Interreg
Balkan-Mediterranean
European Regional Development Fund
Re-Source

Re-Source - Providing services for management of natural resources

D3.3.2
Present state & end user requirements analysis

Re-Source

WP3

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Providing Services for Management of Natural Resources

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Balkan-Mediterranean
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1. Introduction

World population is expected to increase from 7.7 billion people in 2019 to 8.5 billion people by 2020 (United Nations, 2019), with a parallel increase of 50–100% in food demand by the middle of this century (Baulcombe et al., 2009). Meanwhile, between 2011-13, when the world population was still 7 – 7,2 billion people, approximately 842 million people «were estimated to be suffering from chronic hunger» (FAO et al., 2013). Mullan and Haqq-Misra, (2019) argued that a «doomsday» of human civilization due to the mismatch between food demand and food availability is unlike to happen by 2100, but they assumed that the crops' yield will continue to increase into the future similarly to the trend observed between the years 1950 and 2010, when an almost 0.038 t/ha/y yield increase was recorded (USDA, 2013). For this to happen, agriculture sector should continuously integrate in the production processes, any novel products or services that could potentially increase the annual planet's yield production.

It is well known that one of the most important limiting factors for the achievement of optimum crop production is water scarcity (Zamani et al., 2019; Linker et al., 2016). At the moment, irrigation is accountable for the 51.4% and 59% of the total fresh water consumption in USA and EU respectively (EEA, 2019; Maupin et al., 2014), while the water demand on the agriculture sector is expected to further increase up to 30% by 2030 (Beddington, 2009). Moreover, the ongoing climate change impact on rainfall events severity is expected to result in a substantial loss of water through runoff, imposes an extra threat to ground water renewable resources (Resende et al., 2019; Li et al., 2018).

Recently, a number of irrigation optimization algorithms have been developed and proposed (Mazarei et al., 2020; Li et al., 2018, Tsakmakis et al., 2017; Linker et al., 2016) as tools for maximizing the crop water productivity (Carracelas et al., 2019) or minimizing its' vice versa water footprint (Chukalla et al., 2015). In other words, these algorithms aim to derive an irrigation schedule which achieves the optimum crop yield per cubic meter of water consumed by the plants throughout their cultivation circle. Nevertheless, these algorithms are still not widely used by the farmers, either because their performance is poor or just because they are too complicated to be used by them. In this scope, Re-Source aims to offer a simple and reliable solution for irrigation scheduling (in terms of amount and time), bridging the gap between existing technology - scientific knowledge and the end users, namely farmers.

In the case of Greece, the potential benefits of the Re-Source irrigation scheduler implementation will be evaluated in the Region of Thessaly. For this reason, a thorough research was conducted regarding data related to irrigation systems, water consumption, water needs, available water bodies, hydrologic conditions and weather conditions, composing a picture of the current situation in the region. The gathered data are presented in this report.

2. Raw data and information

2.1. The Greek Study area – Region of Thessaly

The Region of Thessaly is located in central Greece (Figure 1), covering an area of approximately 14,036.64 km^2.

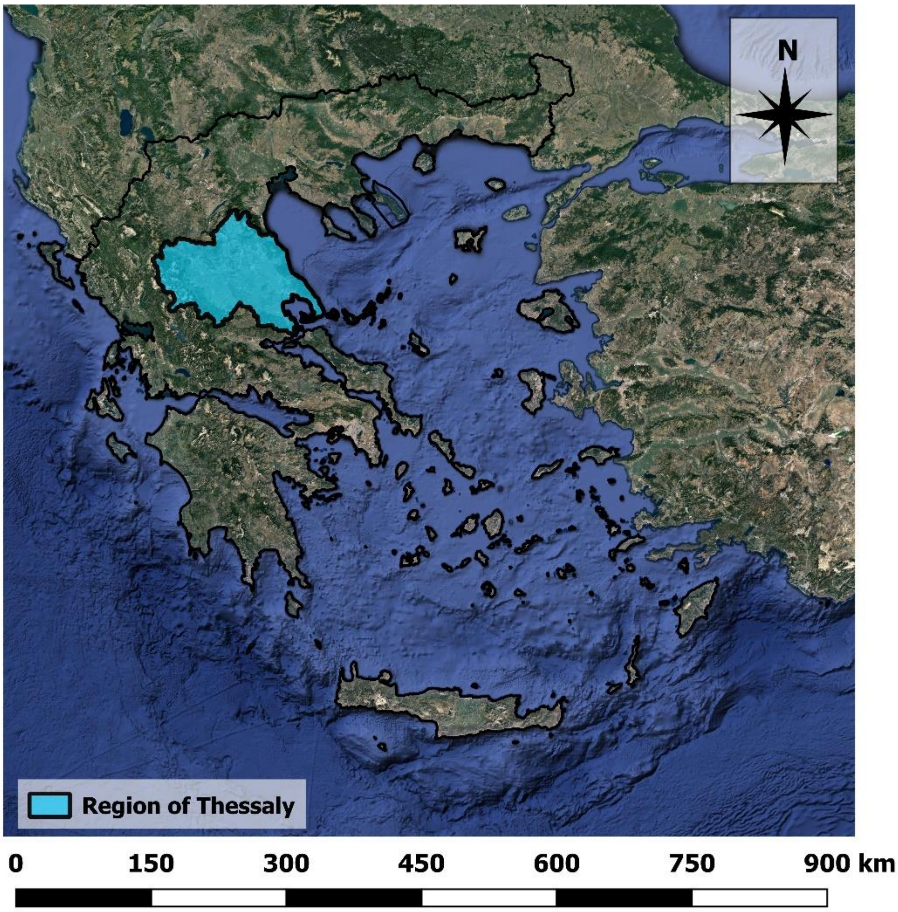

Figure 1. Geographical borders of Region of Thessaly within Greece.

Through the latest reform of local-authorities infrastructure (Kallikratis – 2010), Region of Thessaly was sub-divided into 5 Regional Units and 25 Municipalities. According to the 2011 National Demographic survey, the resident population of the Region is estimated to be 732,762 people.

The socio-economic activities within the Region of Thessaly classifies it as the third most productive region in the country with a gross value added fluctuating between 8.000,00 – 8.100,00 million euros (ELSTAT, 2019). Among the productive sectors in the area, agriculture stands as one of the most significant, producing substantial amounts of cotton, maize, cereals, legumes etc, covering the country domestic needs, but at the same time providing the country exports with high quality products.

As a result, agriculture sector occupies a significant portion of the available land within the region. It is estimated that the occupied area is approximately equal to 4.067,3 km^3. A descriptive distribution of the land uses within the region is presented in Table 1.

Table 1. Proportional land use distribution within Region of Thessaly.

Land Use	Percentage of the Total Land Area
Urban	< 1%
Pastures	19.4%
Agriculture	37.9%
Forest	22.7%
Roads/Water bodies	4.2%

Agriculture is estimated to consume annually roughly 1.303 hm^3 of water, almost 91.8% of the total water amount consumed in the region. Table 2 shows the estimated water consumption of the major socio-economic activities within the region.

Table 2. Annual water consumption from major socio-economic activities within the Region of Thessaly.

Sector	Water Consumption (hm^3)	As a Portion of the Total Consumed Water (%)
Irrigation	1,306	91.8
Domestic use	94	6.6
Livestock	13	0.9
Industry	9	0.6
Total	1,422	-

2.2. National Water District EL08

It is noteworthy that the geographical borders of Region of Thessaly are almost matching with the borders of National Water District EL08, with just few geographical parts of the geographical region (mainly west - northwest) belonging to other water districts (Figure 2). The EL08 has a simple geomorphological picture with mountainous areas in the perimeter of the district and the majority of the plain areas located in the central part. The EL08 covers an area of roughly 13,377 km^2, a marginally smaller area than that of the geographical region.

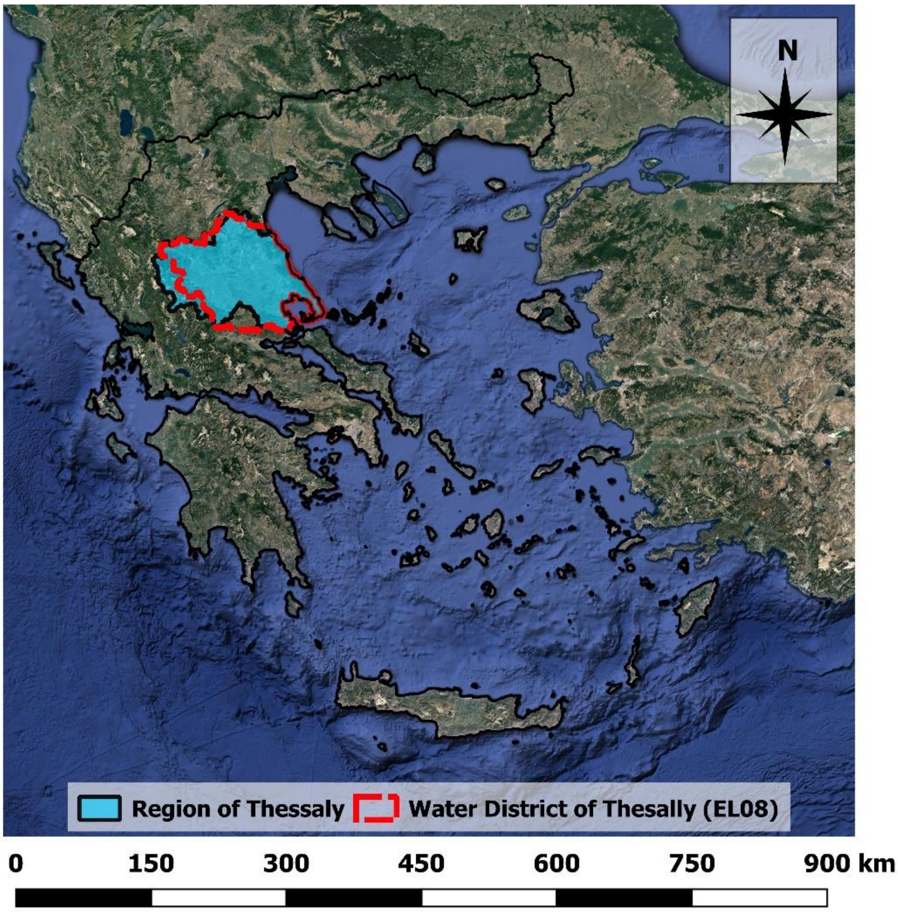

Figure 2. Geographical borders of Region of Thessaly and National Water District EL08 within Greece.

According to National Water Committee decision 706/16-07-2010 (Government Gazette B' 1383/02.09.2019 & Government Gazette B' 1572/28.09.2010), the EL08 is divided in two main river basins, the basin of Pineios river (EL0816) and the basin of Almiros-Pelion streams (EL0817) (Figure 3). The Pineios river basin covers an area of 11.062 km^2, while the basin of Almiros-Pelion river covers a substantially smaller area equal to 2.078 km^2.

Complying with INSPIRE directive (2007) and the Water Framework Directive (2000/60/EC), the competent authorities have further divided the main river basins into sub-river basins. According to this sub-division Pineios river basin was divided in 9 sub-river basins, while Almiros-Pelion basin into 25 sub-river basins. Table 3 presents the sub-river basins that belong to each main river basin with their INSPIER ID, while Figures

4 and 5 illustrate the geographical borders of sub-river basins within Pineios river basin and Almiros-Pelion basin respectively. As it is illustrated in Figure 4 and resulting from Table 3 data, Pineios river basin is consisted of five small sub-basins (2067, 2065, 2062, 2069, 2154) and four main sub-basins (2066, 2077, 2070, 2061), with the latter to cover more than 90% of the total basin area. The small sub-basins delineate geographical zones with unique relief (e.g. plateaus), located in mountainous areas.

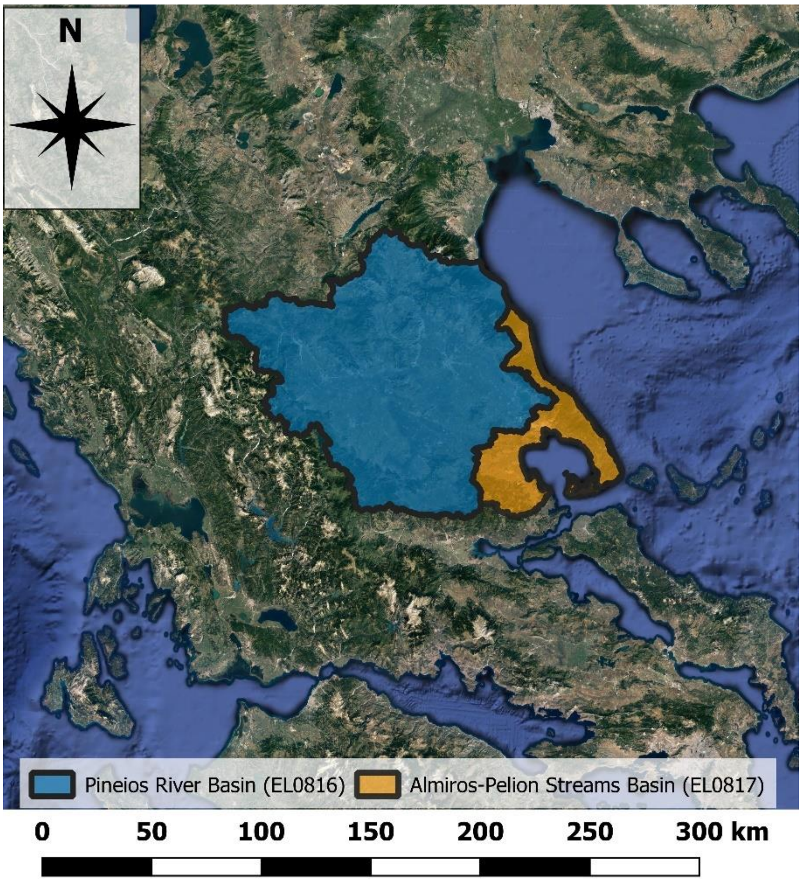

Figure 3. Pineios River and Almiros-Pelion river basins geographical borders.

