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Hydrogeochemistry and water quality assessment of irrigation waters from 3 major olive grove areas in Greece.

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Abstract
Surface and ground water samples were collected from three key olive growing regions in Greece in order to assess their overall quality and outline major hydrogeochemical characteristics. The three study areas were selected for their significance to the national olive production as well as for their diverse physiographic characteristics and imposed cultivation practices. Results suggest that quality status in general is acceptable with few exceptions; however issues related with salinization were identified that could potentially lead to environmental degradation. Hydrogeochemical characteristics are affected by geogenic (natural) factors and anthropogenic influences to some extent. Overall, the controlling factors appear to be: geological setup, hydrogeological regime, irrational cultivation practices and groundwater overexploitation. Environmental sustainability in the three examined regions is thought feasible on the grounds of a critical balance between environmental protection and production optimization. This balance may be achieved through the implementation of focused measures designed for each of the three cultivated areas and every plot participating in the study.

Keywords: hydrogeochemistry, irrigation water, olive grove areas, impact assessment, salinization

1. INTRODUCTION

Olives and olive oil are traditional products of Greece that date back a few millennia and mark two of the most characteristic ingredients of the Mediterranean nutrition. Their production is a major element of the overall national agricultural potential and sustains local economies with a high financial profit. Besides that, extensive olive tree groves form characteristic landscapes of high environmental and aesthetic value. Considering the above, olive groves' sustainable cultivation is an issue of major significance related both with financial and environmental effects. Critical part of that, are the hydrogeochemical and environmental characteristics of the water used for irrigation purposes, which is related with the yield potential (quantity and quality) and the possible environmental pressures to surface and ground waters, as well as to soil resources of the regions. The present study examines comparatively the quality characteristics of irrigation waters from 3 major Greek olive grove areas, and attempts to make an initial assessment of their suitability for irrigation, an identification of the potential origin of environmental issues and their anticipated effects. Based on the major identified issues specific measures are suggested and remedial actions proposed in order to mitigate the potential adverse environmental effects.

The three case study areas are located in the southern part of the Greek territory (figure 1): a) southeastern Peloponnese, Nileas area, b) central Crete, Peza area and c) eastern Crete, Merambello area. Following the Emberger's bioclimatic classification [1] Nileas is characterized by sub-humid climatic conditions while Peza and Merambello by semi-arid. The geological structure of the three areas is complex, controlled by active fault tectonics and quite diverse, but in all cases affects local hydrogeochemical conditions. Peza area is dominated by quaternary formations which host a heterogeneous aquifer system along with the alluvial deposits which cover the eastern part of the study area [2-4]. Merambello which lays east of Peza, is characterized mainly by limestones and quaternary formations within which aquifers of variable potential and characteristics develop [2,5-8] while Nileas is dominated by a more complex geological structure mainly consisting of limestones, flysch, volcanic formations and quaternary deposits [6, 9,10].

Figure 1: Geographical location of the three study areas

2. SAMPLING AND ANALYSIS

Totally 97 irrigation water samples (surface and groundwater) were collected from the three study areas during the wet hydrological period of 2011 (November-December) and the dry hydrological period of 2012 (July-August). In situ measurements of pH, EC and T were performed by means of a portable instrument. Water samples were immediately filtered in the field through 0.45 μm membrane filters and separated into two aliquots of 1L and 50ml respectively. The smaller aliquot was acidified down to pH≈2 with ultrapure HNO_3 in order to prevent metal precipitation and complexation, and stored in new polyethylene bottles. Analyses were performed at the accredited laboratory of the Land Reclamation Institute. Samples were analyzed for 15 parameters (table 1) including major ions, trace elements and physicochemical attributes. Results were verified about their consistency with the aid of ionic balance ratio [11] and found to be within the acceptable margins (<10%).

Table 1: Analytical results for the 2 sampling periods of the studied areas

Area		PEZ (n=21)			MER (n=40)			NIL (n=36)		
Parameter	Units	min	max	med	min	max	med	min	max	med
pH	-	6.8	8.4	7.4	7.4	8.1	7.7	6.6	8.1	7.2
EC	µS/cm	763	2,840	1007	525	9,140	2295	193	1,706	801
K	mg/L	1	5	4	1	40	13	0	5	2
Na	mg/L	31	87	54	15	1,228	313	10	104	33
Ca	mg/L	47	700	156	53	166	93	24	233	139
Mg	mg/L	10	45	28	17	170	44	5	46	14
Cl	mg/L	57	143	91	28	2,256	579	15	293	40
HCO_3	mg/L	162	549	348	159	362	196	61	500	385
SO_4	mg/L	33	1,696	149	<20	430	116	<20	350	34
NO_3	mg/L	<1	63	4	3	21	5	1	54	13
NH_4	mg/L	0.08	0.99	0.22	<0.1	1.52	0.39	0.07	1.72	0.60
B	µg/L	<50	687	119	<50	620	176	<50	<50	<50
Fe	µg/L	<5	2,039	15	<5	6,571	53	<5	629	22
Mn	µg/L	<2	108	12	<2	391	2	<2	944	7
Ni	µg/L	<3	59	17	<3	111	4	<3	26	6

