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Water Mismanagement in Agriculture: a Case Study of Greece. Starting with “how” and "why"

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Abstract. The present study concerns the plain of Arta, located in the northwestern part of Greece, in one of the most surplus water areas of the country, where the highest annual precipitation occurs. However, despite the region's water wealth, the plain is experiencing water shortages, posing challenges to agricultural productivity. This study delves into the examination of this paradox with the objective of offering insights into fundamental inquiries such as "What are the annual irrigation requirements of the plain and how are they distributed throughout the year?" “Is the water supplied by the collective irrigation network adequate to meet these requirements?" and "What proportion of irrigation needs are met by groundwater?". In the absence of data and measurements, a methodology was therefore developed for the approximation of the water balance, using software tools and drawing on the experience and knowledge of farmers, thus creating the basis for optimizing agricultural production and addressing management issues. To calculate the water requirements, the CROPWAT 8.0 software was used, utilizing the climatic data from six meteorological stations in the region, while a qualitative survey was conducted to estimate the rate of groundwater consumption, targeting a group of stakeholders and a group of farmers. The crops' annual water requirements were calculated to be 49.1 hm^3, with drilled water meeting 41.1% of these needs. The public irrigation system's water supply is sufficient to meet the crops' annual water requirements. Water shortages and over-extraction of groundwater provide substantial management difficulties that need to be tackled. These challenges present significant chances for enhancement and growth and are essential for the region’s economic and social sustainability.

Keywords. Agriculture, Arta plain, CROPWAT 8.0, Crop water requirements, Water resources management.

1. Introduction

Agriculture is a primary sector of development for most rural areas, contributing significantly to the economy and social progress through employment and income. Moreover, agriculture provides the largest share of food globally while also providing a significant number of ecosystem services (e.g., food, raw materials, and fuel) [1-3]. The context for the evolution of agricultural landscapes is crucial

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for achieving the United Nations Sustainable Development Goals (SDGs), such as food security and responsible consumption and production [4, 5].

In recent decades, population growth, urbanization [6,7], rising living standards in developed countries [8] and food industry marketing [9] have led to significant shifts in dietary preferences and consumption [10], creating the need to implement new agricultural methods. In order to meet the increasing food demand, intensive and extensive farming practices were introduced, using more fertilizers and pesticides and tying up more resources (water and soil) to increase production and productivity. However, according to the law of diminishing marginal returns, it is likely that a further increase in inputs, for example fertilizer, will result in a decrease in yield [11]. In modern industrial society, conventional agriculture pursues greater efficiency by increasing fossil energy inputs (fuels, pesticides, and fertilizers) over biomass, which was the key source of energy before industrialization began [12]. Increased inputs (fuels, pesticides, and fertilizers) contributed to increased agricultural production but also led to the environmental degradation of agricultural systems and reduced biodiversity [11]. Agriculture is inextricably linked to nature, and the results of their interaction reflect their degree of dependence. Crop production is a major driver of environmental change, and its intensification often undermines conditions necessary for its sustainability, such as ecosystem services including biodiversity and water regulation [13, 14]. Declining biodiversity increases the incidence of pests and diseases [15], overexploitation of the land reduces soil productivity [16] and pollution of water bodies poses serious risks to ecosystem balance and human health [17]. The adoption of ecological approaches in agricultural systems is considered imperative in order for the sector to shift towards the axis of sustainable development by pursuing socio-economic benefits while demonstrating respect for the environment.

Climate change exacerbates these difficulties by causing changes in water availability and distribution, and by intensifying the frequency and intensity of extreme events such as floods and droughts [3]. The aim is therefore to achieve resilient crops and efficient management of natural resources (water and soil) by using sustainable practices in order to enhance fertilization efficacy [18, 19] and mitigate the energy footprint of agriculture. Profit drives farmers' choices of crops and agricultural methods. It is advantageous for ecologically focused management techniques to simultaneously focus on securing agricultural income in this context. For European countries, the majority of the rules and regulations that meet these objectives are laid down in the Common Agricultural Policy.

It is essential to support farmers to enhance their living conditions, adapt to impending challenges (climate change, food security), and adopt environmentally friendly practices. In this effort, information dissemination and feedback between researchers, farmers, institutions, and local authorities play an important role. In addition, for effective evaluation and the development of coherent management policies, it is essential to record spatially and temporally the practices applied, the resources committed, and the crops selected.

The present research focuses on the plain of Arta. It has been described as the "orchard of Epirus" since its fertile soils have been cultivated for centuries, constituting a basic source of employment and income and contributing significantly to the local economy and social cohesion. However, in recent years, there has been a significant reduction in the area under cultivation as a result of structural issues that have arisen, such as a lack of labor and management issues concerning the irrigation system and crop yields. The deterioration of the region's agricultural sector is also reflected in the demographic shrinkage, with the population decline reaching 6% in the last decade (2011–2021) [20, 21]. Many fields have been abandoned, and the lack of data and information on yields, inputs, and farming practices makes it difficult to resolve the issues. The high proportion of small farmers (small plots of land and small-scale farming) and the related lack of various types of collective farming (cooperatives) also play an important role in weakening the sector.

