater quality; Wastewater irrigation; Greek legislation for treated municipal wastewater reuse

1. Introduction

The rapid increase of population all over the globe, elevated living standards, overexploitation of ground water in arid and semi-arid regions, and socioeconomic and environmental issues exert an excessive pressure over natural resources, and water resources in particular, and this makes it absolutely necessary to find alternative water sources.

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With this objective, a lot of effort has been made on establishing regulations and guidelines for reusing treated wastewater in order to eliminate potential hazards concerning farmers, consumers, and environment. The World Health Organization Guidelines [1–4] and the California State Regulations [5] were the models for developing the reuse criteria throughout the world [6]. Furthermore, the United States Environmental Protection Agency (USEPA) in cooperation with the United States Agency of International Development (USAID) in 1992 published regulations for wastewater reuse [7] and revised them in 2004 [8]. Australia was also one of the pioneers who published guidelines in 2000 [9] and revised them in 2004 [10]. Furthermore, in 2006, the Australian Government published a new revision that gave emphasis on environmental impacts that may accrue from chemical and microbial hazards [11]. Guidelines for the impact of the irrigation water salts not only on the soil physical properties, but also on the crops according to the irrigation method were published and revised by Ayers [12], Ayers and Tanji [13], and Ayers and Westcot [14,15].

Europe published the E.E.C./91/71 [16] directive which concerns the urban wastewater treatment by which the EU members have to comply. According to this directive, all EU members have to meet, among other aims, deadlines for establishing wastewater treatment systems depending on town's population. The compliance with the mentioned directive and hence the wastewater treatment plants establishment increase the treated wastewater quantities. In 2011, the Greek Government issued the 145116/11 Joint Ministerial Decision (JMD) [17] by which criteria, rules, measures, and procedures have been legislated for the treated wastewater reuse.

At the same period, the Greek Ministry of Rural Development and Food and the Prefecture of Laconia, taking in to account that in the case of the Laconian region all the mentioned reasons for the necessity of the treated wastewater reuse for irrigation exist [18], funded a project titled "Experimental investigation of the reuse of municipal wastewater treatment plant's effluent for olive trees irrigation in the Prefecture of Laconia." According to the project, a two-year experiment was conducted in a 0.5 ha olive orchard with two experimental applications concerning the irrigation water quality (fresh water [FW] and treated municipal wastewater [TMWW]). The aim was to provide evidence for the suitability of TMWW as an irrigation water source for the olive tree productivity, the oil quality, and the effects that the application of TMWW may have on soil physical, hydraulic, and chemical characteristics. In general, our concern was to check the suitability of the TMWW for indirect[1] and restricted[2] (limited) irrigation according to the Greek legislation [17]. This was decided due to the nature of the olive tree and its product (olive oil) which complies with the restricted irrigation. At this point, it must be mentioned that Kalavrouziotis et al. [19] reported that "treatment and reuse strategies have to be effective and to comply with future needs of high-quality effluent for unrestricted utilization." This does not contradict with our experimentation which took in mind the minimum of the quality requirements (restricted irrigation) for a cultivation which is suitable for indirect irrigation. Olive orchard was selected for experimentation, because it is the prevailing cultivation in semi-arid regions, and also is the cultivation that its irrigation status rapidly changes from rain fed to irrigated. Furthermore, the olive tree cultivation is expanded to marginal lands or even more to deforested lands, which increases the need for irrigation water.

2. Materials and methods

2.1. Experiment Field

The 0.5 ha experimental field is located about 4 km south of Sparta and about 6 km away from Sparta's municipal wastewater treatment plant. Because of the distance between the experimental field and the Sparta's wastewater treatment plant, the quantity of TMWW needed for irrigation was transferred with a 30-ton tank track and stored in open sealed pond at every irrigation event. FW was conveyed through open channels to the head of the field, and also stored to a different nearby open sealed pond. Two different pressurized pipe irrigation systems (one for the FW and one for the TMWW) for the irrigation were installed. For the application of the irrigation water, two sprayers per tree (localized surface irrigation) with 90 l/h flow each were selected. The olive orchard has 140 olive trees. According to the experimental plan (randomized complete block design), 66 of them were irrigated with TMWW and the other 74 were irrigated with FW, but only the 66 of them were taken into account for the experimental results.