3. RESULTS AND DISCUSSION

3.1 General hydrogeochemical trends

Based on the analytical results, the samples from the three study areas differ significantly in the concentration range of specific parameters as well as in the dominant water types which are related with the prevalent hydrogeochemical conditions. A general consideration of irrigation waters' chemistry is displayed in figure 2.

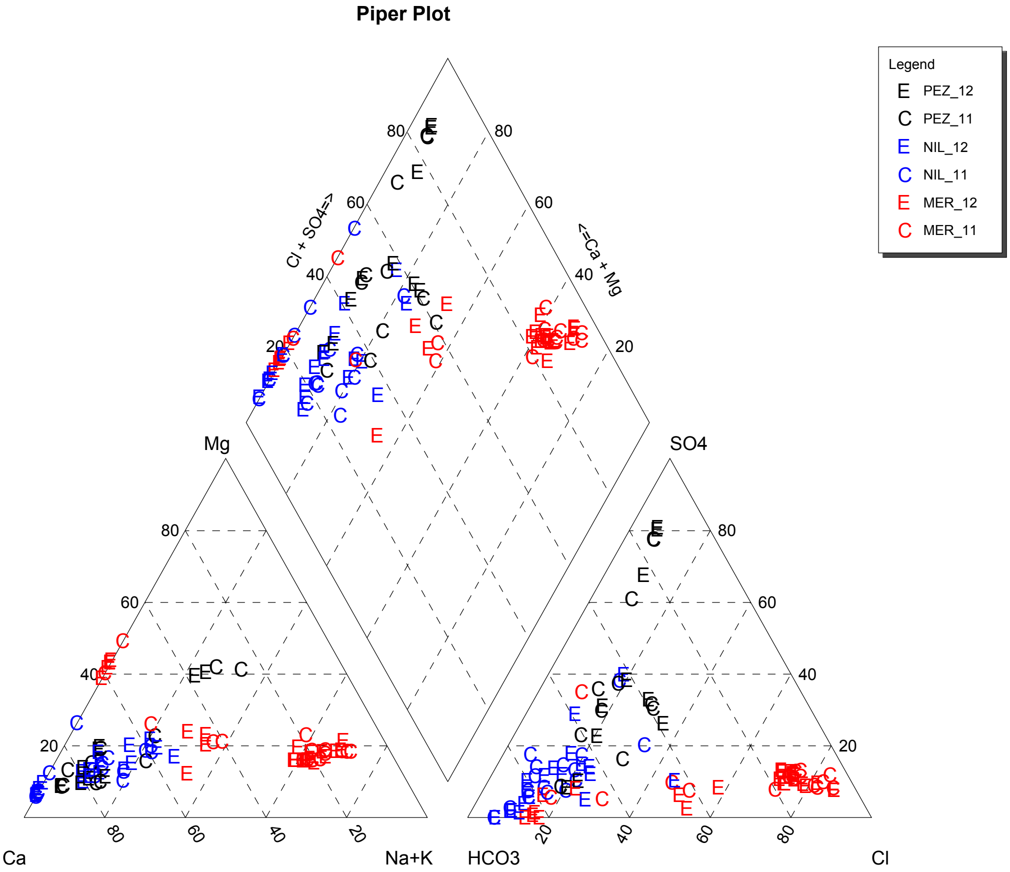

Figure 2: Piper diagram for the studied water samples (values for 2011 and 2012)