Table 3. Main river basins division into sub-river basins in water district EL08.

River Basin	Sub-River Basin INSPIRE ID	Area (km^2)
EL0816	GR.CWA.HY.WTRSHDA.2067	19.87
Pineios	GR.CWA.HY.WTRSHDA.2065	66.43
	GR.CWA.HY.WTRSHDA.2062	150.25
	GR.CWA.HY.WTRSHDA.2061	1,913.59
	GR.CWA.HY.WTRSHDA.2066	5,888.73
	GR.CWA.HY.WTRSHDA.2069	148.02
	GR.CWA.HY.WTRSHDA.2070	1,663.47
	GR.CWA.HY.WTRSHDA.2077	1,045.73
	GR.CWA.HY.WTRSHDA.2154	167,80

EL0817	GR.CWA.HY.WTRSHDA.2068	136.99
Almiros-Pelion	GR.CWA.HY.WTRSHDA.2071	88.94
	GR.CWA.HY.WTRSHDA.2072	28.10
	GR.CWA.HY.WTRSHDA.2073	11.65
	GR.CWA.HY.WTRSHDA.2074	33.82
	GR.CWA.HY.WTRSHDA.2076	181.80
	GR.CWA.HY.WTRSHDA.2079	20.30
	GR.CWA.HY.WTRSHDA.2080	20.16
	GR.CWA.HY.WTRSHDA.2082	24.09
	GR.CWA.HY.WTRSHDA.2083	204.40
	GR.CWA.HY.WTRSHDA.2155	13.88
	GR.CWA.HY.WTRSHDA.2150	11.11
	GR.CWA.HY.WTRSHDA.2149	23.41
	GR.CWA.HY.WTRSHDA.2128	150.47
	GR.CWA.HY.WTRSHDA.2084	29.72
	GR.CWA.HY.WTRSHDA.2081	61.78
	GR.CWA.HY.WTRSHDA.2078	119.20
	GR.CWA.HY.WTRSHDA.2132	27.63
	GR.CWA.HY.WTRSHDA.1082	39.84
	GR.CWA.HY.WTRSHDA.2130	139.04
	GR.CWA.HY.WTRSHDA.2134	191.87
	GR.CWA.HY.WTRSHDA.4218	217.57
	GR.CWA.HY.WTRSHDA.2138	94.88
	GR.CWA.HY.WTRSHDA.2144	173.23
	GR.CWA.HY.WTRSHDA.2137	32.65

The unique geomorphology of Alimos-Pelion basin is highlighted through its' division process into sub-basins. By observing Figure 5, and the way that the sub-basins have been delimited, it is obvious that the area relief is characterized by intense alterations. A striking case is the peak of Pelion mountain which reaches up to 1,473 m height, is just 7 km far away from the sea level in its' east side (Aegean Sea) and is 12 km far away from the sea level in its' west side (Pagasetic Gulf). The larger sub-basins in Alimos-Pelion basin do not exceed the 220 km^2, while the majority of them (sixteen) cover an area smaller than 100 km^2 (Table 3).

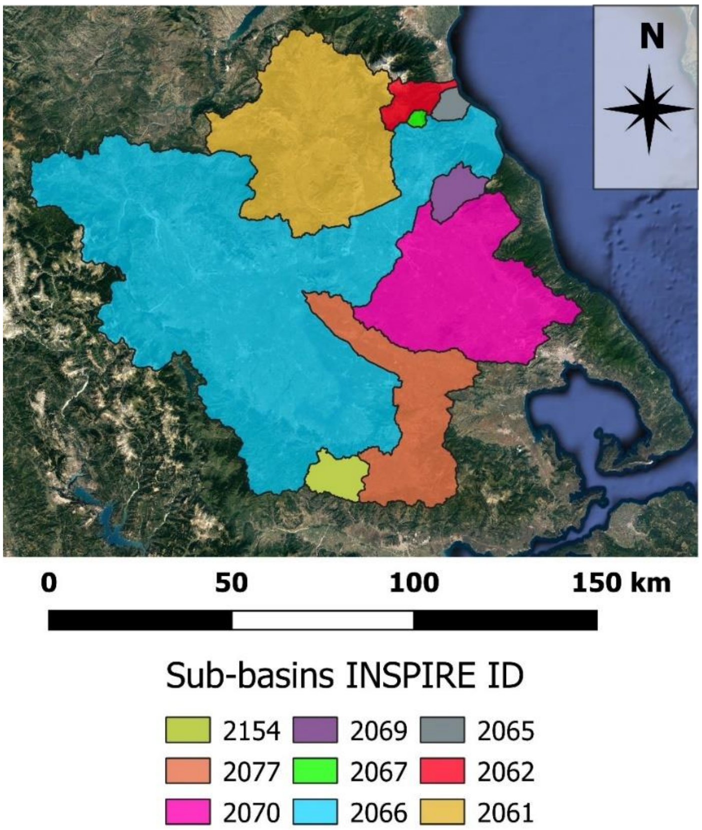

Figure 4. Pineios river basin (EL0816) sub-river basins.

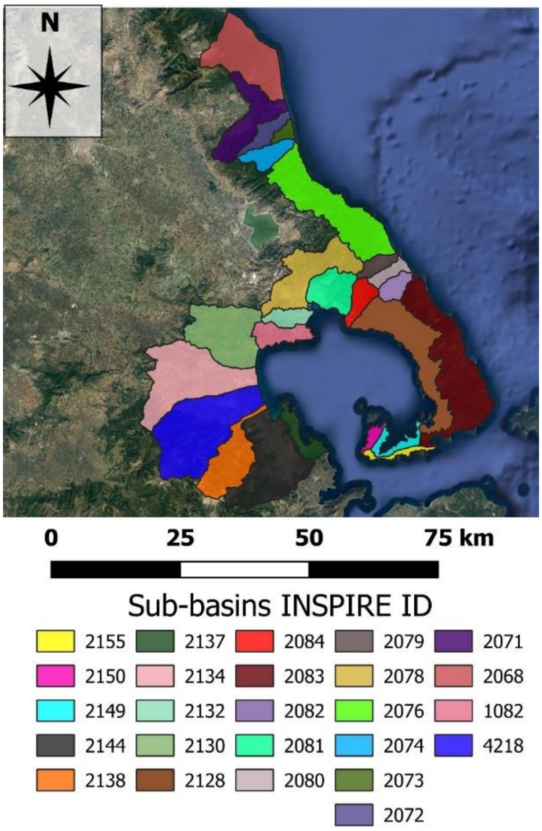

Figure 5. Alimos-Pelion basin (EL0817) sub-river basins.

2.3. Water bodies

2.3.1. Surface water bodies

According to Commission Decision 213/480/EU, the rivers of Mediterranean countries are classified into five types. The characteristics of each type are described in Table 4. Moreover, based on Water Framework Directive (2000/60/EC), the surface water bodies within the river basin districts are categorized as natural rivers, lakes, transitional waters or coastal waters, or as artificial surface water bodies or as heavily modified surface water bodies.

The Water Directorate of Thessaly has been identified 72 river water bodies (WB) within EL08. The identified rivers that belong to all types, but type R-M1 (in total 55 rivers) are illustrated in Figure 6. Additionally, descriptive data about the individual rivers' category, type and hydrological characteristics are presented in Table 5.

Table 4. River Classification according to European Commission Decision 2013/480/EU.

Type	River characterization	Catchment (km^2)	Geology	Flow regime
R-M1	Small Mediterranean streams	< 100	Mixed (except silicious)	Highly seasonal
R-M2	Medium Mediterranean streams	100 – 1,000	Mixed (except silicious)	Highly seasonal
R-M3	Large Mediterranean streams	1,000-10,000	Mixed (except silicious)	Highly seasonal
R-M4	Mediterranean mountain streams		Non -silicious	Highly seasonal
R-M5	Temporary streams			Temporary

As it is illustrated in Figure 6, the Pineios River basin is dominated by the presence of Pineios river. The latter starts its course in the north western highlands of EL0816, moves southwardly for roughly 32 kilometers and then turns right, following an eastward and slightly northward course for another 95 km, creating moderate meanders, until reaching its delta in Aegean Sea at the north east of the basin. The main Pineios river course is divided into 12 sections represented by the index numbers 5, 10, 30, 31, 32, 33, 36, 37, 45, 46, 47 and 48 in Figure 6. All of the sections belong to Mediterranean river type R-M3, but they differ in length and runoff capacity (Table 5). It is estimated that the annual runoff potential of Pineios river in its delta is roughly 3,165.46 hm^3.

On its way from the mountains to the sea, Pineios river, receives additional water from a substantial number of smaller rivers, which form a dense network specially in the west-southwest part of the basin. The springs of these rivers are located in the north, west and south mountains dominating the perimeter of the EL0816. As they descend from the mountains, it is common that the individual rivers merge to form bigger water bodies before they finally pour their waters in the main Pineios river course. The most significant enrichment points of Pineios river are the points where the river cross the rivers with index numbers 1, 4, 29, and 44 (Figure 6), with annual runoff potentials equal to 304.88 hm^3, 259.86 hm^3, 935.16 hm^3 and 465.47 hm^3, respectively.

Just 5 river water bodies are identified in Almiros-Pelion Strems basin, with their annual runoff potential to be well below 50 hm^3.

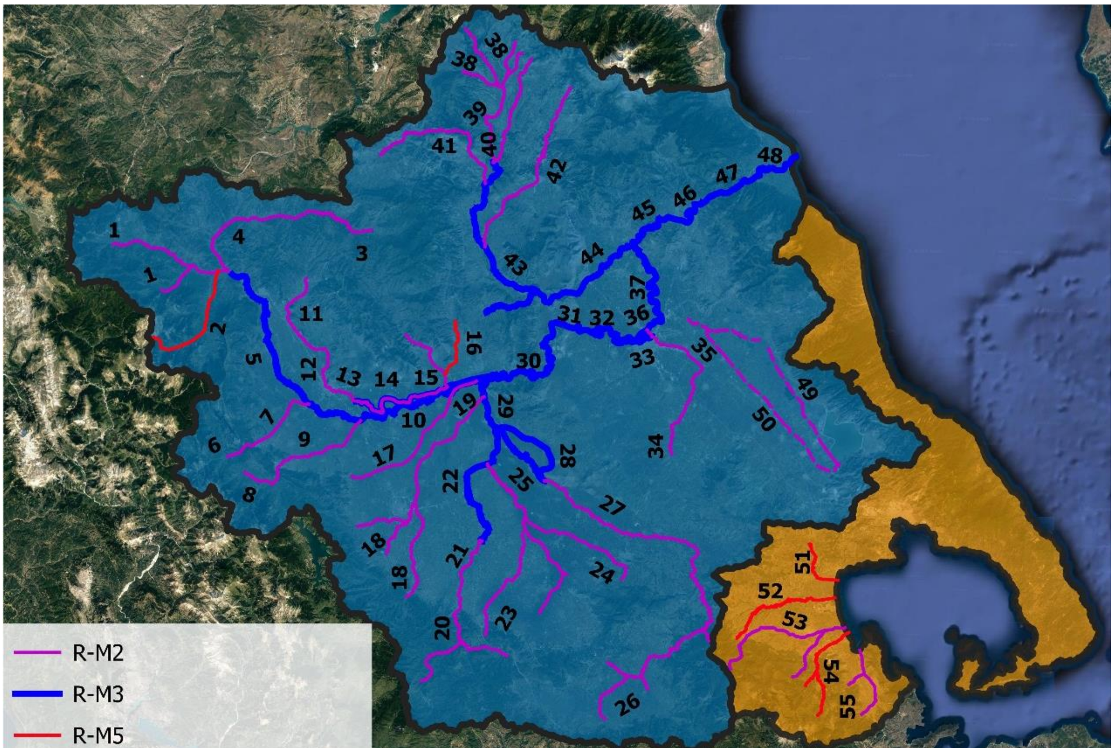

Figure 6. Illustration of river water bodies and their corresponding type (Commission Decision 2013/480/EU) in Pineios River and Almiros-Pelion Streams basins.

Table 5. Thessaly Water District (EL08) river water bodies data.