The management of water resources is a primary issue. Although this is a hydrologically wealthy area, there is a temporal and spatial imbalance in the distribution of water, leading to irrigation through boreholes, most of which are unregistered or have been drilled for various other reasons (anti-freezing, fire protection). The main factor is the area's collective irrigation network, which was put into operation in the 1960s and comprises some 55 km of open earthen pipes and 18 km of concrete pipes. The open earthen pipelines are subject to significant water losses due to run-off, deep percolation, and evaporation. As a result, in areas remote from the water intake points, such as Neochori and Pachykalamos, irrigation water, especially during the summer months, is not sufficient, with the result that most farmers irrigate exclusively with drilled water, for the extraction of which considerable amounts of energy are spent. An additional factor that is turning farmers towards the use of drilled water is the fact that the collective irrigation network operates from April to September, unable to meet the needs of crops that should be irrigated throughout the year. At the same time, the low cost to farmers of using the surface water supplied by the collective irrigation network leads to a waste of water resources, leaving some farmers with boreholes as their only source of irrigation. The charges for the collective irrigation network are fixed, calculated per hectare of cultivated area, and do not take into account the quantity consumed, which is not even measured. It is worth noting that in areas in the southern part of the plain, where it borders the Amvrakikos Gulf, there have been cases of groundwater salinity due to the extensive groundwater abstraction. To date, no irreversible effects have occurred due to the hydrological wealth of the area. However, given that groundwater consumption for irrigation is increasing uncontrollably, once usage exceeds recharge levels, serious environmental degradation impacts are expected, with the main beneficiaries being groundwater systems and soil resources, leading to adverse effects on agricultural production. The potential improvement in water availability lies in improving water management [22].

In terms of irrigation methods in the area, surface irrigation, sprinkler irrigation, and drip systems predominate in proportions of about 40%, 40%, and 20%, respectively [23]. The irrigation practices applied by the majority of farmers lie in their experience and the advice passed down to them by their elders [24]. Another phenomenon that has been observed is that, in some cases, drainage canals are used to irrigate cultivated land, which raises important issues since drainage water carries a high organic load due to leaching from neighboring fields. Finally, as reported in previous research [24], many farmers use rivers and drainage channels either for washing spray equipment or for dumping waste, endangering water quality and the balance of the rural ecosystem.

It is clear that there are structural and key issues to be addressed in the Arta Plain in order to rebuild the agricultural sector, prevent any environmental risks they pose, and address future challenges related to climate change and water availability. Nevertheless, the absence of measurements and data regarding crop water requirements and the amount of groundwater utilized in agriculture presents a challenge in evaluating the water balance. This creates significant barriers in formulating agricultural development programs and managing water resources effectively. The present research aims to tackle the problem of incomplete data by developing a thorough technique that combines software programs and utilizes the knowledge and perspectives of farmers and local stakeholders (Figure 1). More precisely, it utilizes the CROPWAT 8.0 program to calculate water requirements. Initially, an effort is made to calculate the total requirements of the plain by considering all the crops recorded in it. This distinguishes the present study from prior ones, which only calculated the needs of the main crops [25-33, etc.]. The distribution of these needs coverage between the surface network and boreholes is determined based on the findings of a qualitative survey. By comparing the results of the estimates with available measurements carried out at the water intake points of the surface network[1] in 2016, 2017, and 2018, important conclusions are drawn regarding the ability to meet irrigation needs and the use of water resources. This study addresses fundamental inquiries regarding the water adequacy of the region, the temporal distribution of demand and supply, and the underground consumption. Understanding the competing uses of water, the environmental costs, and the economic impacts of inefficient water management, the results of this research provide the basis for understanding the current situation and prioritizing the problems that need to be addressed.

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[1] The measurements had been carried out under a water metering service agreement between the University of Ioannina, the GOLR of Arta, and the LOLR of Arachthos and Louros.

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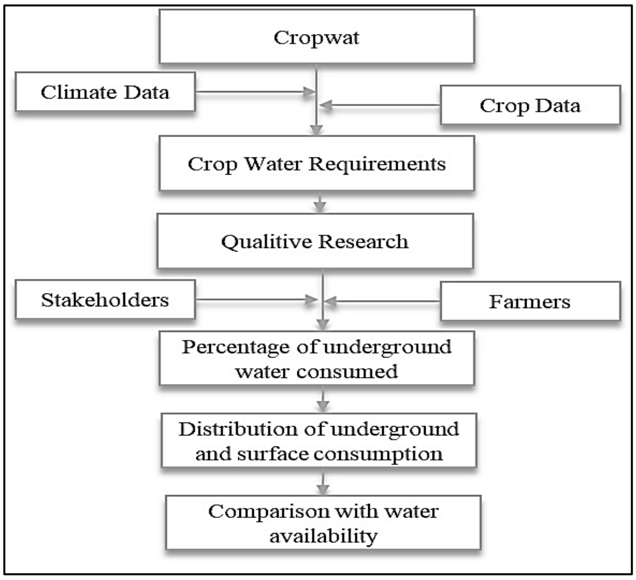

Figure 1. Methodology applied.