[1]Indirect reuse: The storage of treated wastewater (reclaimed water) in surface or underground reservoirs before reuse and mixing with other waters [17].

[2]Irrigation with restrictions (limited) is the irrigation implemented only to crops whose products are consumed after heat treatment or other processing or not intended for human consumption or do not come into direct contact with the ground, such as feed crops, industrial crops, grasslands, trees (not including fruit trees), provided that when collecting the fruits are not to be in contact with the ground, seed crops [17].

Table 1
Information about Sparta's Municipal wastewater treatment plant

Sparta's original treatment plant	
Served district	Sparta (wastewater and septic sewage)
Stage of wastewater treatment	Secondary
Treatment methodology	Activated sludge
Disinfection	Chlorination
Treated wastewater disposal field	Evrotas River
Design-study	1985–1989
First worked	1989
Served people	16,150 residents (anticipation for 2005)
Flow took into account at the designing stage (0.16 m^3/resident-day)	2,630 m^3/d
New treatment plant	
Served District	Sparta (wastewater and septic sewage)
Stage of wastewater treatment	Tertiary
Treatment methodology	Activated sludge and nitrogen and phosphorous removal
Disinfection	Chlorination
Treated wastewater disposal field	Evrotas River
Design-study	1993–1996
First worked	2008
Served people	40,000 residents
Flow took into account at the designing stage (0.2 m^3/resident-day)	8,000 m^3/d
Unit upgrade	
Type of upgrade	Filtration
Design study	2005

Source: Department of Health and Social Welfare of Laconia.

During irrigation water samples were taken both from the TMWW and the FW and the statutory analysis were conducted concerning the irrigation water quality. Furthermore, soil chemical analysis was conducted on soil samples taken from three depths (0–30 cm, 30–60 cm, and 60–90 cm) at each experimental plot at the beginning and at the end of the irrigation period. The aim was to see not only the differential effects of the TMWW and the FW on the soil characteristics, but also the rain water effects on the soil characteristics for these two different applications. Also comparisons were made concerning the quantity of the produced olives and the quality of the produced olive oil between the two applications. As mentioned already, the experiment was carried out between 2011 and 2012, and the irrigation events were 7 and 12 times, respectively, irrigating approximately every 6–8 d depending on the FW availability. Furthermore, it is a local practice to irrigate olive trees every 6–15 d.

2.2. Sparta's municipal wastewater treatment plant

At Table 1, the main information about Sparta's municipal wastewater treatment plant is presented.

Table 2
Maximum permissible values of some characteristics of reclaimed wastewater ([17] Annex I Table 1)

Type of reuse	*Escherichia coli* (EC/100 ml)	BOD_5[a] (mg/l)	SS[b] (mg/l)	Turbidity (NTU)	Minimum treatment
Restricted irrigation	≤200	25	35	–	Secondary biological treatment and disinfection
		According to 5673/400/1997 Ministerial Decision			

[a]Biochemical oxygen demand.
[b]Suspended solids.

2.3. Chemical analysis

According to the 145116/11 JMD, the desirable characteristics of the reclaimed TMWW for irrigation in our case which was an indirect reuse (we store the treated wastewater) and limited irrigation (olive trees) are presented in Tables 2, 3 and 4.

The analyses conducted for checking the quality of the FW and the reclaimed TMWW are presented at Table 5. The bold marked analyses were conducted once per year because these elements were not expected to be found in both water sources in significant amounts.

3. Results and discussion

The analyses results for every irrigation event for the two years of experimentation are presented in Tables 6 and 7.