River Figure6 Index	River National ID	Surface Water Body Category	Length (m)	Watershed Area (km^2)	Mean Annual Runoff (hm^3)	WB Type
1	EL0816R000218054N	NSWB	43.8	343.83	304.88	R-M2
2	EL0816R000218155N	NSWB	20.3	165.89	99.24	R-M5
3	EL0816R000200060N	NSWB	11.9	104.38	62.42	R-M2
4	EL0816R000200056N	NSWB	37.0	216.69	259.86	R-M2
5	EL0816R000200053N	NSWB	36.0	187.54	911.34	R-M3
6	EL0816R000216052N	NSWB	8.4	137.58	129.30	R-M2
7	EL0816R000216051N	NSWB	16.1	164.97	236.27	R-M2
8	EL0816R000212049N	NSWB	5.5	154.91	97.76	R-M2
9	EL0816R000212048N	NSWB	19.6	93.05	132.91	R-M2
10	EL0816R000200039N	NSWB	44.2	32.13	1,398.52	R-M3
11	EL0816R000210047N	NSWB	25.6	209.32	66.67	R-M2
12	EL0816R000210046N	NSWB	3.1	51.00	83.16	R-M2
13	EL0816R000210045H	HMSB	3.9	5.20	85.12	R-M2
14	EL0816R000210042N	NSWB	30.2	160.47	211.98	R-M2
15	EL0816R000210143N	NSWB	27.3	209.58	71.91	R-M2
16	EL0816R000210144N	NSWB	12.3	105.02	26.43	R-M5
17	EL0816R000208040N	NSWB	32.5	159.44	94.87	R-M2
18	EL0816R000206125N	NSWB	63.3	457.93	176.82	R-M2
19	EL0816R000206124N	NSWB	25.5	147.63	221.10	R-M2
20	EL0816R000206231H	HMSB	10.6	33.03	121.30	R-M2
21	EL0816R000206230H	NSWB	19.3	26.92	129.37	R-M2
22	EL0816R000206226N	NSWB	25.8	137.68	384.96	R-M3
23	EL0816R000206228N	NSWB	25.0	166.43	50.29	R-M2
24	EL0816R000206229N	NSWB	20.3	517.62	153.31	R-M2
25	EL0816R000206227N	NSWB	17.7	35.81	214.33	R-M2
26	EL0816R000206038N	NSWB	66.5	567.08	140.69	R-M2
27	EL0816R000206037N	NSWB	29.3	349.87	238.51	R-M2
28	EL0816R000206036N	NSWB	25.00	221.99	299.47	R-M3
29	EL0816R000206023N	NSWB	11.5	99.49	935.16	R-M3
30	EL0816R000200022N	NSWB	29.8	320.28	2,418.43	R-M3
31	EL0816R000200021N	NSWB	4.2	8.34	2,420.54	R-M3
32	EL0816R000200020N	NSWB	20.6	125.05	2,441.20	R-M3
33	EL0816R000200016A	ASWB	2.3	0.17	0.03	R-M1
34	EL0816R000204019N	NSWB	16.9	208.29	35.53	R-M2
35	EL0816R000204018N	HMSB	16.7	384.08	103.31	R-M2
36	EL0816R000200017H	HMSB	6.6	7012	2,545.61	R-M3
37	EL0816R000200015N	NSWB	27.5	177.05	2,572.30	R-M3
38	EL0816R000202014N	NSWB	33.4	192.02	54.23	R-M2
39	EL0816R000202013N	NSWB	17.6	89.24	79.43	R-M2
40	EL0816R000202512N	NSWB	18.2	173.15	48.90	R-M2
41	EL0816R000202411N	NSWB	26.1	146.88	41.48	R-M2
42	EL0816R000202310N	NSWB	43.9	353.99	76.17	R-M2
43	EL0816R000202007N	NSWB	36.5	547.33	422.26	R-M3
44	EL0816R000202006N	NSWB	23.0	254.68	465.47	R-M3
45	EL0816R000200005N	NSWB	10.2	63.57	3,061.37	R-M3
46	EL0816R000200004N	NSWB	11.8	120.95	3,106.27	R-M3
47	EL0816R000200003N	NSWB	8	26.42	3,116.08	R-M3
48	EL0816R000201002N	NSWB	13.9	130.6	3,165.46	R-M3
49	EL0816R000000062A	ASWB	37.9	275.20	80.34	R-M2
50	EL0816R000000064A	ASWB	36.2	187.54	136.15	R-M2
51	EL0817R000701068N	NSWB	12.5	131.96	36.33	R-M5
52	EL0817R000901069N	NSWB	18.2	118.6	28.63	R-M5
53	EL0817R001101070N	NSWB	24.3	160.09	43.63	R-M2

54	EL0817R001301071N	NSWB	22.3	94.8	27.89	R-M5
55	EL0817R001501072N	NSWB	16.4	150.37	41.38	R-M2

NSWB= Natural surface water bodies; ASWB= Artificial surface water bodies; HMSB= heavily modified surface bodies

The location of lake surface water bodies in EL08 water district are illustrated in Figure 7. As it is depicted in the figure there are 6 artificial lakes within the district, all of them within the borders of Pineios River basin. The largest lake is lake Karla covering an area of roughly 34.92 km^2, followed by the artificial lake Smokovou with an estimated surface equal to 9.91 km^2. The rest of the lakes are pretty small, covering areas smaller than 2 km^2. The later are water reservoirs created almost exclusively for irrigation purposes. It is noteworthy that 4 out of 6 lakes are within sub-river basin with inspire ID 2070 (Figure 4). Descriptive, available data for each lake are presented in Table 6.

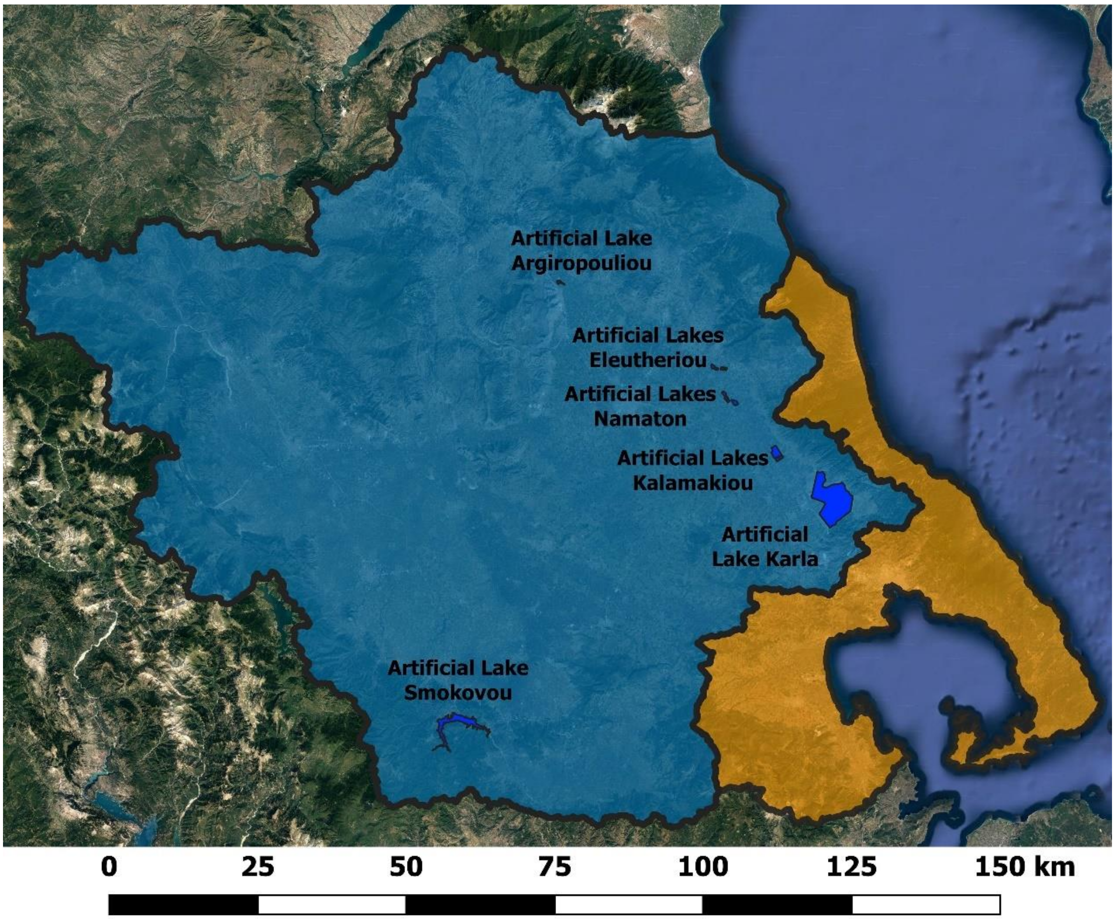

Figure 7. Illustration of lakes in Pineios River and Almiros-Pelion Streams basins.

Table 6. Thessaly Water District (EL08) lake water bodies data.

Name	National ID	Surface Water Body Category	Area (km^2)	Mean Depth (m)
Lake Karla	EL0816L000000002H	HMSB	34.92	< 15
Lake Kalamakiou		HMSB	2.70	< 3
Lake Namatos		HMSB	1,42	< 3
Lake Eleutheriou		HMSB	0,89	< 3
Lake Argiropouliou	EL0816L000000001H	HMSB	0.49	< 3
Lake Smokovou	EL0816RL00206201H	HMSB	9.91	< 15

NSWB= Natural surface water bodies; ASWB= Artificial surface water bodies; HMSB= heavily modified surface bodies

The available descriptive data regarding annual water withdrawals from the individual rivers and lakes are presented in Table 7. Specifically, the annual water withdrawals from EL0816 basin rivers are estimated to be approximately 1,673.7 million m^3, while from the basin lakes 65 million m^3. On the contrary, the annual withdrawals from Alimos-Pelion Streams basin is estimated to be significantly lower just 0.7 million m^3.

Table 7. Estimated annual water withdrawals from the rivers and lakes of Thessaly Water District (EL08).

River Figure 6 Index	River National ID	Potential Annual Withdrawals ($\times 10^6$ m^3/y)	Withdrawal Purpose	Annual Withdrawal Volume (% of the mean annual runoff)	Summer Withdrawal Volume (% of the mean summer runoff)	Intense of Withdrawal Pressure
Pineios River Basin (EL0816) Rivers						
1	EL0816R000218054N	0.30	Irrigation	0.10%	0.00%	Low
2	EL0816R000218155N	1.32	Irrigation	1.33%	0.00%	Low
3	EL0816R000200060N	0.11	Irrigation	0.18%	0.00%	Low
4	EL0816R000200056N	2.53	Irrigation	0.97%	0.00%	Low
5	EL0816R000200053N	97.10	Irrigation	10.65%	32.56%	Low
6	EL0816R000216052N	0.08	Irrigation	0.06%	0.00%	Low
7	EL0816R000216051N	43.61	Irrigation	18.46%	42.02%	Low
8	EL0816R000212049N	0.01	Irrigation	0.01%	0.00%	Low
9	EL0816R000212048N	25.56	Irrigation	19.23%	59.11%	Low
10	EL0816R000200039N	276.68	Irrigation	19.78%	56.43%	Low
11	EL0816R000210047N	13.37	Irrigation	21.56%	34.59%	Low
12	EL0816R000210046N	26.70	Irrigation	32.11%	77.71%	Medium
13	EL0816R000210045H	32.93	Irrigation	38.69%	77.92%	Medium
14	EL0816R000210042N	71.22	Irrigation	33.60%	77.80%	Medium
15	EL0816R000210143N	25.69	Irrigation	35.72%	77.87%	Medium
17	EL0816R000208040N	66.65	Irrigation	70.25%	77.69%	High
18	EL0816R000206125N	34.08	Irrigation	19.28%	62.16%	Low
19	EL0816R000206124N	45.70	Irrigation	20.67%	66.75%	Low
20	EL0816R000206231H	83.15	Irrigation	68.55%	90.00%	High
21	EL0816R000206230H	93.46	Irrigation	72.24%	95.04%	High
22	EL0816R000206226N	201.06	Irrigation	52.23%	90.00%	High
23	EL0816R000206228N	29.82	Irrigation	59.30%	66.41%	High
24	EL0816R000206229N	50.00	Irrigation	32.61%	66.70%	Medium
25	EL0816R000206227N	61.03	Irrigation	28.47%	66.59%	Low
26	EL0816R000206038N	1.80	Irrigation	1.28%	0.00%	Low

27	EL0816R000206037N	34.69	Irrigation	14.55%	35.16%	Low
28	EL0816R000206036N	55.59	Irrigation	18.56%	45.78%	Low
29	EL0816R000206023N	421.98	Irrigation	45.12%	83.29%	Medium
30	EL0816R000200022N	437.15	Irrigation	18.08%	62.58%	Low
31	EL0816R000200021N	440.06	Irrigation	18.18%	62.96%	Low
32	EL0816R000200020N	468.18	Irrigation	19.18%	66.28%	Low
34	EL0816R000204019N	9.91	Irrigation	27.90%	50.73%	Low
35	EL0816R000204018N	48.42	Irrigation	46.87%	57.32%	Medium
36	EL0816R000200017H	516.60	Irrigation	20.29%	69.93%	Low
37	EL0816R000200015N	633.53	Irrigation	24.63%	85.11%	Low
44	EL0816R000202006N	44.81	Irrigation	9.63%	30.96%	Low
45	EL0816R000200005N	678.45	Irrigation	22.16%	83.12%	Low
46	EL0816R000200004N	680.62	Irrigation	21.91%	82.98%	Low
47	EL0816R000200003N	683.50	Irrigation	21.93%	82.78%	Low
Almiros-Pelion Streams Basin (EL0817) Rivers						
51	EL0817R000701068N	0.04	Irrigation	0.12%	1.25%	Low
52	EL0817R000901069N	2.94	Irrigation	10.28%	90.00%	Low
53	EL0817R001101070N	2.65	Irrigation	6.08%	64.18%	Low
54	EL0817R001301071N	2.59	Irrigation	9.28%	97.54%	Low
55	EL0817R001501072N	0.01	Irrigation	0.03%	0.28%	Low
Artificial Lakes						
-	EL0816L000000002H	0.11	Irrigation	0.32%	-	Low
-	EL0816L000000001H	1.74	Irrigation	38.79%	-	Medium
-	EL0816RL00206201H	64.65	Irrigation	99.46%	-	High

2.3.2. Sub-surface water bodies

The aquifer of Pineios River basin is divided into 27 groundwater systems. The borders of these systems are illustrated in Figure 8, while descriptive data about them are presented in Table 8. The area and shape of the delineated groundwater systems vary significantly, as the definition of their borders were based mainly on strictly geomorphological criteria. In general, the groundwater systems tend to be large, with simple shapes in the plain areas, whilst on the contrary exhibit complex shapes and cover small areas in the highlands. Moreover, a substantial difference exists in the mean annual enrichment of the groundwater systems, with some of them, like groundwater systems with index number 3, 7 and 18 (Table 8), to receive annually over 120 million cubic meters of water, while on the other hand systems like 8 and 16 receive less than 10 million cubic meters. These differences of the amount of groundwater systems' enrichment are attributed to the differences in their size, their geomorphology, their soil hydraulic characteristics, as well as the variation in the received annual precipitation height.