2. Materials and Methods

2.1. Study Area

The study area extends between the prefectures of Arta and Preveza, with most of the land located in the prefecture of Arta (39° 8' 11.51" N, 20° 57' 34.20" E). Administratively, it is part of the Region of Epirus, which is ranked as the 13th region in Europe with the lowest GDP per capita for 2017 and the 3rd region with the highest percentage of its population over 65 years (27.3%) for 2020, according to Eurostat data[34, 35]. The geographical location of the plain highlights its importance, as it is bordered by the Arachthos and Louros rivers, which have significantly contributed to the cultivability of its soils (Figure 2). In its southern part, the plain is bordered by the Amvrakikos Gulf, part of which is protected by the Ramsar Convention [36] and Natura 2000 network [37]. It is a wetland of high environmental importance which is directly affected by the agricultural practices applied to the agricultural landscape. The climate of the area is characterized as Mediterranean, with hot and dry summers and mild, rainy winters.

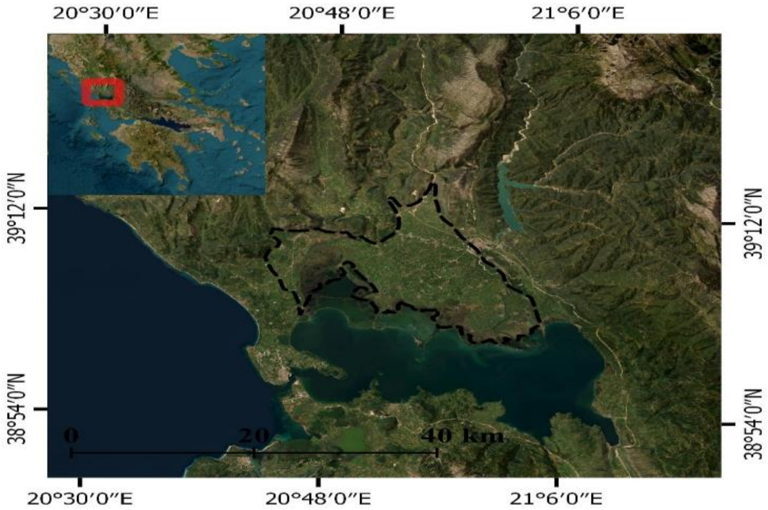

Figure 2. Study area.

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2.2. Calculation of Crop Water Needs

The total water needs for the crops of Arta Plain were estimated using decision support software CROPWAT 8.0, developed by FAO [38], based on FAO Irrigation and Drainage Paper 56 [39]. Initially, an attempt was made to import the climatic data from the CLIMWAT database. However, the nearest station found was located in Corfu, and the data were not considered fully representative of the area under study. Therefore, data from six meteorological stations installed along and across the plain by the Department of Agriculture of the University of Ioannina were used, whose data are available online at OpenHi.net [40]. Monthly values were then converted to daily steps using the Hydrognomon4 program [41]. For enhanced utilization of multi-station data, the area was divided into nine spatial units based on the municipal units that constitute it (Arachthos, Amvrakikos, Arta, Filippiada, Filothei, Kommeno, Louros, Xirovouni, and Vlaherna) (Figure 3).

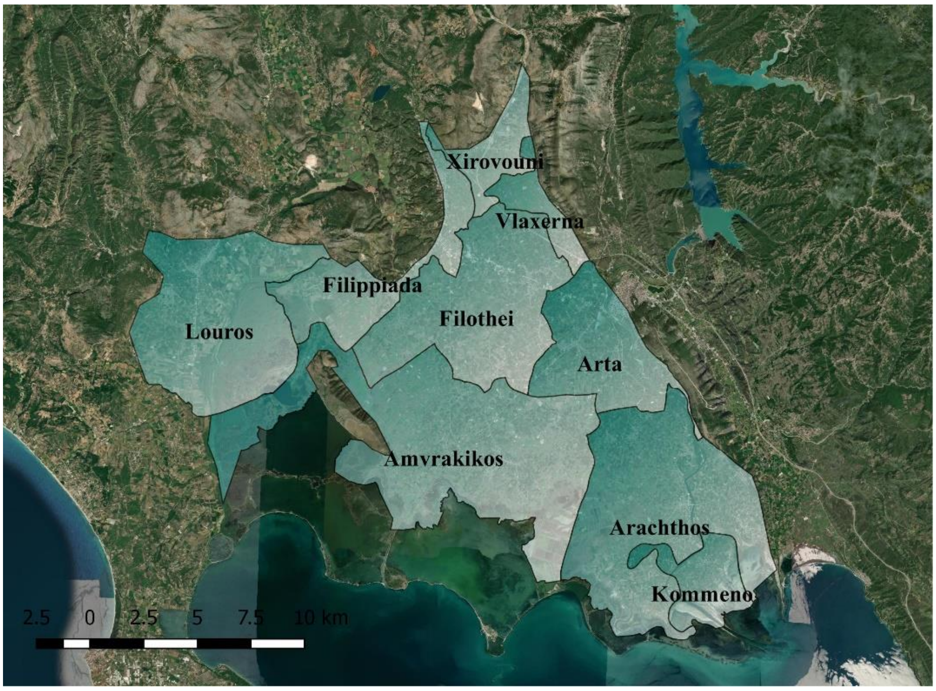

Figure 3. Spatial units delineated according to the municipalities within the research area.