From Tables 6 and 7, sodium adsorption ratios (SAR) are calculated for each irrigation event and also for both water sources (FW and TMWW) using the following equation:

Table 3
Maximum permissible concentrations of metals and elements ([17] Annex II, Table 4)

Metal	Maximum concentration (mg/l)
Al (aluminum)	5
As (arsenic)	0.1
Be (beryllium)	0.1
Cd (cadmium)	0.01
Co (cobalt)	0.05
Cr (chromium)	0.1
Cu (copper)	0.2
F (fluorine)	1.0
Fe (iron)	3.0
Li (lithium)	2.5
Mn (manganese)	0.2
Mo (molybdenum)	0.01
Ni (nickel)	0.2
Pb (lead)	0.1
Se (selinium)	0.02
V (vanadium)	0.1
Zn (zinc)	2.0
Hg (mercury)	0.002
B (boron)	2

Table 4
Desirable agronomic characteristics of the treated wastewater for using it as an irrigation source ([17] Annex III, Table 5)

Potential problem in the irrigation	Units	Degree of constraints on the implementation		
		Insignificant	Small–medium	High risk
Salinity (Affects the availability of soil water)				
ECw[a]	dS/m	<0.7	0.7−3.0	>3.0
or				
TDS[b]	mg/l	<450	450−2,000	>2,000
Infiltration				
SAR[c] = 0–3 and ECw =		>0.7	0.7−0.2	<0.2
3–6		>1.2	1.2−0.3	<0.3
6−12		>1.9	1.9−0.5	<0.5
12–20		>2.9	2.9−1.3	<1.3
20–40		>5.0	5.0−2.9	<2.9
Specific ion toxicity				
Sodium (Na)				
Surface irrigation (adsorption by the roots)	SAR	<3	3−9	>9
Sprinkle irrigation (adsorption through leaves)	mg/l	≤70	>70	
Chloride ions (Cl)				
Surface irrigation (adsorption by the roots)	mg/l	<140	140−350	>350
Sprinkle irrigation (adsorption through leaves)	mg/l	≤100	>100	
Other implications				
Nitrogen (NO_3-N)[d]	mg/l	<5	5−30	>30
HCO_3 (Only for sprinkle irrigation)	mg/l	<90	90–500	>500
pH	6.5–8.5			

Notes: [a]EC Electrical conductivity decisiemens per meter at 25˚C.
[b]Total dissolved solids.
[c]SAR Sodium adsorption ratio.
[d]NO_3-N Nitrate nitrogen in terms of nitrogen.

Table 5
List of analyses conducted for FW and reclaimed treated wastewater at every irrigation event or once a year (bold marked)

	Fresh water	Reclaimed treated wastewater	Methodology [20,21]
pH (20°C)	✓	✓	APHA[a] 4500-H^+ B
ECw (20°C)	✓	✓	APHA 2510
BOD_5	–	✓	AWWA[b] 5210/B
COD	–	✓	AWWA 5210/C
Total hardness	✓	–	E.P.A. 130.2
Total alkalinity	✓	–	Standard method/0403
TN	–	✓	AWWA 4500-N/C
TP	–	✓	AWWA 4500-N/P
SS	–	✓	–
NH_4^+	✓	✓	Merck analogous to APHA 4500-NH_4 F
NO_2^-	✓	✓	Merck Analogous to APHA 4500 NO_2 B
NO_3^-	✓	–	Apha 4500 NO_3 B
Cl^-	✓	✓	Apha 4500 Cl B
Free Cl_2	–	✓	AWWA 4500-Cl_2/G
K	✓	✓	APHA 3111 B
Na	✓	✓	APHA 3111 B
Ca	✓	✓	APHA 3111 B
Mg	✓	✓	APHA 3111 B
Fe	✓	✓	APHA 3113
Mn	✓	✓	APHA 3113
Cu	✓	✓	APHA 3113
Mo	✓	✓	APHA 3113
As	✓	✓	APHA 3113
Pb	✓	✓	APHA 3113
Cr	✓	✓	APHA 3113
Ni	✓	✓	APHA 3113
B	✓	✓	APHA 3113
Mo	✓	✓	APHA 3113
Co	✓	✓	APHA 3113
Al	✓	✓	APHA 3113
Se	✓	✓	APHA 3113
Zn	✓	✓	APHA 3113
Cd	✓	✓	APHA 3113
SO_4^{-2}	✓	–	Standard methods 4110B

Notes: [a]American Public Health Association (APHA).
[b]American Water Works Association (AWWA).

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (1)$$

where Na^+ = Sodium (meq/l), Ca^{2+} = Calcium (meq/l), Mg^{2+} = Magnesium (meq/l)

By combining Table 4 for surface irrigation (sprayers) and Tables 6 and 7, conclusions are made about the effects of every irrigation event presented at Tables 8 and 9.