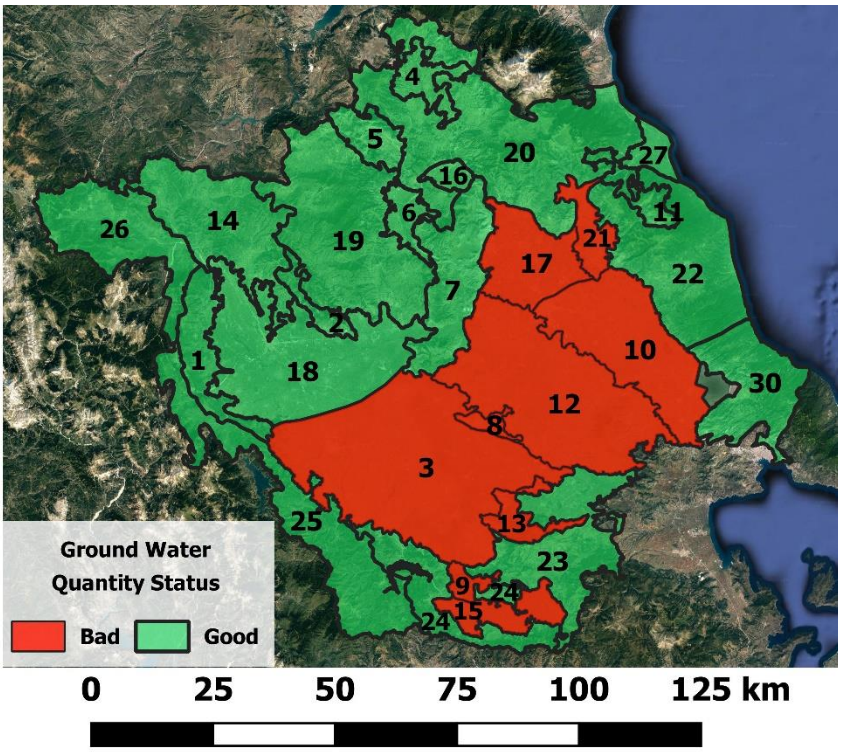

Figure 8. Groundwater systems borders and quantity status in the Water District of Thessaly (EL08).

However, the most striking difference among the individual groundwater systems is the pressure that is imposed to them, in the form of water withdrawals by human activities like crops' irrigation and cities water supply (Table 8). In some cases, the overexploitation that is imposed to the available groundwater systems, has as a result the degradation of them in terms of water quantity (Figure 8). For instance, the mean annual water withdrawals from groundwater systems with index number 3, 10 and 12, are well above the corresponding systems' mean annual enrichment (Table 8). Consequently, these systems are continuously under an intense pressure due to human activities and an overall threat to their sustainability is imposed. Looking closely to the Table 8 data regarding the annual withdrawals for irrigation and water supply purposes, it is obvious that the amount of water used for irrigation is overwhelmingly higher than that for water supply, with the latter to consume annually roughly 60.53 million cubic meters of water, while the corresponding amount for the former is estimated to 757.89 million cubic meters.

Five out of the six groundwater systems that the Almiros-Pelion Streams basin is divided in are considered to be in good quantity status (Table 8). Again, in this basin, the water withdrawals from the groundwater systems for crops' irrigation purposes (84.93×10^6 m^3) were found to be larger than that for water supply (19.58×10^6 m^3), but the difference is not so striking as in the case of Pineios River basin, due to the smaller portion of arable land in Almiros-Pelion Streams basin.

In conclusion, it is estimated that annually approximately 842.82 million cubic meters of water were pumped from EL08 groundwater bodies for irrigation purposes.

Table 8. Mean annual enrichment and withdrawals from groundwater systems in Thessaly Water District (EL08).

Groundwater System Figure 8 Index	Groundwater System Natural ID	Area (km^2)	Mean Annual Enrichment ($\times 10^6$ m^3/y)	Mean Annual Withdrawals ($\times 10^6$ m^3/y)	Irrigation ($\times 10^6$ m^3/y)	Water supply ($\times 10^6$ m^3/y)	Groundwater Body Quantity Condition
Pineios River Basin (EL0816) Groundwater Bodies							
1	EL0800010	219.34	55	5.54	3.61	1.93	Good
2	EL0800020	75.61	20	8.51	7.76	0.74	Good
3	EL0800030	1,261.98	140	145.21	141.74	3.47	Bad
4	EL0800040	116.89	23	12.87	12.35	0.52	Good
5	EL0800050	124.87	32	1.58	1.14	0.44	Good
6	EL0800060	86.69	16	11.86	11.13	0.73	Good
7	EL0800070	382.73	120	56.97	41.11	15.85	Good
8	EL0800080	37.11	9	9.36	9.10	0.25	Bad
9	EL0800100	42.22	10	6.40	6.00	0.40	Bad
10	EL0800110	578.18	60	88.52	84.23	4.29	Bad
11	EL0800120	94.82	27	1.32	1.19	0.13	Good
12	EL0800130	921.96	40	44.92	42.23	2.69	Bad
13	EL0800180	97.74	24	6.61	6.03	0.58	Bad
14	EL0800190	532.69	65	16.73	16.18	0.55	Good
15	EL0800200	146.01	30	12.34	12.13	0.22	Bad
16	EL0800210	45.18	5	2.10	1.44	0.66	Good
17	EL0800220	309.73	90	58.48	54.74	3.73	Bad
18	EL0800230	819.89	350	207.16	195.30	11.86	Good
19	EL0800240	854.12	40	10.86	8.89	1.97	Good
20	EL0800250	1,153.42	75	16.27	13.21	3.07	Good
21	EL0800260	113.67	20	14.66	24.22	0.44	Bad
22	EL0800270	648.21	90	42.73	41.05	1.68	Good
23	EL0800290	493.89	40	13.62	12.81	0.81	Good
24	EL0800300	314.92	25	5.11	4.00	1.11	Good
25	EL0800310	600.11	25	3.32	2.56	0.75	Good

26	EL0800320	439.45	50	4.49	2.83	1.66	Good
27	EL0800330	74.35	7	0.91	0.91	0.00	Good
Almiros-Pelion Streams Basin (EL0817) Water Bodies							
28	EL0800090	251.68	40	14.18	13.50	0.68	Good
29	EL0800140	268.51	50	28.14	26.36	1.78	Bad
30	EL0800150	375.58	90	2.09	1.60	0.49	Good
31	EL0800160	505.52	118	8.50	8.04	0.46	Good
32	EL0800170	589.17	80	39.65	27.07	12.58	Good
33	EL0800280	127.83	25	11.94	8.36	3.59	Good

2.4. Weather conditions

According to Koppen's classification, the Csa climate type (typical hot-summer Mediterranean climate) prevails in the area. The mean air temperature fluctuates between 16 and 17 ^{o}C, while the difference among daily maximum and daily minimum temperature can be well above 22 ^{o}C. The hottest months of the year are July and August and the coldest ones are January, February and December. Frost events are common and they usually occur between November and April.

Nevertheless, the air temperature does not show a similar pattern throughout the EL0816. The temperature is lower in the mountainous areas dominating the perimeter of the basin and shows increased values in the central plain areas. This is clearly depicted in Figure 9, which illustrates the reference evapotranspiration (ETo) distribution in the EL0816 basin and its sub-basins (Panagopoulos et al., 2014). The depicted values are the mean ETo values of the hydrological year (the time period from October 1st of one year to September 30th of the next) calculated with Hargreaves method for the years 1971-2020. The required data were obtained from meteorological stations scattered across the region. An interpolation algorithm, integrating relief corrections, was then implemented to obtain the distribution maps. Figure 9a illustrates the mean ETo values distribution for the entirety of the hydrological year, whilst Figure 9b the mean ETo values distribution for the time period from April 1st to September 30th, the period including the hottest months of the year. It is noteworthy that when considering the period April to September, the maximum ETo value is approximately 960 mm, just 300 mm less than the corresponding value for the whole hydrological year, showing that roughly 76% of the total annual evapotranspiration demands occur during this time period. Despite the anticipated differences in maximum and minimum ETo values in Figure 9a and Figure 9b, the ETo distribution pattern that is illustrated by the two figures is almost the same. The Figure 9 patterns indicate that the highest ETo values occur in the south-east part of sub-basin 2066, and the plain where sub-basin 2066 borders with sub-basins 2061 and 2070. On the other hand, the lowest ETo values are exhibited in the mountainous areas located at the north east of EL0816, in the junction of sub-basins 2154 and 2062. A representative example of an extreme ETo variation is the sub-basin 2061, where the small plain in sub-basin's southeast border shows ETo values almost 200 mm larger than that of the plateaus located in the center of the sub-basin, just 16 km away. However, it should be mentioned that considering the sub-basin 2066 and specifically the large plain that stretches in its northwest-southwest side, the ETo value can vary substantially, even within areas with similar altitude in the very same plain, up to 100 mm. A similar difference is observed between the lower southeast part and upper northwestern part of the 2070 sub-basin's plain.

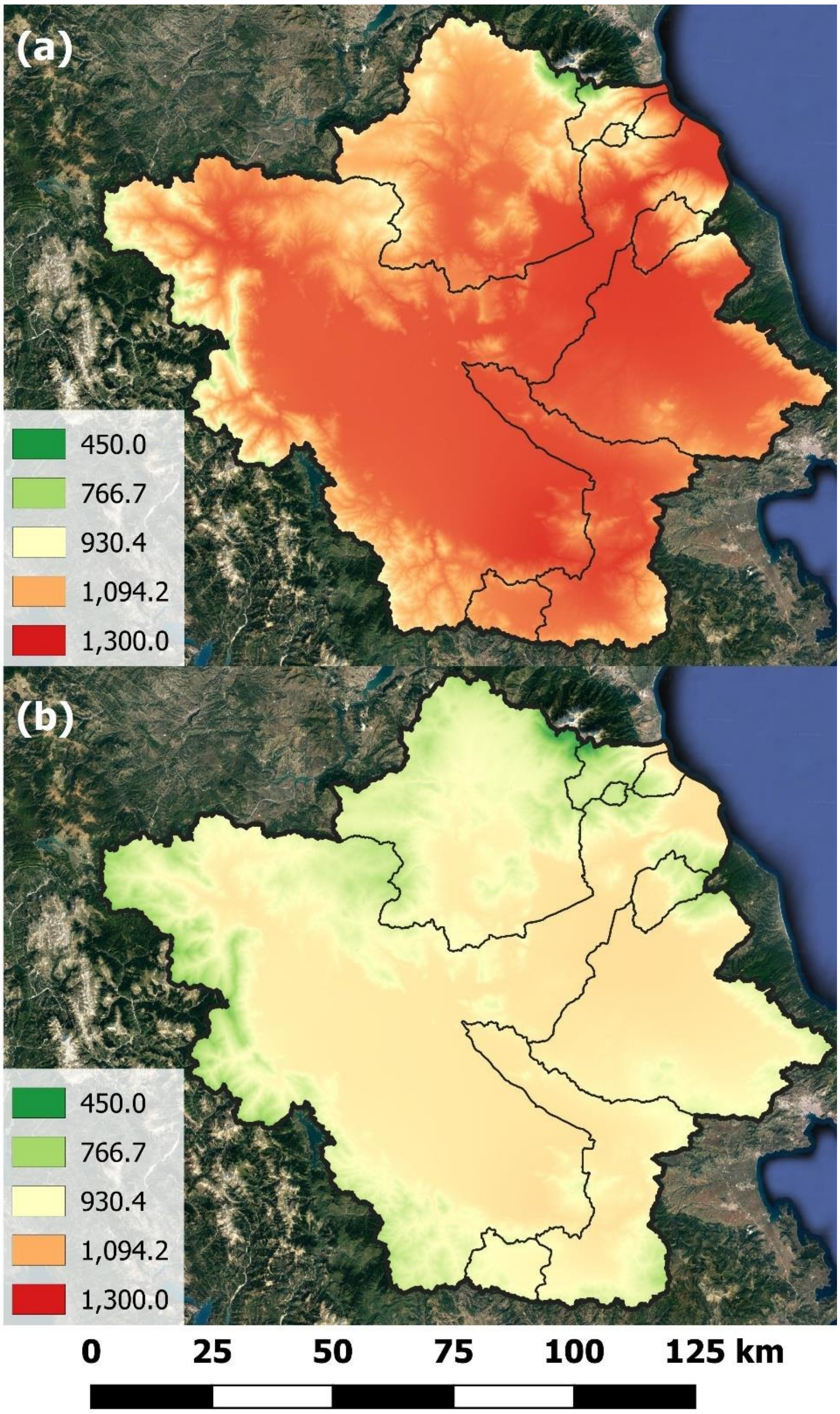

Figure 9. (a) Mean annual (hydrological year) reference evapotranspiration (ETo) (mm) distribution for the years 1971 – 2000 in River Pineios basin sub-basins; (b) Mean reference evapotranspiration (ETo) (mm) distribution between months April-September for the years 1971 – 2000 in River Pineios basin sub-basins

Similarly to air temperature, the precipitation height within the EL0816 is not uniformly distributed (Figure 10). It is considered as relatively high in the west mountainous part, it declines in the central plains and increases again in the east mountainous area. The most frequent rainfall events occur between October and January, whilst the driest months are July and August. Snowfalls are also quite frequent during winter months and March, especially in the area of the north west highlands.

A mean hydrological year precipitation height for the entirety of the district is estimated approximately to 678 mm. However, the maximum yearly precipitation height is estimated up to 1,820 mm, while the minimum to roughly 441 mm. When considered the time period between April to September the maximum and minimum precipitation height is found to be approximately 611 mm and 160 mm, respectively. Consequently, a conclusion can be derived, that during this time period falls just one third of the total yearly rainfall height. Again, as in the case of ETo, despite the differences in the maximum and minimum values of Figure 10a and Figure 10b, the distribution patterns that are illustrated by the two graphs are almost identical.