The "new" centers of each spatial unit were then found through QGIS, and the meteorological data for each center were calculated using the Inverse Gravity Spatial Interpolation method as follows:

$$KLIM = \sum_{i=1}^{N} KLIM_i \cdot w_i$$

$$w_i = \frac{\frac{1}{d_i}}{\sum_{i=1}^{N} \frac{1}{d_i}}$$

where $KLIM$ is the simulated climate value (temperature, precipitation, etc.), $KLIM_i$ is the measured value of the parameter at weather station i located at a distance d_i from the considered location (center of the municipal unit), and w_i is the weight function.

Then the climatic data (minimum air temperature, maximum air temperature, air humidity, wind speed, solar radiation), altitude, and coordinates were entered into the CROPWAT 8.0 software. The steps followed are as follows:

- Calculating the reference ET_0,.

- Calculating the ET_C of each crop.
- Calculating the irrigation water requirement of the crops.

2.2.1. Calculating the Reference ET_0

The data on the recorded crops in the area refer to the year 2021 and was provided by the Greek Payment and Control Agency for Guidance and Guarantee Community Aid (OPEKEPE). For this reason, the climate data of the same year were used. In the area under review, 68 different crops were recorded with a total area of 9,197.06 ha. The crops under cover were excluded, as they extend to less than 0.5% of the sample and their investigation requires adjustment of parameters. Crop parameters were obtained after a literature search [39, 42-47]. Data were entered for 61 out of 68 crops. The input data needed were planting date, growth stages, Kc values (crop coefficient), rooting depth, critical depletion, yield response, and crop height. Climate and topographic data were then used to calculate the reference crop evapotranspiration ET_0 according to the Penman-Monteith method [39, 48]. Reference crop evapotranspiration concerns a reference crop (grass) with predetermined constant parameters and resistance coefficients that facilitate its calculation [49]. The Penman-Monteith equation develops as follows:

$$ET_0 = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_a - e_d)}{\Delta + \gamma\,(1 + 0{,}34U_2)}$$

Where:
ET_0 = reference evapotranspiration (mm day^{-1})
R_n = net radiation at the crop surface (MJ m^{-2} day^{-1})
G = soil heat flux density (MJ m^{-2} day^{-1})
T = mean daily air temperature at 2 m height (°C)
U_2 = wind speed at 2 m height (m s^{-1})
e_a = saturation vapour pressure (kPa)
e_d = actual vapour pressure (kPa)
$e_a - e_d$ = saturation vapour pressure deficit (kPa)
Δ = slope vapour-pressure curve (kPa °C^{-1})
γ = psychrometric constant (kPa °C^{-1})

2.2.2. Calculating the ET_C of Each Crop

With the reference evapotranspiration ET_0 now known, in which the climatic data of the region of interest have been incorporated, the evapotranspiration ET_C is calculated for each crop, taking into account the coefficient K_c, which carries all the characteristics of each crop [39].

$$ET_C = K_c \times ET_0$$

Where:
ET_C = crop evapotranspiration (mm day^{-1})
K_c = crop coefficient (dimensionless)
ET_0 = reference crop evapotranspiration (mm day^{-1})

2.2.3. Calculating the Irrigation Water Requirement of the Crops

Crop water requirements (CWR) correspond to the depth of water required to compensate for the amount lost through evapotranspiration (ET_C) for a disease-free crop and are calculated as the sum of ET_C carried out throughout the growing season [50]. Some of these needs are met by rainwater. However, a proportion of rain is lost through runoff and deep infiltration [51]. The rainfall available to meet the water needs of crops is defined as effective rainfall (ER). The remaining water is met through irrigation and is calculated as follows:

$$IWR = (CWR - ER)$$

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2.3. Estimation of the Percentage of Water Consumed from Boreholes

In order to estimate the amount of groundwater consumed to meet irrigation needs, a two-phase qualitative survey was conducted among two different groups of people. The qualitative survey was chosen among others as it aims to obtain information that cannot be obtained from measurements and derives from the experience of the participants [52]. In the first phase, the survey was addressed to a group of local stakeholders responsible for water management and rural development in the region. The meeting was planned and took place during a workshop of the e-Pyrros research project, of which this survey is part. All local stakeholders were notified of the forthcoming workshop and the topic it deals with. The meeting took place in March 2023 and was attended by a total of 16 representatives. In a second phase, the survey targeted farmers in the area. The farmers were randomly selected either in the survey field or at the Local Improvement Organizations, where they go to pay their bills (payment for the use of irrigation and drainage canals) and settle issues related to the operation of the network. Farmers must have experience in at least 3 of the 4 leading crops to participate in the survey. To define the sample in this phase, the 'saturation' strategy was followed, which is widely used in qualitative surveys and is based on continuing sampling to the point where responses do not add any further information to the data already collected [53, 54]. In both phases of the survey, consent was sought from respondents for their participation and use of the results, and the anonymity and confidentiality of the questionnaires were emphasized. The survey's goal was to determine how many of the four dominant crops in the area use borehole water for their irrigation needs and in what percentage. According to the OPEKEPE census, the main crops of the plain are citrus, kiwifruit, clover and olives, since together they represent 84% of the total area of the plain. It was pointed out at the beginning of the interviews that if the knowledge and experience required for a valid answer is not available, it is preferable not to answer the question.