For 2011, we can see that for the infiltration and the Cl^- toxicity there are small to medium and insignificant constraints, respectively, both for FW and waste water implementation with the exception of one case of infiltration (10/8) and one case of Cl^- toxicity (20/7). For salinity, there are insignificant constraints for the water application in all the irrigation events, but there are small to medium constraints for all wastewater irrigation applications.

For 2012, we can see that constraints for infiltration and Cl^- toxicity are small to medium and insignificant, respectively, for all irrigation events and both for FW and TMWW applications with the exception of one case of TMWW irrigation (24/8) where the constraint is insignificant. As for the salinity in all cases, both FW and TMWW applications have insignificant

Table 6
Analyses result for the fresh water (W) and the wastewater (Ww) for the year 2011

Irrigation dates	Units	20/7		27/7		03/8		10/8		26/8		02/9		16/9	
Elements		W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww
pH (20℃)	–	8.1	7.8	8	7.95	7.9	8.09	7.98	7.48	8	8.01	7.9	7.96	7.8	7.56
ECw (20℃)	μS/cm	535	731	543	722	578	784	583	694	571	706	539	715	568	755
BOD_5	mg/l	0	12	0	14	0	20	0	10	0	19	0	16	0	22
COD	mg/l		79		85		120		60		115		90		105
Total hardness	mg/l	247	–	250	–	247	–	325	–	310	–	325	–	331	–
Total alkalinity	mg/l	240	–	256	–	268	–	273	–	263	–	245	–	250	–
TN	mg/l	–	22	–	25	–	32	–	19	–	30	–	26	–	33
TP	mg/l	–	7.6	–	9	–	15	–	5	–	8	–	9	–	11
SS	mg/l	–	19	–	28	–	39	–	32	–	45	–	19	–	28
NH_4^+	mg/l	<0.01	4.6	<0.01	20	<0.01	35	<0.01	14	<0.01	33	<0.01	25	0.02	30
NO_2^-	mg/l	0.12	–	0.19	–	0.17	–	0.08	–	0.12	–	0.02	–	<0.01	–
NO_3^-	mg/l	41	–	42	–	44	–	44	–	40	–	41	–	46	–
Cl	mg/l	58	200	30	45	20	46	27	45	20	49	25	40	20	43
Free Cl_2	mg/l	–	<0.01	–	<0.01	–	<0.01	–	<0.01	–	<0.01	–	<0.01	–	<0.01
K	mg/l	<2	11	<2	13	<2	12	<2	11	<2	13	<2	10	<2	14
Na	mg/l	10	44	12	43	13	47	14	45	11	40	10	42	11	38
Ca	mg/l	72	57	75	78	90	82	95	98	77	70	80	65	99	76
Mg	mg/l	16	13	20	14	21	14	21	14	19	14	18	14	20	14
Fe	μg/l	<10	33	20	150	58	165	17	147	17	130	15	165	11	172
Mn	μg/l	5	18												
Cu	μg/l	<10	<10												
Mo	μg/l	10	<1												
As	μg/l	<1	<1												
Pb	μg/l	<1	<1												
Cr	μg/l	<1	<1												
Ni	μg/l	6	8	<2	6	2	2	<2	<2	<2	4	<2	3	<2	<2
B	μg/l	<10	<10	<10	19	<10	17	<10	20	<10	20	<10	25	<10	27
Co	μg/l	<1	<1												
Al	μg/l	15	23	17	60	16	51	25	66	16	70	19	58	20	56
Se	μg/l	<1	<1												
Zn	μg/l	<10	31												
Cd	μg/l	<0.1	<0.1												
SO_4^{-2}	mg/l	28	–	27	–	27	–	30	–	25	–	29	–	26	–

constraints with the exception of two cases of TMWW irrigation (18/8 and 24/8) where the constraint is small to medium.

Between these two years, we can see that the infiltration and Cl^- toxicity constraints are the same. Also the salinity constraints for the FW applications are the same in both years. On the contrary, constraints for the salinity are different for the TMWW applications between these two years (small to medium for 2011 and insignificant for 2012). In both years and in both applications the pH values are within bounds.