Looking closely the Figure 10 patterns, it is observed that a significant difference in precipitation height exists among the western plain of sub-basin 2066 and the eastern plain that stretched between sub-basins 2066, 2070 and 2154. Specifically, the very western parts of sub-basin's 2066 western plain could receive yearly up to 900 mm of rainwater, whilst the eastern plains just half of the amount, roughly 440 mm of rainwater. This difference is almost the same for the time period between April and September, but the precipitation height in western and eastern plains was 300 mm and 160 mm, respectively, in this case. However, even within the same plain, in relatively small distances the precipitation height may vary substantially. For instance, within the borders of sub-basin 2070, the lower eastern plain part receives yearly roughly 441 mm of rainwater, but the upper western part of the plain a moderate higher amount approximately 500 – 550 mm of water. The same pattern is observed in the April-September period as well.

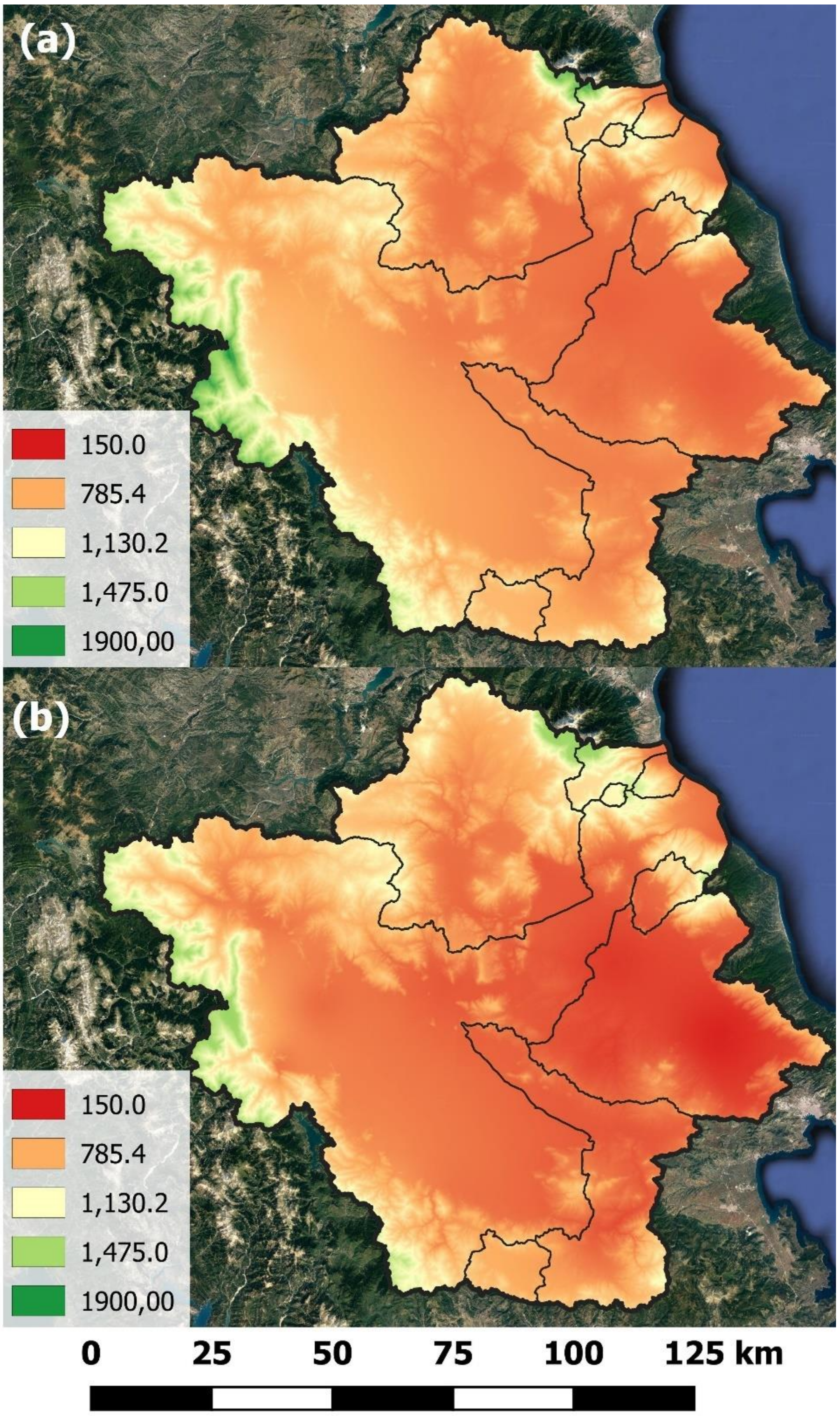

Figure 10. (a) Mean annual (hydrological year) rainfall (mm) distribution for the years 1971 – 2000 in River Pineios basin sub-basins; (b) Mean rainfall (mm) distribution between months April-September for the years 1971 – 2000 in River Pineios basin sub-basins.

2.5. Geology

In Figure 11 are illustrated the main geological formations within EL08. The western plain is consisted of modern alluvial deposits, probably the result of the intense rivers network that crosses the area (Figure 6). A plain dominated with lacustrine deposits is intervene in the south-central of the EL08, followed by an extended area of inseparable land formations towards east. The northern part of the district is consisted of gneisses, schists and amphibolite, alternating by limestones and dolomites, while in the south are found upper cretaceous limestones mainly.

Molasses, ophiolites, diabases, marbles and scree glaciers can be found within the EL08 as well, but they cover a limited area and are located mainly in the mountainous areas, playing an important role in the agricultural activities that taking place within the district.

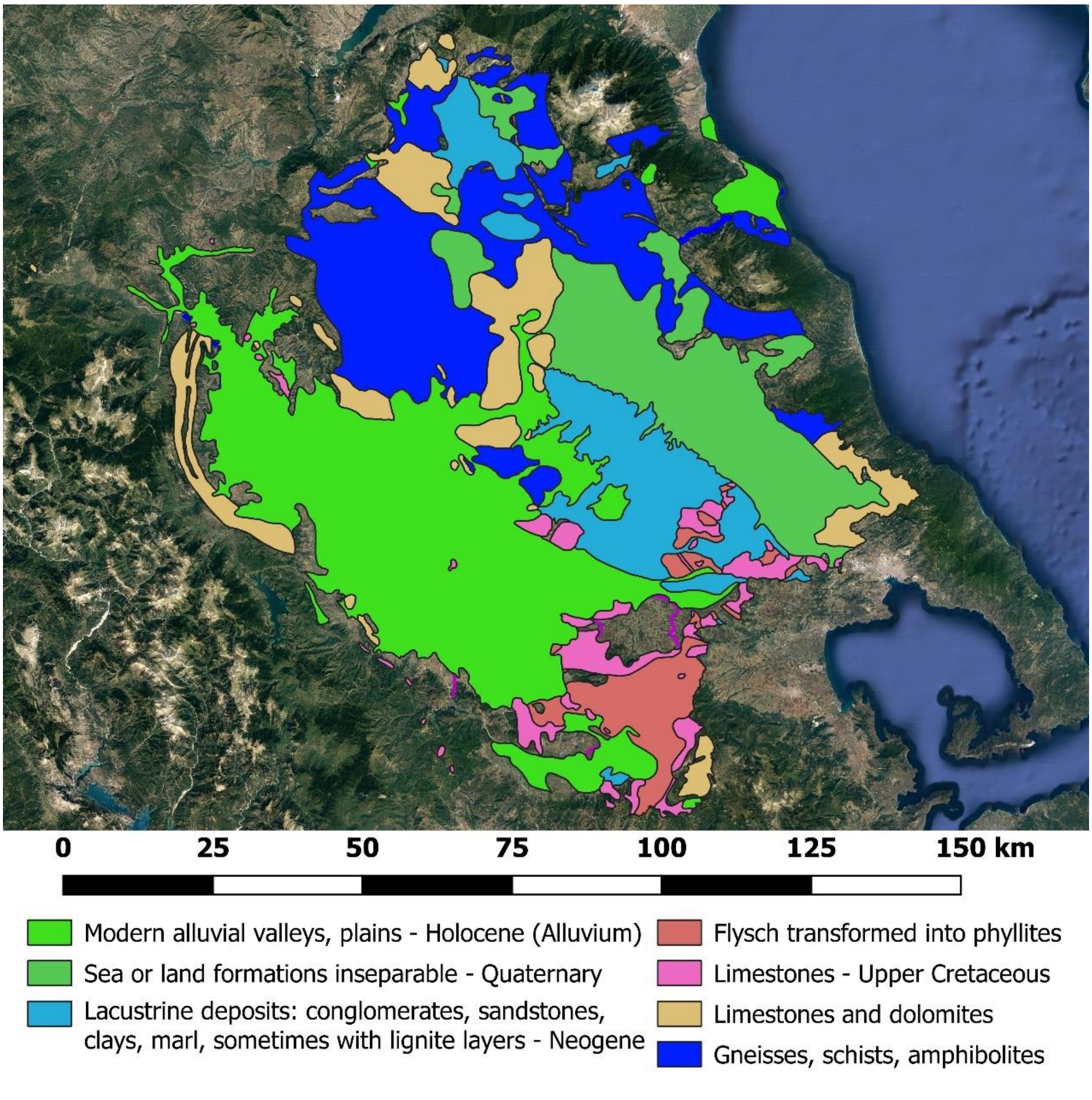

Figure 11. Main geological formations within EL08.

2.6. Land use by agriculture sector

According to 2017 national data report by the Greek Payment Authority of Common Agricultural Policy (OPEKEPE), the total cultivated land in Water District of Thessaly was roughly 602,978.89 ha. Cereals (including wheat), cotton, maize, legumes, processed tomatoes, vegetables, alfalfa and biodiesel crops (sunflower, rapeseed) are the main arable crops that are cultivated in the EL08, but perennial crops like olive groves, orchards (apples, stone fruits), nut trees(chestnut trees, almond trees, walnut trees) and vineyards are common as well. However, arable crops cover roughly 483,805.35 ha of arable land, occupying almost the entirety of the district plain areas, while perennial crops cover a significant lower portion of land (59,767.31 ha) and are usually cultivated in mountainous areas and plateaus. Table 8 presents the estimated area of each of the arable and perennial crops. Noteworthy, just three arable crops, cereals, cotton and alfalfa, cover well over 65% of the total EL08 arable land. Regarding the perennial crops, olive groves stand as the most significant among them, covering a total area of approximately 29,000 ha, an area marginally larger than that covered by orchards, nut trees and vineyards in sum. Additionally, in 2017 a not negligible percentage of land equal to roughly 4% of the total arable land, has been allowed to lie fallow.

Table 9. Arable and perennial crops area cover in Water District of Thessaly (EL08).

Crop Name	**Covering Area (ha)**	**Covering Area as a Percentage of the Total Arable Land (%)**
	Arable Crops	
Tomatoes	4,307.49	0.70
Vegetables	4,724.57	0.77
Legumes	12,560.02	2.05
Alfalfa	83,078.35	13.58
Biodiesel	1,834.88	0.30
Cotton	143,814.64	23.51
Maize	35,478.21	5.80
Cereals	198,007.19	32.37
	Perennial Crops	
Olive Groves	28,878.36	4.72
Orchards	14,236.94	2.33
Nut trees	11,908.94	1.95
Vineyards	4,743.08	0.78

To better understand the distribution of the various arable and perennial crops and thus the needs in terms of irrigation within the EL08, the crop distribution is further examined in depth in a sub-basin level.

2.6.1. Arable and perennial crops distribution in sub-basin 2061

The descriptive data regarding the land cover by the different arable and perennial crops within sub-district 2061 are presented in Table 10, while the crops' distribution is illustrated in Figure 11. Except cereals and alfalfa, which stand as the most popular crops in the sub-district covering over 60% of the total arable land, a substantial presence of perennial crops exist in the sub-district. Specifically, almost half of the total EL08 vineyards (Table 9) are cultivated within sub-basin 2061, covering a total area of approximately 2,056 ha. Additionally, substantial is the presence of nut trees, which cover an area of roughly 3,089 ha, nearly a quarter of the total nut trees area that is cultivated in EL08. The most popular crops in sub-basin 2061 and their corresponding land cover are presented in Figure 12.

Table 10. Crops and their corresponding occupying area in the sub-river basin 2061.

Crop Name	**Covering Area (ha)**	**Covering Area as a Percentage of the sub-district Total Arable Land (%)**
	Arable Crops	
Tomatoes	7.6	0.01
Vegetables	389.8	0.74
Legumes	110.6	0.21
Alfalfa	16,103.1	30.54
Biodiesel	13.9	0.03
Cotton	158.1	0.30
Maize	1,872.9	3.55
Cereals	16,369.3	31.05
	Perennial Crops	
Olive Groves	1,422.3	2.70
Orchards	2,324.9	4.40
Nut trees	3,089.3	5.86
Vineyards	2,056.4	3.90

It occurs that almost all the orchards and vineyards that are cultivated in sub-district 2061 are located in the south eastern plain (Figure 11). On the contrary, nut trees are spread in the central north and central south plateaus, mixed with fields that are cultivated with cereals, maize and alfalfa fields. It is notable, that the westernmost plateau in the sub-district was nearly exclusively cultivated with alfalfa. Moreover, roughly 10% of the arable land was let to lie fallow.