A considerable percentage of the examined Merambello water samples are profoundly affected by salinization phenomena as it may be conducted by the elevated values of Na (up to 1228 mg/L), Cl (up to 2256 mg/L) and EC (up to 9140 μS/cm). The origin of salinization is related with seawater intrusion, as may be deduced by the spatial distribution of the saline samples (near coastline) and the absence of alternative salinization factors (e.g. evaporates, connate waters etc). However, return irrigation water could probably enhance the recorded salinization but is not considered as the driving factor. In compliance with the above, the dominating water type is Na-Cl which is typical for saline environments with ongoing seawater intrusion (Hem, 1985), whilst some of the samples appear to have Ca-Cl water type which is related with ion-exchange hydrogeochemical processes where the abundant Ca originating from the dominant calcareous substrate replaces Na of seawater [11,12]. The comparison between the analytical results of the two sampling periods (wet and dry) reveals only minor differentiations regarding seawater related parameters; hence salinization is likely to be an established phenomenon which is invariable of any periodical influences. Nevertheless, sulfates do not appear in the expected (elevated) concentrations (median value is 116 mg/L) due to the intrusion of the marine environment; the latter phenomenon should be related with secondary redox processes which affect the concentrations of potential oxidants like SO_4. The presence of organic rich quaternary geological formations creates favorable conditions for oxygen depletion; thus sulfates are possibly reduced to H_2S and cannot be detected in significant concentrations, likewise reported in other Greek areas of similar geological environments [13,14]. Concerning the rest of the analyzed parameters, Ca exhibit slightly elevated values as a result of the aforementioned ion-exchange process and due to calcite dissolution which is in abundance in the karstic environment. Nitrates are practically absent (median value 5 mg/L) but their concentrations are rather a result of the reduced environment than the negligible impact from fertilization. In support of this, ammonium is enriched in water samples with a median value of 0.4 mg/L which is close to the maximum parametric limit for potable waters [15]. Ammonium is the typical nitrogen ion in reduced environments, so its concentrations are expected to be elevated compared with NO_3. Finally, heavy metals concentrations are low with few exceptions for Mn (391 μg/L) and Ni (111 μg/L). The statistical population of these parameters reflect no systematic approach to the elevated values (e.g. due pollution) but possibly local conditions of geogenic impact.

In respect to Peza area, Ca values chiefly control the hydrogeochemical conditions (up 700 mg/L) with prevalent water types $Ca\text{-}HCO_3$ and $Ca\text{-}SO_4$. Both types reflect calcium's dominance but refer to different enrichment processes. The former is related with calcite dissolution as a result of limestone's karstification whilst the latter is attributed to evaporitic minerals (e.g. gypsum $CaSO_4.2H_20$) which are probably hosted in bedrock formations. In contrast with Merambello area no salinization phenomena occur; hence EC values fall within the ordinary margins for natural waters [16] except some minor elevations probably related with local conditions of salt dissolution (e.g. halite and/or gypsum). Additionally for Peza area, nitrogen ions (NO_3 and NH_4) have low values denoting practically negligible impact from fertilization. Few exceptions of elevated values over 50 mg/L are related to local individual impacts of effluents in the form of point pollution sources (e.g. manure accumulation or septic tanks) on wells of small depth (and shallow groundwater level) that are characterized by high vulnerability; this can be deduced by the simultaneous increase of NO_3, NH_4 and Cl concentrations which is indicative in similar cases for manmade impacts caused by effluents [6,17].

Finally, Nileas' samples are characterized by the strong influence of the karstic substrate which is reflected to the dominant water type of $Ca\text{-}HCO_3$ for almost the entire set of samples and the relevant elevated values of Ca (median value 139 mg/L). All the other parameters are within the margins of natural waters [16] except from NH_4 which are elevated (up to 1.72 mg/L) in a number of the examined samples compared with the rest and probably denote local influence of redox conditions and fertilization, since Cl are low thus excluding impact from manure or domestic wastes. Heavy metals concentrations are low, apart from some individual values (e.g. for Mn 944 μg/L) that may be attributed to impact from Fe-Mn (hydro) oxides. Compared with the other examined areas, Nileas seems to have the best irrigation water quality sources.