By combining Tables 3, 6, and 7, conclusions are made between each metal analysis results and each metal legislated bound and so conclusions are drawn concerning FW and TMWW quality and suitability for irrigation implementation. These results are presented at Table 10.

From Table 10 is obvious that there are no constraints concerning metal ions for reusing Sparta's municipal treated wastewater as an irrigation water source.

Combining Tables 3, 6, and 7, conclusions are made about the quality of the TMWW with respect to BOD_5 and SS values (Table 11). Conclusions about the bacterial status of the TMWW cannot be made because we did not conduct such an analysis for technical reasons.

From Table 11, we can see that also the quality of the TMWW with respect to BOD_5 and SS values makes it suitable for indirect reuse and restricted irrigation. The slightly above bound values of BOD_5 and SS are not a problem, because as it is discussed, the possibility of indirect reuse, which means reusing treated wastewater after storage with a retention time of

Table 7
Analyses result for the fresh water and the wastewater (Ww) for the year 2012

Irrigation dates		29/6		07/7		13/7		19/7		27/7		03/8		09/8		18/8		24/8		31/8		07/9		13/9	
Elements	Units	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww	W	Ww
pH (20°C)	–	7.61	7.91	7.47	7.78	7.83	7.88	7.8	7.9	7.83	7.88	8.03	7.78	7.88	7.81	7.96	7.77	7.95	7.75	7.91	7.6	7.89	7.32	7.9	7.45
ECw (20°C)	μS/cm	602	611	646	606	520	629	550	650	520	629	556	612	537	691	549	725	531	700	528	620	535	615	541	660
BOD_5	mg/l	–	29	–	30	–	22	—	20	–	35	–	35	–	50	–	70	–	50	–	30	–	22	–	24
COD	mg/l	–	66	–	78	–	60	–	52	–	67	–	85	–	86	–	104	–	79	–	80	–	55	–	60
Total hardness	mg/l	308	–	322	–	296	–	302	–	296	–	257	–	259	–	269	–	285	–	275	–	255	–	267	–
Total alkalinity	mg/l	304	–	318	–	280	–	299	–	244	–	317	–	307	–	322	–	263	–	311	–	278	–	311	–
TN	mg/l	–	15	–	14	–	21	–	25	–	21	–	14	–	19	–	22	–	20	–	15	–	14	–	17
TP	mg/l	–	3.7	–	6.8	–	2.9	–	10	–	2.9	–	64	–	9	–	13.9	–	22	–	15	–	10	–	8
SS	mg/l	–	20	–	43	–	19	–	26	–	19	–	7	–	37	–	61	–	35	–	42	–	15	–	21
NH_4^+	mg/l	0.04	4.3	0.02	4.12	0.04	4.56	0.02	4.42	0.04	4.56	0.03	4.38	0.05	13.6	0.04	16.94	0.03	15.9	0.02	12.2	0.05	4.5	0.04	5.25
NO_2^-	mg/l	0.2	1.14	0.45	1.29	0.1	0.77	0.09	1.1	0.1	0.77	0.07	0.11	0.11	0.35	0.06	0.53	0.07	0.64	0.05	0.95	0.1	1.1	0.11	0.53
NO_3^-	mg/l	37	–	32	–	41	–	40	–	41	–	45	–	46	–	42	–	42	–	35	–	38	–	40	–
Cl	mg/l	28	50	27	52	23	31	20	50	23	51	20	46	20	51	20	56	20	48	22	52	21	50	23	51
Free Cl_2	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.02	<0.01	0.03	<0.01	0.02	<0.01	0.04	<0.01	0.06	<0.01	0.05	<0.01	0.04	<0.01	0.06	<0.01	0.03
K	mg/l	2	10	2	12	2	22		20	2	22	1.5	15	1.4	21	1.3	19	1.4	21	1.2	19	2	23	1.5	20
Na	mg/l	12	44	16	48	13	42	12	46	13	42	13	48	12	54	12	50	14	52	13	46	13	55	12	42
Ca	mg/l	95	88	97	66	90	60	93	70	90	60	95	70	91	81	94	85	95	77	92	68	90	65	91	70
Mg	mg/l	17	13	19	12	17	11	17	12	17	11	19	14	19	12	21	13	19	12	20	13	17	14	18	12
Fe	μg/l	122	764	144	578	73	258	15	321	73	258	12	80	14	155	19	94	25	80	14	92	12	95	13	85
Mn	μg/l	6	16																						
Cu	μg/l	<10	<10																						
Mo	μg/l	8	<1																						
As	μg/l	<1	<1																						
Pb	μg/l	<1	<1																						
Cr	μg/l	<1	<1																						
Ni	μg/l	15	20	<2	<2	<2	<2	<2	21	<2	<2	<2	<2	8	37	<2	<2	<2	<2	9	23	<2	<2	<2	<2
B	μg/l	<10	<10	<10	<10	<10	<10	<10	14	<10	<10	<10	<10	<10	13	<10	26	<10	<10	<10	<10	<10	16	<10	<10
Co	μg/l	<1	<1																						
Al	μg/l	25	76	59	117	53	180	50	210	53	180	42	273	114	293	24	66	60	150	58	210	47	265	30	180
Se	μg/l	<1	<1																						
Zn	μg/l	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	17	<10	11	<10	11	<10	13	<10	<10	<10	<10	<10
Cd	μg/l	<0.1	<0.1																						
SO_4^-	mg/l	31	–	39	–	33	–	35	–	33	–	27	–	27	–	28	–	28	–	30	–	25	–	27	–