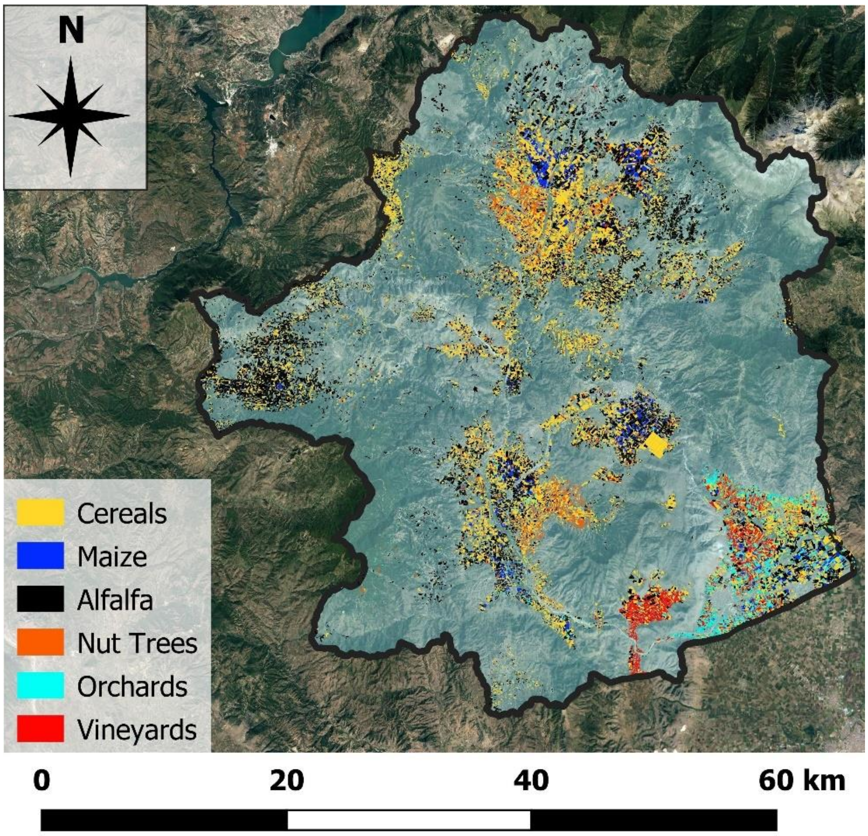

Figure 12. Main and arable-perennial crops spatial distribution in the sub-river basin 2061.

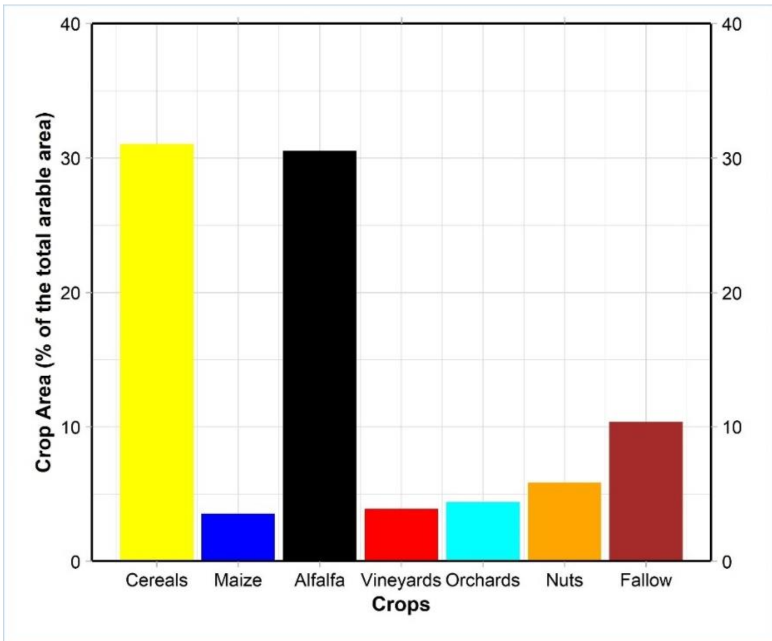

Figure 13. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2061 arable land.

2.6.2. Arable and perennial crops distribution in sub-basin 2062

Sub-basin 2062 in one of the five small basins composing EL0816, covering an area of just 150 km^2. The sub-basin is almost entirely a mountainous area, except for a plateau in its south-western side. The total arable land is estimated to be roughly 1,348 ha, just 9% of the sub-basin's total area. Once more, cereals and alfalfa are the most popular crops covering nearly 65% of the total arable land (Table 11). The crops' puzzle within sub-basin 2062 is completed with the presence of small areas cultivated with vegetables, legumes, nut trees and orchards. Surprisingly, approximately 246 ha, 18.25% of the total arable land, were let to lie fallow in 2017. Figure 13 shows the proportional use of the arable land by the different crops.

All the cultivated fields within sub-basin 2062 are located in the south-western plateau. The fields are cultivated in a random pattern, resulting in arbitrary alterations of fields cultivated with cereals, followed by fields cultivated with legumes, followed by fields cultivated with nut trees etc (Figure (14).

Table 11. Crops and their corresponding occupying area in the sub-river basin 2062.

Crop Name	**Covering Area (ha)**	**Covering Area as a Percentage of the sub-district Total Arable Land (%)**
	Arable Crops	
Tomatoes	-	0.00
Vegetables	7.6	0.56
Legumes	19.7	1.47
Alfalfa	468.1	34.72
Biodiesel	-	0.00
Cotton	-	0.00
Maize	4.7	0.35
Cereals	430.5	31.94
	Perennial Crops	
Olive Groves	-	0.00
Orchards	3.8	0.29
Nut trees	11.6	0.86
Vineyards	-	0.00

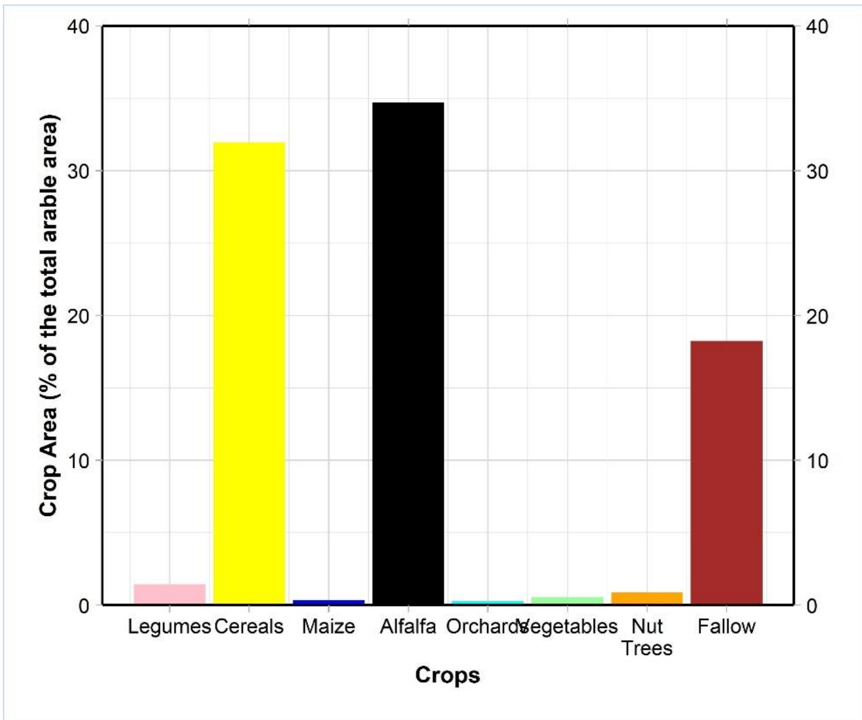

Figure 14. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2062 arable land.

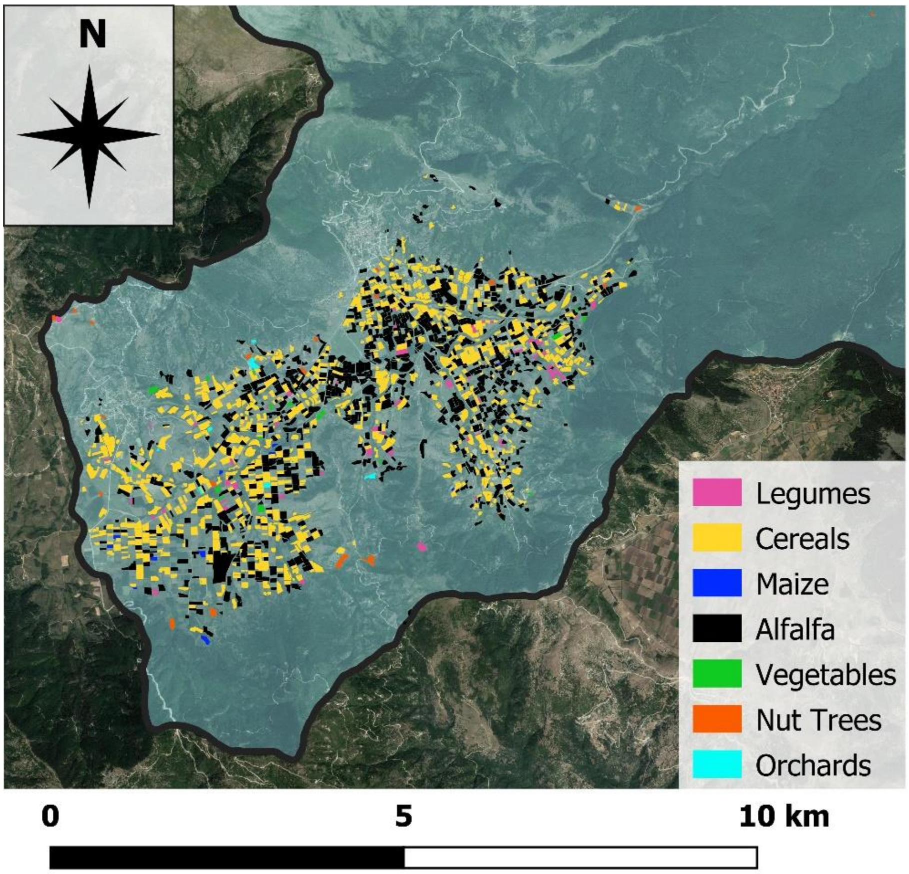

Figure 15. Main and arable-perennial crops spatial distribution in the sub-river basin 2062.

2.6.3. Arable and perennial crops distribution in sub-basin 2066

Being the largest sub-basin of EL0816 with a total area of 5,888.73 km^2, sub-basin 2066 covers almost completely the western part of EL0816, and extends up to the Aegean Sea through a narrow branch, which is extended northeast following the course of Pineios river main current. Nearly all of the cotton, maize, vegetables and biodiesel crops are cultivated within 2066 (Table 12). Moreover, over the half of alfalfa fields, a quarter of the orchards and half of the vineyards that are cultivated in EL08 are found in sub-basin 2066. In Figure 15 the land cover percentages of the main arable and perennial crops within the sub-basin are presented.

Table 12. Crops and their corresponding occupying area in the sub-river basin 2066.

Crop Name	Covering Area (ha)	Covering Area as a Percentage of the sub-district Total Arable Land (%)
	Arable Crops	
Tomatoes	1,355.7	0.47
Vegetables	3,339.4	1.17
Legumes	1,729.7	0.61
Alfalfa	48,594.3	17.00
Biodiesel	1,154.1	0.40
Cotton	96,349.7	33.70
Maize	25,414.9	8.89
Cereals	63,155.5	22.09
	Perennial Crops	
Olive Groves	5,192.1	1.82
Orchards	3,591.9	1.25
Nut trees	2,288.3	0.80
Vineyards	1,967.9	0.69

Observing the distribution of the most popular crops within the sub-basin (Figure 16b), three major clusters can be found. The first cluster regards maize crop and is located in the western-central side of the basin. It's the place where Pineios river main current is descended from the north highlands and turns right towards east (Figure 6). The presence of the Pineios river, as well as the relatively high precipitation height that falls to the area during maize's cultivation period (April to August) (Figure 10b), are considered as key factors for the overwhelming presence of the crop there, as they ensure the crop's high irrigation water requirements. The second cluster has to do with cotton crop. This cluster is very extended and covers a large area from the south-western border of the sub-basin up to its' very center. It is noteworthy that this area is crossed by a substantial number of rivers like river 22 and 25 (Figure 6), which contribute substantially to the irrigation needs of the water demanding cotton crop. Finally, the third cluster refers to cereals and is located in the center of the sub-basin, to the lower part of the branch that is created by the Pineios river current as the latter follows a northeast direction (Figure 6, Figure 16b).

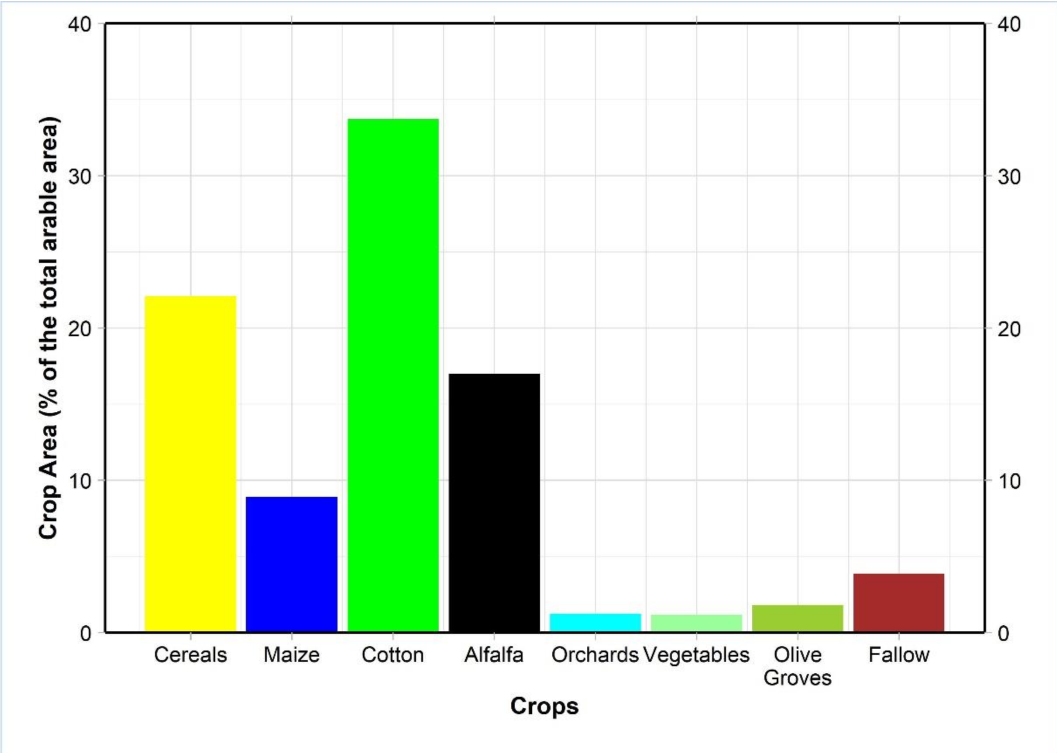

Figure 16. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2066 arable land.