3. Results

The registered crops, granted from the Greek Payment and Control Agency for Guidance and Guarantee Community Aid (OPEKEPE), are grouped according to their characteristic parameters and classified according to the proportion of the total area they occupy in the following table (Table 1). Crops for which the necessary input data could not be found for processing (chestnut, lotus, oregano, rosemary, eucalyptus, aloe, sea buckthorn) have been excluded. Excluding these crops, the areas for which the model results were used amount to 9184.63ha, and all percentages were estimated on this basis. As mentioned previously, the study area was divided into nine sub-areas to make the best use of the climatic data and their variation within the agricultural field area. Consequently, for most crops, more than one calculation was performed (entering different climate data) depending on how many spatial units they occur in. Therefore, columns 1–9 of the table represent the quantities of irrigation water required on an annual basis for each spatial unit (1:Amvrakikos, 2:Arachthos, 3:Arta, 4:Filippiada, 5:Filothei, 6:Kommeno, 7:Louros, 8:Xirovouni, 9:Vlaherna), as determined by the Cropwat modelling.

Table 1. Area coverage rate and annually irrigation water requirements for each crop.

Crops 2021 (OPEKEPE)	**Study area (ha)**	**Area coverage rate %**	**Annually Irrigation Water Requirements**								
			1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**
Citrus	2878.1	31.3	502.8	502.9	503	502.9	503.4	503.8	504.4	503.5	503.5
Alfalfa	2317.3	25.2	453.8	451	451	451	448.3	445.6	437.5	445.3	445.3
Kiwi	1565	17	734.9	735	735.1	735	734.2	733.4	730.2	733.2	733.1
Olive trees	1005.4	10.9	527.2	527.3	527.4	527.3	528.2	529	531.2	528.8	528.7
Grass warm	493.2	5.4	647.2	647.3	647.4	647.3	651.7	651.5	650.8	651.2	651.2
Maize	487	5.3	469.8	469.8	469.9	470	474.		491.	478.	478.8

Crops 2021 (OPEKEPE)	**Study area (ha)**	**Area coverage rate %**	**Annually Irrigation Water Requirements**								
			1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**
							2		8	8	
Oats	105.9	1.2	264.2	264.3	264.4	264.3	268.4		285.7	272.3	272.3
Rice	80.7	0.9		512	512.2						
Cotton	56.8	0.6				652.7	656.2				
Wheat	34.4	0.4	344.2			344.4	335.9			353.5	353.5
Barley	24	0.3	262.5				266.6			270.4	270.4
Sorghum	21.3	0.2	264.6	264.6	264.7		268.4		283.5	272	272
Walnut	11.9	0.1	653.7	653.8	654		658.1		665.4	661.7	661.6
Potatoes	11.6	0.1	431.6	431.7	431.8		436.9		457.7	441.6	
Watermelons	10.9	0.1	223.2	223.2	223.3		227.7				
Hazelnut trees	9.6	0.1	384.6		384.8		389.1	393.5			
Pomegranates	8.5	0.1	814.7	814.8			821.2	821.1	820.3		
Spinach	8.2	0.1	69.3	69.4	69.4		72.2			70.4	
Wine Grapes	7.6	0.1	400.5	400.6	400.7		402.1	403.8	410.1	403.9	403.8
Peach-Apricot-Plum trees	5.1	0.1	776.7	776.8	777		779	781.8	792.5		
Almond trees	5.1	0.1	573	573			574.3		582.5	576	
Apple-Cherry-Pear trees	4.2	<0.1	628.4	628.5	628.7		630.1		640.6		
Vegetables	3.5	<0.1	186.7	186.8	186.9		191.1			195.1	
Pulses	2.7	<0.1	234.4	234.4			253.2	257.2			
Avocando	2.2	<0.1	630.1				630.5				
Eggplants	1.9	<0.1	409.3	409.4	409.5		414				
Green beans	1.9	<0.1	159.4	159.5	159.5		161.6			162.5	162.5
Cabbage	1.6	<0.1	522.3	522.4	522.6		527			525.4	
Peppers	1.5	<0.1	311.7	311.7	311.8		300.7			320.4	
Broccoli	1.4	<0.1	371.1	371.2	371.3		370.7			380.9	
Cauliflowers	1.3	<0.1	395.9	396	396.1		400.7				
Lettuce	1.3	<0.1	102.1				110.2			113.4	
Berries	1.2	<0.1	580.4	580.5							
Zucchini	1.2	<0.1	131.6	131.7	131.7		143.6			144.3	
Broad beans	1.1	<0.1	221		221.2		226.2				
Melons	1	<0.1	278.7	278.7	278.8		282.9				
Soya	0.9	<0.1	393.7								
Corn	0.9	<0.1	125.1				128.				