Table 8
Constraints on the water and wastewater implementation for irrigation events in 2011

Irrigation dates	Water source	Degree of constraints on the implementation			
		Salinity	Infiltration	Cl^- toxicity	pH
20-7	W	I[a]	S-M[b]	I	WB[c]
	Ww	S-M	S-M	S-M	WB
27-7	W	I	S-M	I	WB
	Ww	S-M	S-M	I	WB
3-8	W	I	S-M	I	WB
	Ww	S-M	S-M	I	WB
10-8	W	I	S-M	I	WB
	Ww	I	I	I	WB
26-8	W	I	S-M	I	WB
	Ww	S-M	S-M	I	WB
2-9	W	I	S-M	I	WB
	Ww	S-M	S-M	I	WB
16-9	W	I	S-M	I	WB
	Ww	S-M	S-M	I	WB

[a]Insignificant (I).
[b]Small-medium (S-M).
[c]Within bound (WB).

Table 9
Constraints on the fresh water and wastewater implementation for irrigation events in 2012

Irrigation dates	Water source	Degree of constraints on the implementation			
		Salinity	Infiltration	Cl^- toxicity	pH
29-6	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
7-7	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
13-7	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
19-7	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
27-7	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
3-8	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
9-8	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
18-8	W	I	S-M	I	WB
	Ww	S-M	S-M	I	WB
24-8	W	I	S-M	I	WB
	Ww	S-M	I	I	WB
31-8	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
7-9	W	I	S-M	I	WB
	Ww	I	S-M	I	WB
13-9	W	I	S-M	I	WB
	Ww	I	S-M	I	WB

Table 10
Results of metal analyses and metals concentrations bounds

Metal	Maximum concentration (mg/l)	Characterization
Al (aluminum)	5	Under bound in both years and all cases for W and WW
As (arsenic)	0.1	Under bound in both years for W and WW
Be (beryllium)	0.1	Not conducted
Cd (cadmium)	0.01	Under bound in both years for W and WW
Co (cobalt)	0.05	Under bound in both years for W and WW
Cr (chromium)	0.1	Under bound in both years for W and WW
Cu (copper)	0.2	Under bound in both years for W and WW
F (fluorine)	1.0	Not conducted
Fe (iron)	3.0	Under bound in both years and all cases for W and WW
Li (lithium)	2.5	Not conducted
Mn (manganese)	0.2	Under bound in both years for W and WW
Mo (molybdenum)	0.01	Under bound in both years for W and WW
Ni (nickel)	0.2	Under bound in both years for W and WW
Pb (lead)	0.1	Under bound in both years for W and WW
Se (selinium)	0.02	Under bound in both years for W and WW
V (vanadium)	0.1	Not conducted
Zn (zinc)	2.0	Under bound in both years and all cases for W and WW
Hg (mercury)	0.002	Not conducted
B (boron)	2.0	Under bound in both years and all cases for W and WW

the treated wastewater in the pond before irrigation, will reduce $BOD_5$and SS under the bound values. In our case, the retention time was 1–3 h only.