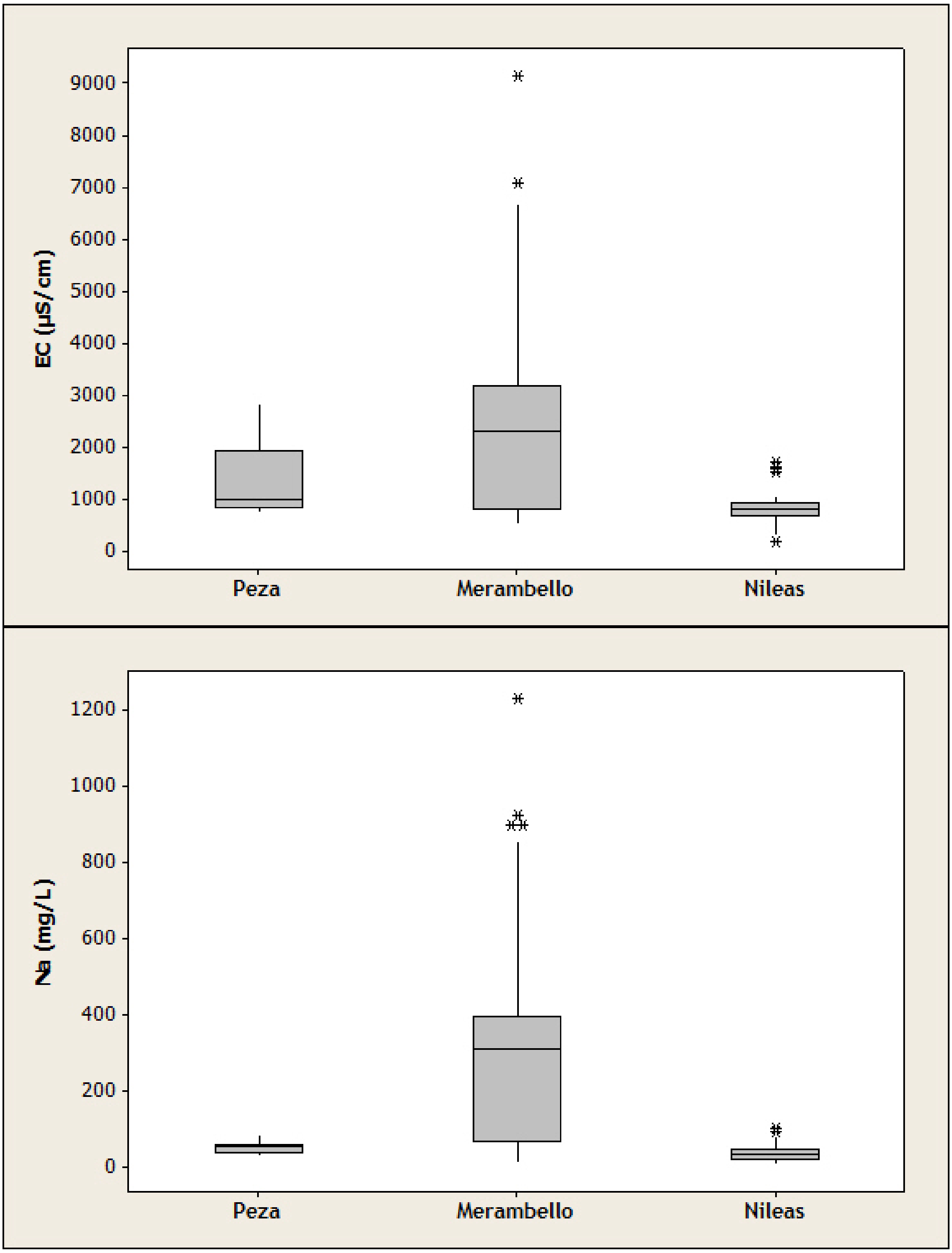

Figure 3: Boxplots of EC and Na with the addition of whiskers (lines) and outliers (dots) for the studied samples

A comparison of the statistical populations for EC and Na (figure 3) as key factors that indicate salinization makes clear that Merambello samples are by bar more influenced, having greater median values, whiskers and outliers (extremes) than the rest for both EC and Na; Peza area is significantly less influenced whilst Nileas appears negligible occurrence of saline waters. The origin of salinization in Peza seems to be different than in Merambello due to low Na values that indicate probably an effect from substrate salt dissolution and/or impact from reclaimed irrigation waters rather than seawater intrusion as in Merambello.

3.2 Assessment of irrigation suitability of water and actions to mitigate identified environmental degradation factors

The assessment of irrigation suitability for the examined samples identified as dominant environmental issues the salinization which characterizes mainly Merambello area and secondarily Peza. Other issues of minor importance with local characteristics were identified to be individual elevated concentrations of B (Peza, Merambello), Mn (Nileas), Ni (Peza) and Fe (Peza, Merambello). Despite the fact that some of the examined samples exhibit elevated concentrations of nitrogen compounds, these are not regarded as environmental threats for olive groves, since nitrogen excess may facilitate and supplement the total amount of applied fertilization; hence improving soil fertility and in turn crop yield, whilst directly reducing crop production cost by cutting down on applied fertilizers[17-20].