Two more, distinct, minor crop clusters are observed within the sub-basin (Figure 16a). To begin with, the first minor cluster is located closely to the Pineios river delta, at the very east of the sub-basin. In this cluster all the biodiesel crops of the sub-basin are cultivated. The second cluster is observed to the mid of sub-basin's branch and is cultivated with orchards.

Olive groves, vineyards and nut trees fields (Figure 16a) can be seen all over the fields that are located in the slopes of the mountains found in the western and northern sides of sub-basin's perimeter. It's worthy to mention that although alfalfa covers almost 17% of the total arable land within the sub-basin, its cultivation is so evenly distributed that the cultivated fields are barely visible in Figure 16b.

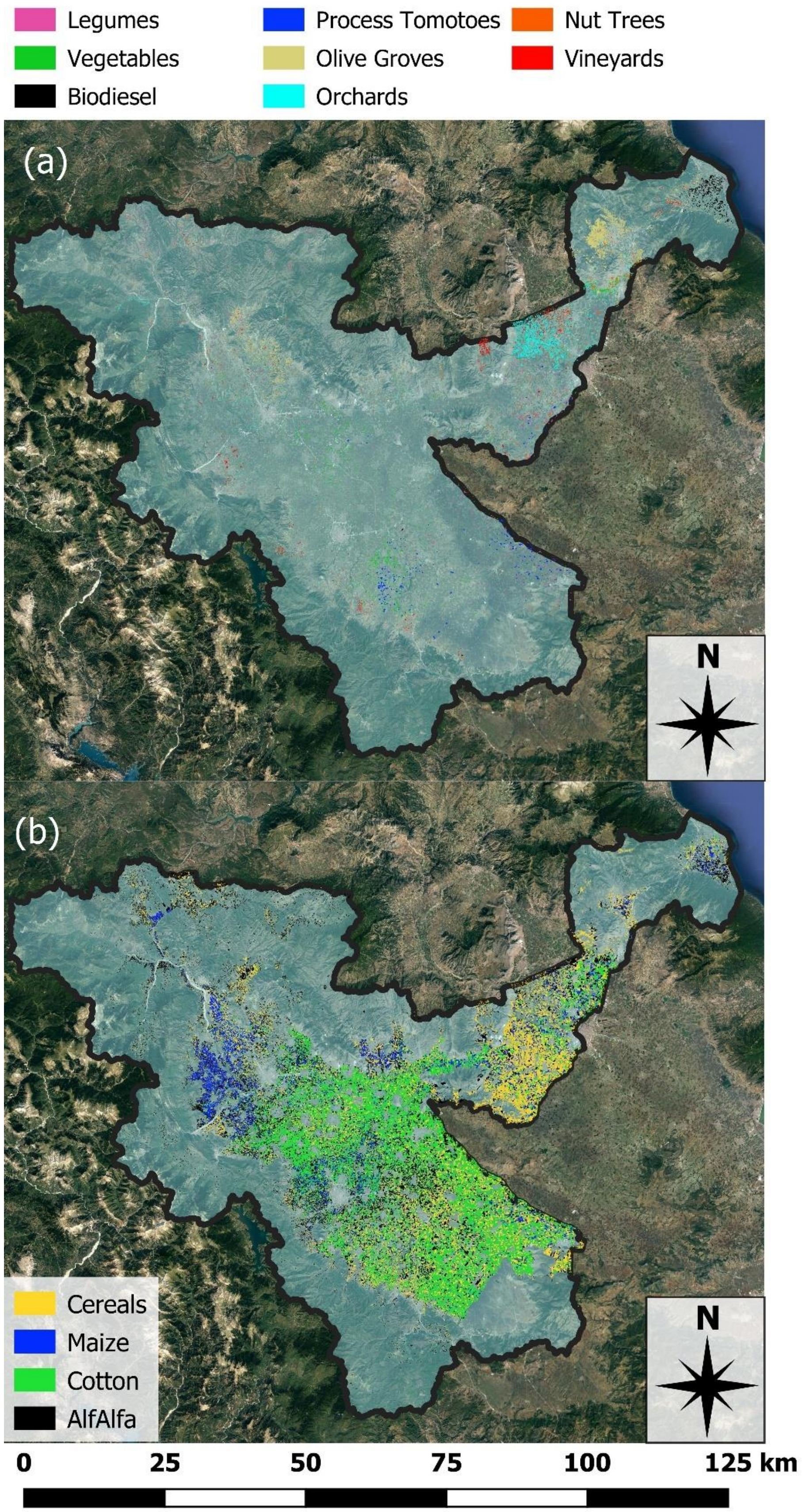

Figure 17. (a) Minor arable and perennial crops and (b) major arable and perennial crops spatial distribution in the sub-river basin 2066.

2.6.4. Arable and perennial crops distribution in sub-basin 2067

Sub-basin 2067 is the smallest of the EL0816 sub-basins, covering an area of just 19.87 km^2. Essentially, sub-basin 2067, is a small plateau surrounded by ridges. However, it is impressive that almost 40% (~7.7 km^2) of the sub-basins total area is arable land. The most popular crops are cereals and alfalfa occupying 70% and 11% of the arable land respectively (Table 13). A small portion of fields is cultivated with vegetables, legumes, biodiesel crops, maize, orchards and nut trees. Except for the fact that nut trees fields are mostly located in the slopes of the mountains, the rest of the crops' distribution is arbitrary without any specific clusters or patterns (Figure 18). Remarkably, a substantial portion of land (roughly 7% of the total arable land) was let to lie follow in 2017 (Figure 2019).

Table 13. Crops and their corresponding occupying area in the sub-river basin 2067.

Crop Name	Covering Area (ha)	Covering Area as a Percentage of the sub-district Total Arable Land (%)
Arable Crops		
Tomatoes	-	0.00
Vegetables	2.1	0.26
Legumes	15.1	1.96
Alfalfa	87.5	11.33
Biodiesel	3.9	0.50
Cotton	-	0.00
Maize	4.2	0.54
Cereals	532.9	69.10
Perennial Crops		
Olive Groves	-	0.00
Orchards	0.5	0.06
Nut trees	9.4	1.22
Vineyards	-	0.00

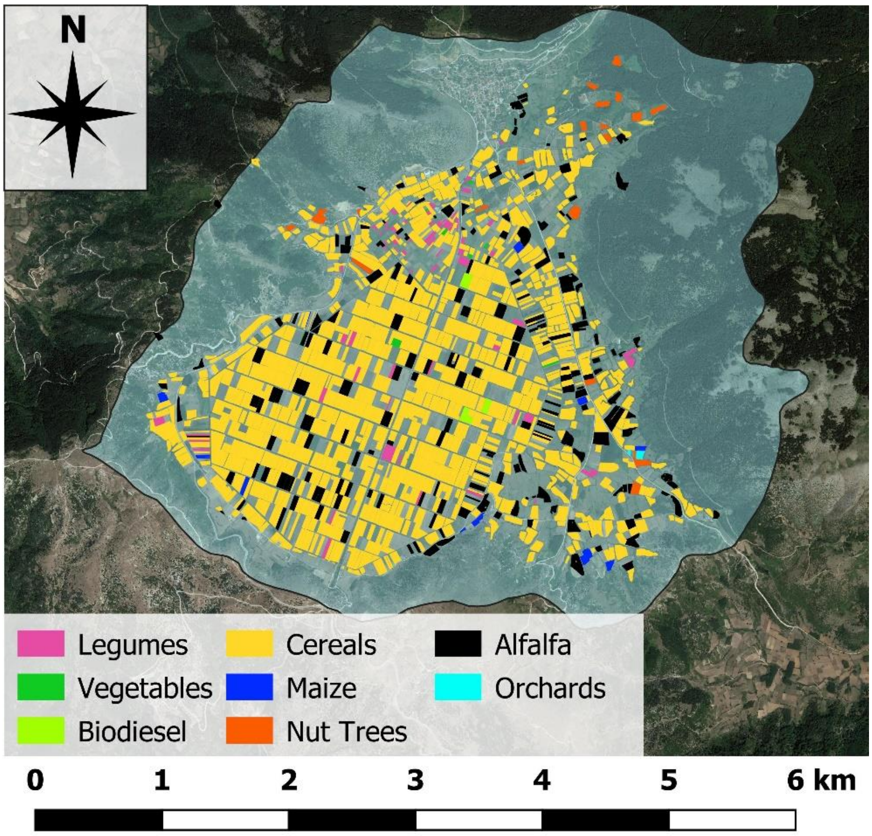

Figure 18. Main and arable-perennial crops spatial distribution in the sub-river basin 2067.

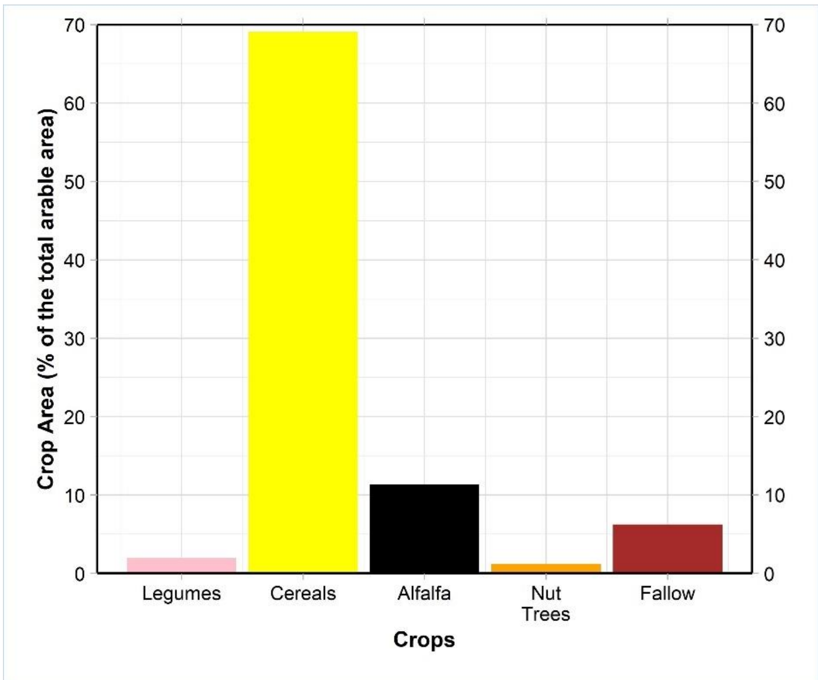

Figure 19. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2067 arable land.

2.6.5. Arable and perennial crops distribution in sub-basin 2069

In contrast to the rest of EL0816 sub-basins, in the case of sub-basin 2069 perennial crops overwhelm arable ones. Specifically, olive groves and nut trees occupy more than 50% of the total arable land, while orchards are present as well (Table 14). From the arable crops cereals is by far the most popular crop covering roughly 1,160 ha., but alfalfa, vegetables, cotton and maize are cultivated is a smaller scale too. Moreover, approximately 7% of the arable land was let to lie fallow (Figure 21).

The lowlands of the sub-basin are characterized by the presence of nut trees, orchards in the very south part, as well as fields cultivated with arable crops scattered arbitrarily all over the area (Figure 20). On the other hand, olive groves are exclusively located in the highlands mainly in the northern part of the sub-basin.

Table 14. Crops and their corresponding occupying area in the sub-river basin 2069.

Crop Name	Covering Area (ha)	Covering Area as a Percentage of the sub-district Total Arable Land (%)
Arable Crops		
Tomatoes	-	0.00
Vegetables	47.4	0.26
Legumes	0.6	0.01
Alfalfa	101.2	2.29
Biodiesel	-	0.00
Cotton	30.3	0.69
Maize	99.4	2.25
Cereals	1,158.7	26.26
Perennial Crops		
Olive Groves	1,134.8	25.72
Orchards	155.1	3.51
Nut trees	1,285.1	29.13
Vineyards	9.9	0.23

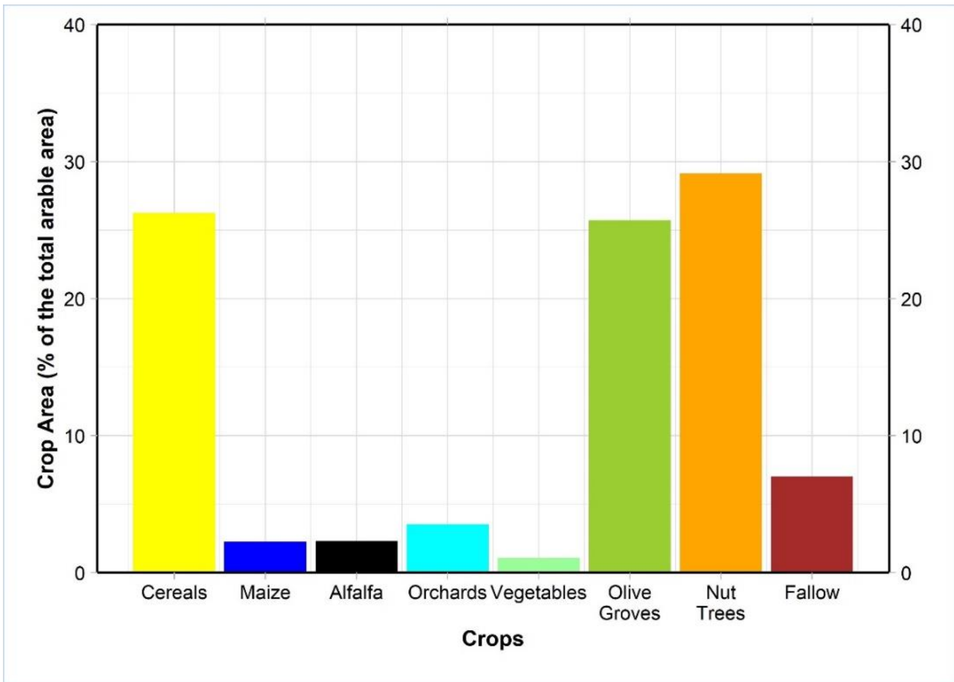

Figure 20. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2069 arable land.