Assuming a 1 d retention time and, according to Table 1, 8,000 m^3/d available TMWW for irrigation, calculations can be made (Table 12) to see the number of acres with olive trees that can be irrigated. According to the Greek legislation [22] we have:

- Class I citrus, olive trees, and vines with $K = 0.55$ ([22] Annex II categories of crops according to plant coefficient).
- Irrigation method efficiency for drip irrigation and sprayers 90% ([22] Annex III limits implementation).
- Water losses coefficient during conveyance 5% ([22] Annex III limits implementation for irrigated areas over 100 acres).
- Joint conveyance and irrigation method coefficient 85.5% ([22] Annex III limits implementation).
- Irrigation period from 15 April to 30 September ([22] Annex III limits implementation).
- The irrigation water needs for eastern Peloponnesus Water District 03 for crop class I per month is: ([22] Annex I).

In the same period the average TMWW quantity that can be exploited for irrigation is:

8,000 $m^3/d \times (15 + 31 + 30 + 31 + 31 + 30)$ d = 8,000 m^3/d 168 d = 1.344.000 m^3

1,344.000 m^3/563.16 10 × m^3/acre = 238.6 acres

1,344.000 m^3/675.63 10 × m^3/acre = 198.9 acres

So the minimum and maximum areas which can be irrigated with a 1 d retention time of the treated wastewater in the storage pond are 238.6 and 198.9 acres, respectively. It is obvious that by increasing the storage capacity of the pond, these areas can be increased.

Apart from the findings concerning the suitability of Sparta's TMWW as an irrigation water source according to the Greek legislation, some more useful observations, measurements, and evaluations have been initiated concerning the effect of TMWW on soil hydraulic properties and also on the plant growth response and productivity. Preliminary results showed statistically significant differences between olive production in both years, better nutritional status of the olives trees irrigated with TMWW than those irrigated with FW, and no differences between olive oil qualities. Furthermore, differences have been observed concerning sodium and potassium in the soil profiles with higher values of those measured at the plots which were irrigated with TMWW. On the contrary, plots irrigated with FW gave higher values of magnesium and calcium due to the concentration of these two elements in the FW. The soil of the plots irrigated with TMWW gave higher values of SAR and EC than those irrigated with FW. Undisturbed surface soil cores collected from the plots irrigated with TMWW gave statistical significant differences concerning saturated hydraulic conductivity than those measured from the plots irrigated with FW. This is an unexpected observation since both waters (TMWW and

Table 11
Results about BOD_5 and SS quality of the wastewater used for irrigation

	Maximum value (mg/l)	Year	Characterization
BOD_5	25	2011	All values under bound
		2012	From 12 values 8 slightly above bound
SS	35	2011	All values under bound
		2012	From 12 values 3 slightly above bound

Table 12
Calculations for minimum and maximum total water needs per period for crop class I (olive trees) (10 × m^3/acre)

Month/ Crop Class I	Water needs per month	Irrigation period	Water needs per month	Water needs per period	Joint conveyance and irrigation method coefficient	Water needs per period
April	63–74	0.5	31.5–37	481.5–578	85.5%	563.16–675.63
May	82–99	1	82–99			
June	93–113	1	93–113			
July	102–121	1	102–121			
August	96–115	1	96–115			
September	77–93	1	77–93			

FW) according to their EC and SAR values were at the same class based on the Greek legislated criteria or in other words based on Ayers and Westcot criteria [23].

4. Conclusions

It could be said that Sparta's TMWW was checked in this project, according to the Greek legislation, as a potential irrigation water source for the years 2011 and 2012, and all the analyses showed that it is suitable for indirect and restricted irrigation. Furthermore, the minimum and the maximum areas that can be irrigated with the treated effluent determined, assuming the minimum detention time is 1 d using legislated data for calculating crop water requirements were between 198.9 and 238.6 acres. The results concerning the effect of TMWW reuse on the plant growth response and productivity were encouraging.

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