The quality of irrigation waters may potentially have effects in several receptors, most important of which may be considered the soil and the olive trees; hence impact assessment and mitigation actions are referred to them. Based on figure 4, Nileas' samples are characterized by low sodium hazard (SAR) and medium to high (few samples) salinity hazard (EC), thus classified to categories C_2-S_1 and C_3-S_1.

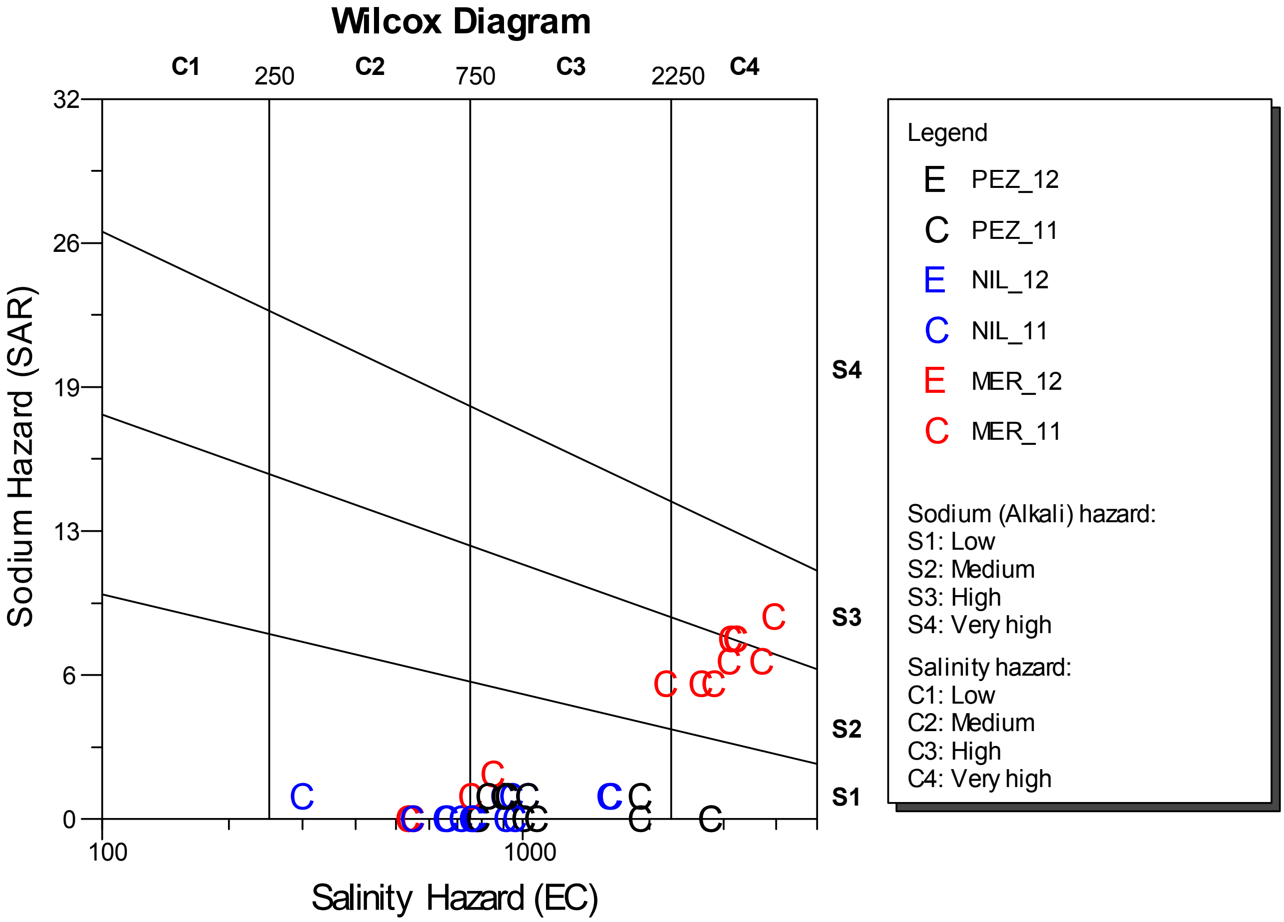

Figure 4: Wilcox diagram for the studied water samples (values for 2011 and 2012)

According to table 2 that provides the potential yield reduction for olive crops due to irrigation water salinity [21], Nileas' irrigated fields are not expected to present any yield reduction since the maximum measured value of irrigation water EC is below 1,800 μS/cm. Soil salinization hazard from the use of irrigation waters is low, provided total volumes of received water (precipitation and irrigation) are sufficient and soil drainage is good. In the few cases of saline soils, it is suggested to sustain soil humidity at high levels through frequent irrigation at small doses and salt leaching beyond natural drainage. Regarding plants' toxicity, irrigation water may have significant effects only in few cases (fields irrigated by water originated from 3 specific boreholes) where Na and Cl concentrations are elevated. Special attention should be given also to remoted cases where elevated concentrations of Mn occur.