Crops 2021 (OPEKEPE)	**Study area (ha)**	**Area coverage rate %**	**Annually Irrigation Water Requirements**								
			1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**
							6				
Radishes	0.8	<0.1	36.1	36.1	36.1		37.4			34.6	
Tomatoes	0.8	<0.1	385.7	385.8	385.9		390.4				394.5
Green onions	0.7	<0.1	86.3	86.3			90			93	
Beets-Beetroot	0.6	<0.1	86.3		86.3		89.8			92.6	
Celina	0.5	<0.1	325.3		325.4		330.2			334.7	
Onions	0.5	<0.1	442.7				447.8				
Fig trees	0.5	<0.1	364	364.1			369		388.3		
Cucumbers	0.4	<0.1	389.9	389.9			394.7				399
Beans	0.4	<0.1									
Table Grapes	0.4	<0.1	472.9	472.9			474.8				
Jujube	0.4	<0.1		373.6							
Carrots	0.3	<0.1	459.3				464.3				
Lentils	0.3	<0.1									
Artichokes	0.3	<0.1	745.8								
Okra	0.2	<0.1	138.6		138.7		142.4			142.9	
Garlic	0.1	<0.1	420.7	420.8			425.6				
Strawberries	0.1	<0.1	270.9	270.9							
Pumpkin	0.1	<0.1	226.7								

To estimate the total volume of water required, separate calculations were performed for each spatial unit by multiplying the irrigation needs of each crop by the area it occupies in each unit. Cropwat data provide information on the water requirements for each ten-day period and on an annual basis. Decadal values were converted into monthly values for the purpose of examining demand fluctuations. The monthly total crop requirements are detailed in the table below (Table 2).

Table 2. Monthly irrigation water requirement.

Months	**Irrigation water requirements (hm^3)**
January	0.0
February	0.7
March	1.2
April	4.5
May	7.8
June	9.2
July	9.7
August	7.9
September	6.2
October	1.1
November	0.9
December	0.0
Total	49.1

According to the intended audience, responses regarding the rates of irrigation for the four major crops through boreholes were divided into two groups. The mean and standard deviation of the replies for each group were calculated to assess the distribution of sample values. The responses are displayed in the table below (Table 3).

Table 3. Qualitative survey responses.

	Percentage of irrigation through drilling			
	Citrus	**Kiwi**	**Alfalfa**	**Olive trees**
		Local stakeholders		
1	60%	100%	50%	30%
2	20%	90%	10%	10%
3	35%	30%	0	-
4	-	-	-	-
5	60%	95%	20%	30%
6	40%	95%	10%	5%
7	50%	90%	10%	10%
8	50%	80%	10%	10%
9	50%	60%	10%	20%
10	80%	70%	10%	10%
11	-	-	-	-
12	-	-	-	-
13	60%	40%	10%	10%
14	100%	100%	90%	5%
15	50%	90%	0%	5%
16	-	-	-	-
Average	55%	78%	19%	13%
Stdev.p	20%	23%	25%	9%
		Farmers		
1	70%	80%	10%	10%
2	55%	80%	10%	20%
3	50%	85%	20%	10%
4	40%	70%	20%	10%
5	60%	100%	10%	10%
6	70%	85%	30%	-
7	70%	90%	20%	10%
8	40%	90%	10%	-
9	70%	85%	10%	0%
10	80%	90%	30%	0%
11	60%	100%	0%	0%
12	60%	90%	10%	0%
13	60%	100%	10%	-
14	50%	80%	0%	0%
15	50%	70%	30%	0%
Average	58%	86%	15%	7%
Stdev.p	11%	9%	9%	6%

Unique data on the quantity of water supplied by the collective irrigation network were obtained through measurements conducted as part of a collaboration between the Department of Agriculture at the University of Ioannina and the responsible water management authorities of the collective irrigation network (Local Organization of Land Reclamation and General Organizations of Land Reclamation). Hourly measurements were conducted near the five water intake points of the communal network throughout the irrigation season (1 April–30 September) for the years 2016, 2017, and 2018. In the same framework, annual flows were also approximated, integrating with respect to time. The annual water quantities needed to meet irrigation needs in the years 2016, 2017, and 2018 were estimated at 192, 145.31, and 132.5 million cubic meters, respectively. The hourly network flows were converted to daily flows and contrasted with the crop water needs as calculated with Cropwat following the same time step (Figure 4). For the year 2018, due to technical difficulties (temporary gate adjustments), no measurements were taken until June 20 and from June 21 to August 20, resulting in gaps in the graph.

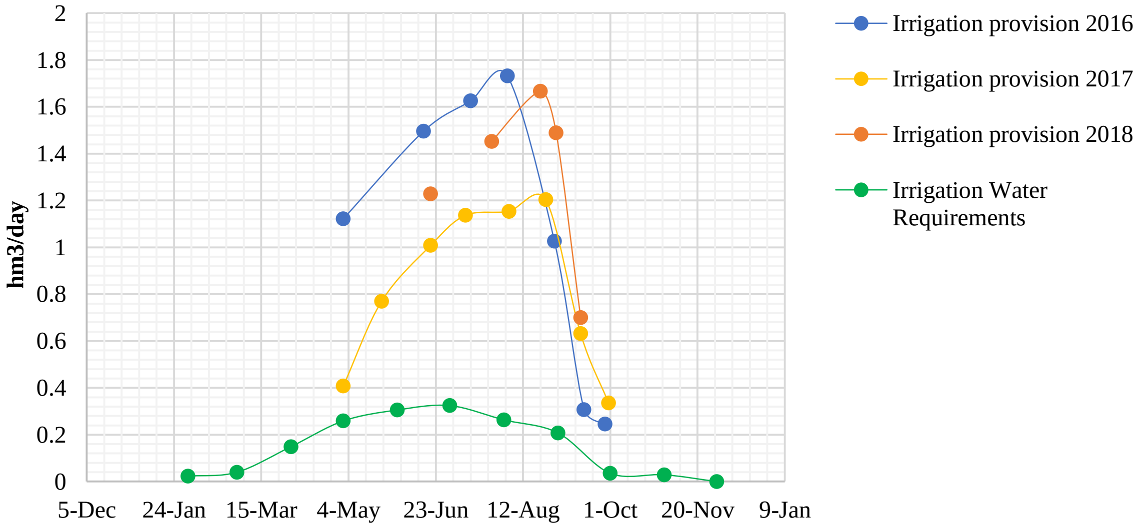

Figure 4. Daily irrigation water flows and crop water requirement.

The amount of groundwater consumed was then calculated. Farmers' assessed rates were deemed more credible and representative than those of local stakeholders due to their lower variability (Table 3). The water requirements of the four main crops were calculated separately for each spatial unit, distinguishing between surface water and groundwater based on the given rates. Groundwater consumption for citrus, alfalfa, kiwi, and olive trees was estimated at 58%, 86%, 15%, and 7% of their respective water requirements. The updated estimations were used to determine the allocation of water requirements between the collective network and the subsurface potential, as shown in Table 4. The now separated water requirements, of the crops are again contrasted with the measurements of the collective irrigation network (Figure 5).

Table 4. Distribution of water needs between the collective network and the underground water resources.

Months	Crop irrigation requirements (hm^3)	Collective irrigation water (% of the total CWR)	Drilling water (% of the total CWR)
January	0.0	0.0	0.0
February	0.7	62.5	37.5
March	1.2	63.0	37.0
April	4.5	63.1	36.9
May	7.8	61.2	38.8
June	9.2	58.5	41.5
July	9.7	56.2	43.8
August	7.9	57.7	42.3
September	6.2	58.1	41.9
October	1.1	58.1	41.9
November	0.9	61.9	38.1
December	0.0	0.0	0.0

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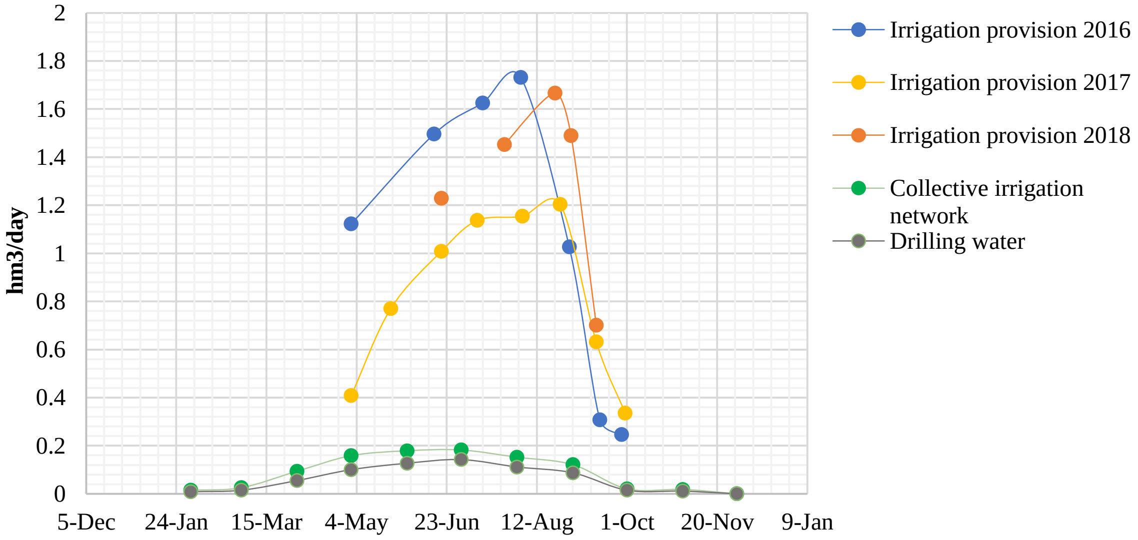

Figure 5. Daily irrigation water flows and crop water requirement (surface and underground water requirement).