Table 2: Irrigation water salinity tolerances for olive crops and estimated yield reduction (adapted from [21])

Yield potential	***100%***	***90%***	***75%***	***50%***
Irrigation water EC	1800 μS/cm	2600 μS/cm	3700 μS/cm	5600 μS/cm

Peza samples are characterized by low sodium hazard (SAR) and high (except one which is very high) salinity hazard (EC), hence classified to categories C_3-S_1 and C_4-S_1. According to table 2, the majority of Peza fields are not expected to experience yield reduction due to high salinity irrigation water (EC median is 1007 μS/cm), whilst few of them irrigated with water of EC over 2600 μS/cm may suffer a yield reduction of 10%. Most of Peza irrigation water sources will not trigger any salinization effects to soils, except from very few cases. In those situations soils should be treated as previously proposed for the cases of Nileas' fields. As these waters may cause difficulties in nutrients' assimilation by plants and lead up to 10% of crop reduction, it is suggested to blend them with waters of higher quality. Plants' toxicity is likewise Nileas' area focused only on few samples (1 borehole and 2 wells) and regards elevated values of Na and Cl.

Finally, the majority of Merambello samples are characterized by medium to high sodium hazard (SAR) and very high salinity hazard (EC), hence classified to categories C_4-S_2 and C_4-S_3 and few of them as C_2-S_1, C_3-S_1 and C_3-S_2. According to table 2 and based on the median value of EC, the majority of Merambello irrigated fields are expected to present a minor yield reduction up to 10%, whilst some of them (irrigated with waters of EC values over 5600 μS/cm) may suffer from heavy yield reduction even more than 50% of the total yield potential. The soil salinization hazard in case of Merambello will be increased, if not adopting proper measures and actions for mitigation. These may include as mentioned before, maintenance of high soil humidity conditions, salt leaching, good drainage conditions and blending with waters of higher quality in appropriate ratios in order to achieve acceptable parameters. Failure to take appropriate actions could result in heavy reduction of crop production and soils' degradation that could eventually lead to desertification. Plants' toxicity is related to the elevated values of Na and Cl for the majority of the samples, while Fe and Mn should be closely monitored.

4. CONCLUSIONS

Surface and ground water samples were collected from three key olive growing regions in Greece in order to assess their overall quality and outline major hydrogeochemical characteristics. Results identified salinization as the major environmental issue affecting mainly Merambello area and secondarily Peza. The magnitude of salinization differs between these areas, probably reflecting their different origin; Merambello suffers a more extended salinization of irrigation waters due to seawater intrusion related with aquifer overexploitation and hydrodynamic evolution, while Peza seems to be affected by natural salinization processes related with evaporitic mineral dissolution. Nileas on the other hand is characterized by irrigation waters of good quality and signs of deterioration were identified only in few individual cases.

The comparative study between surface and groundwater samples showed little differences as expected, due to the fact that artificial surface reservoirs are regularly fed by groundwater exploitation. Minor deviations were noticed to the redox sensitive elements of Fe and Mn that were significantly lower at surface waters as a result of the developed oxidizing conditions.

Despite the identified quality deterioration issues, examined water resources may be used for irrigation even in the more affected areas, provided appropriate measures are taken. These measures include but are not restricted to the reduction of soil salinization hazard through appropriate irrigation volumes applied, careful blending of saline with higher quality water, salt leaching in the form of frequent and small doses, maintenance of optimal soil humidity and good soil drainage. Following these general guidelines, crop production is expected to sustain its optimal quality and quantity without any further impacts to the soil resources, the end product and local economies.

Based on nominal irrigation needs and water quality of specific sources, considerable reduction in crop yields would be expected and also desertification phenomena should have been triggered, at least locally. However, such phenomena are spatially restricted and when they occur are of low intensity. Analysis of the reasons and conditions that have shaped the "paradox" of limited impacts despite the strong influences from deteriorated water resources, suggests that precipitation, insufficient irrigation due to water shortage and the soil texture play a crucial role in restricting the adverse effects of deteriorated irrigation water on crops and soil resources.

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