4. Discussion

Despite the abundance of crops found in the plain of Arta, we observe that only four of them occupy 84% of the plain. Almost 1/3 of the plain is made up of citrus fruit crops, which is to be expected as the area has been known for its production for many decades. Citrus fruit was once an important source of profit and a processing product, as the area was home to juice and packaging facilities, providing employment and income. Nowadays, many citrus fields (mainly oranges) have been abandoned due to a significant reduction in profit margins.

Kiwi, with a covering rate of up to 17%, ranks as the fourth most water-intensive crop. Given the dynamics of kiwifruit in the region in recent years, there are serious concerns. The elevated selling costs from past years, attributed to heightened export operations, have played a significant role in this. Over the past two years, a disease impacting kiwifruit in Italy led to a significant rise in sales and profitability for Arta growers, motivating additional producers to switch to cultivating this crop. However, kiwifruit requires high capital investment and is very demanding in terms of water and energy (refrigeration maintenance, borehole pumps, etc.). The expansion of kiwifruit cultivation should be studied in terms of the carrying capacity of the region's resources, the profit margin of producers, and the trend in demand. The cultivation of yellow kiwifruit, a crop that is equally demanding in terms of capital and resources, has now been launched, with a selling price more than double that of green kiwifruit, and a growing demand on the world market, setting new objectives and challenges for local producers.

In conducting the qualitative survey, a wide variation in the responses given by local stakeholders was observed. In addition, four out of sixteen participants did not provide responses due to their inability to estimate the requested percentages. On the other hand, the estimates of the farmers showed little variation, demonstrating that their experience can contribute to providing useful information. The major crops of the plain are irrigated to a significant extent by drilled water. Kiwi cultivation is based on underground water resources. This is probably also due to the fact that it is a crop with high water requirements almost all year. The producer therefore clearly cannot rely solely on surface water for irrigation as the network is only operational from April to September and, as mentioned above, in remote areas the water is not sufficient to meet the needs. In addition, kiwi and citrus are tree crops that are highly sensitive to frost and for which, during the winter months, anti-freezing practices are applied, including water sprinkling, making borehole drilling a prerequisite for their care.

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The entire area of 9184.63 ha covered by the examined crops requires 49.1 hm^3 of water annually. After turning the results into a daily step and comparing them with the daily irrigation flow measurements, it was discovered that the water potential in the area above the predicted requirements and that the demand varies in line with the supply. In terms of seasonality of demand, the summer months have the highest demand, while the December and January rainfall provide the required quantities. However, given that irrigation flows are reported at the water intake points and that the network consists primarily of earthen open pipes, significant water losses are anticipated during its transport from the source to the agricultural land, estimated to be between 30 and 60% [55].

Conclusions

According to the findings of the present study, the Arta plain has a positive water balance, with the amount of available water exceeding the demand, even taking into account the highest possible rate of losses. In quantitative terms, the estimated annual irrigation needs were determined at 49,1 hm^3, while the quantities of water entering the collective irrigation network exceed 130 hm^3. However, despite the hydrological sufficiency, it is estimated that 41.1% of the water requirements are fulfilled via boreholes, which leads to higher energy consumption, increased agriculture costs, and raises worries about increasing waterlogging issues.

An important factor in the poor management of the resource is the public irrigation network, which was established some 60 years ago and has undergone few improvements since then. The operation of the network (quantity distributed and operating hours) is subject to the decisions of the electricity company that manages the dam in the area, which makes it difficult to plan the irrigation of crops. The proper management of the available quantity of irrigation water is also hampered by the fixed charges per area cultivated rather than per quantity consumed, which in some cases leads to waste of the resource. Moreover, as observed during the conduct of the present study, the 'legacy' practices and irrigation systems applied in the plain of Arta mostly lead to significant wastage.

The present study was based on the official census of cultivated land, excluding forest land, land under renewable energy sources, fallow land, nurseries, and greenhouse crops. The area on the basis of which water needs have been estimated is 9197.06 ha. The total potential area of the plain is estimated at over 20,000 ha. Given its size, hydrological potential, and soil fertility, the area has great potential for development. A study on future climate scenarios and projected water availability combined with the carrying capacity of the land in the region would be of great benefit in developing strategies. Improving the irrigation water distribution network and the irrigation practices applied seems to be a one-way street for the reconstitution and sustainability of the agricultural sector. The predominance of tree crops on the plain hinders the adoption of new crops. Therefore, the establishment of cooperatives, continuous information for farmers on the implementation of new environmentally oriented practices, and securing farm income through subsidized programs could contribute to the long-term development of the area.

In the absence of the necessary data and measurements, the assessments of the present study indicate that water scarcity and extensive borehole drilling are mostly associated with the management of existing water resources. To verify the appraisals, developing a contemporary water usage monitoring network seems essential. Managing water resources is a primary responsibility for restructuring the plain and increasing its potential. Improving water efficiency in agriculture aims to improve long-term food production capacity and ecosystem resilience. Strategic planning based on improving water management should not restrict agricultural development but should be a point of convergence between profitability, social equity, and environmental preservation.

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors did not report any potential conflict of interest.

Consent for Publication

The publication of this manuscript has been authorized by all of the authors.

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