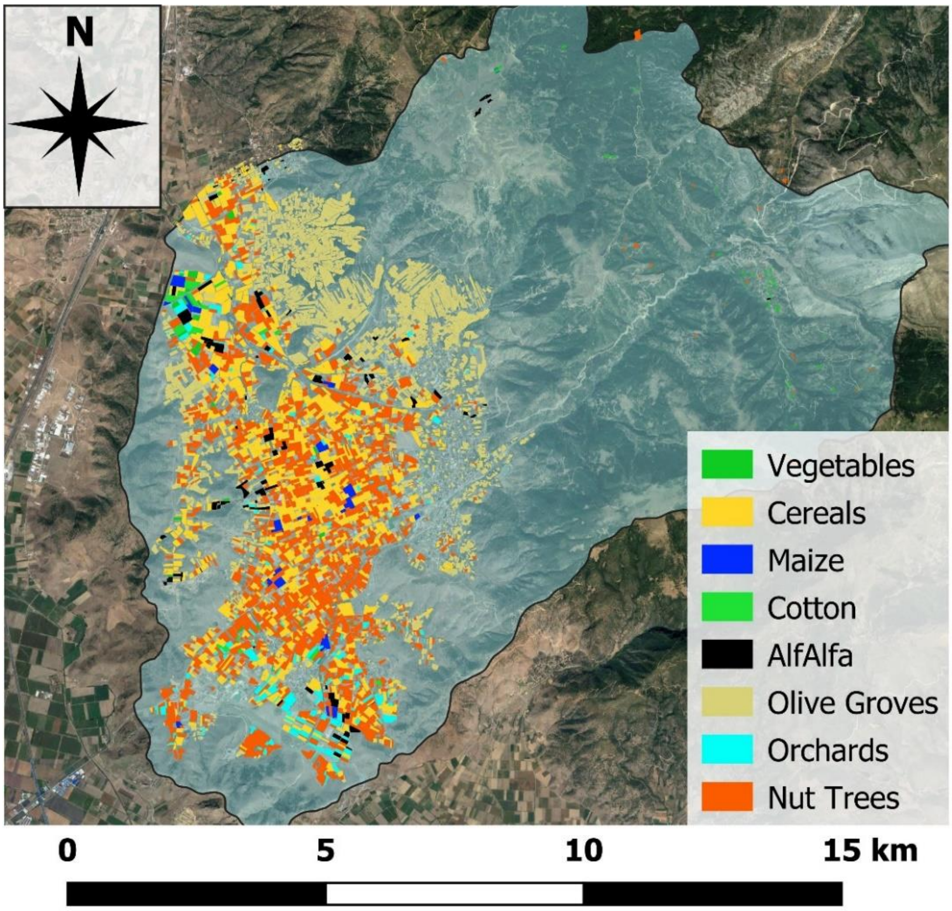

Figure 21. Main and arable-perennial crops spatial distribution in the sub-river basin 2069.

2.6.6. Arable and perennial crops distribution in sub-basin 2070

Sub-basin 2070 is the most intensely cultivated sub-basin of EL0816. Almost 91% of the smallesub-basin's area, approximately 1,517 ha, is arable land. Almost half of the cereals and a quarter of the cotton that are found in EL08 are cultivated here, occupying 49% and 22% of the sub-basin's arable land, respectively. Moreover, substantial land areas are cultivated with legumes, alfalfa, maize, orchards and nut trees (Table 15). It's estimated that 4,474 ha were let lie to fallow in 2017, roughly 3% of the total arable land (Figure 22).

Table 15. Crops and their corresponding occupying area in the sub-river basin 2070.

Crop Name	Covering Area (ha)	Covering Area as a Percentage of the sub-district Total Arable Land (%)
	Arable Crops	
Tomatoes	2,285.3	1.51
Vegetables	736.5	0.49
Legumes	7,726.1	5.09
Alfalfa	8,208.2	5.41
Biodiesel	379.6	0.25
Cotton	33,501.9	22.08
Maize	4,839.8	3.19
Cereals	73,673.3	48.57
	Perennial Crops	
Olive Groves	1,133.7	0.75
Orchards	2,191.9	1.44
Nut trees	3,460.8	2.28
Vineyards	243.7	0.49

It's noteworthy that when considering the two most popular crops, cereals and cotton, the sub-basin 2070 seems to be divided into two parts. The lower half part is cultivated mainly with cereals and in a lesser extend with legumes, whilst the upper half part is dominated by cotton crop (Figure 22b). This separation in probably related with the existence of the rivers 49 and 50 in the upper part (Figure 6), as well as the presence of the lake Karla and the smaller artificial lakes Kalamakiou, Namaton and Eleuteriou (Figure 7), which secure the required water quantities for the irrigation of water demanding cotton crop. On the contrary, the absence of any lake surface water bodies in combination with the bad quantity groundwater status in the lower half part of the sub-basin (Figure 8), has as a result the preference of the less water demanding crops cereals and legumes The.

Moreover, a cluster of orchards is observed in the northeast highlands, whilst fields with nut trees spread all over the mountain slopes ranging from northeast to southeast of the sub-basin (Figure 22b). Regarding the rest of the crops no systematic cultivating patterns were observed. More or less they can be found in random fields, mingled among cereals and cotton.

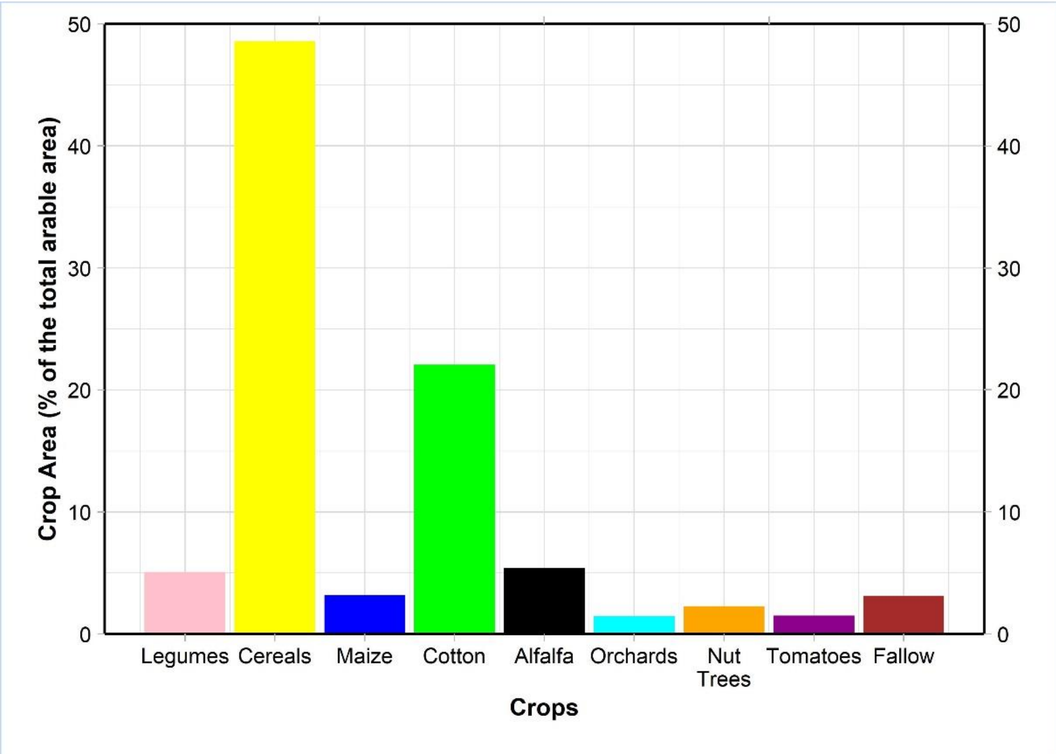

Figure 22. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2070 arable land.

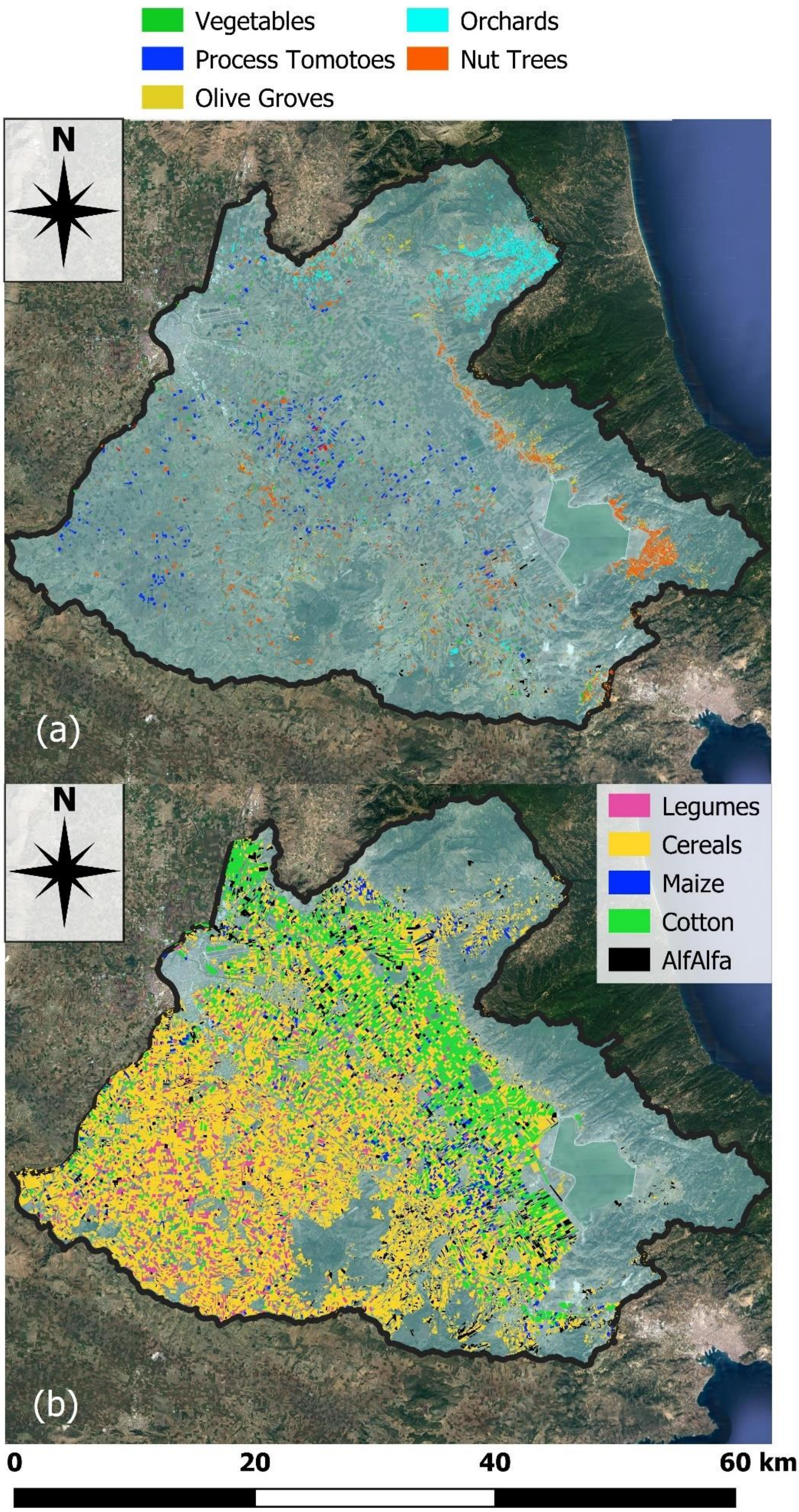

Figure 23. (a) Minor arable and perennial crops and (b) major arable and perennial crops spatial distribution in the sub-river basin 2070.

2.6.7. Arable and perennial crops distribution in sub-basin 2077

The sub-basin is consisted of a large long narrow plain located in its' northern part and a highland plateau in its' southern part. Cereals, cotton and alfalfa are the most popular crops in the sub-basin, occupying most of the 74% of the arable land (Table 16). Legumes and maize occupy a substantial portion of land as well, while the rest of the arable crops (vegetables, tomatoes, etc) and perennial crops are of lesser importance (Figure 24).

Cotton is cultivated exclusively in the northern lowlands of the sub-basin, while the rest of the crops can be found both in the plain and the highlands without any clear pattern (Figure 24). The intense presence of cotton only in the northern part is probably connected with the river 27 (Figure 6) which crosses this area and secure adequate water amounts for cotton's irrigation, but also to the higher temperatures prevailing there compared to the highlands area, that are a mandatory requirement for the optimal development of the cotton crop (Figure 9).

Table 16. Crops and their corresponding occupying area in the sub-river basin 2077.

Crop Name	Covering Area (ha)	Covering Area as a Percentage of the sub-district Total Arable Land (%)
	Arable Crops	
Tomatoes	630.2	0.83
Vegetables	528.8	0.69
Legumes	3,846.9	5.05
Alfalfa	9,108.3	11.96
Biodiesel	708.4	0.93
Cotton	11,244.3	14.77
Maize	2,677.4	3.52
Cereals	37,149.2	48.79
	Perennial Crops	
Olive Groves	45.6	0.06
Orchards	94.8	0.13
Nut trees	798.6	1.05
Vineyards	147.6	0.19

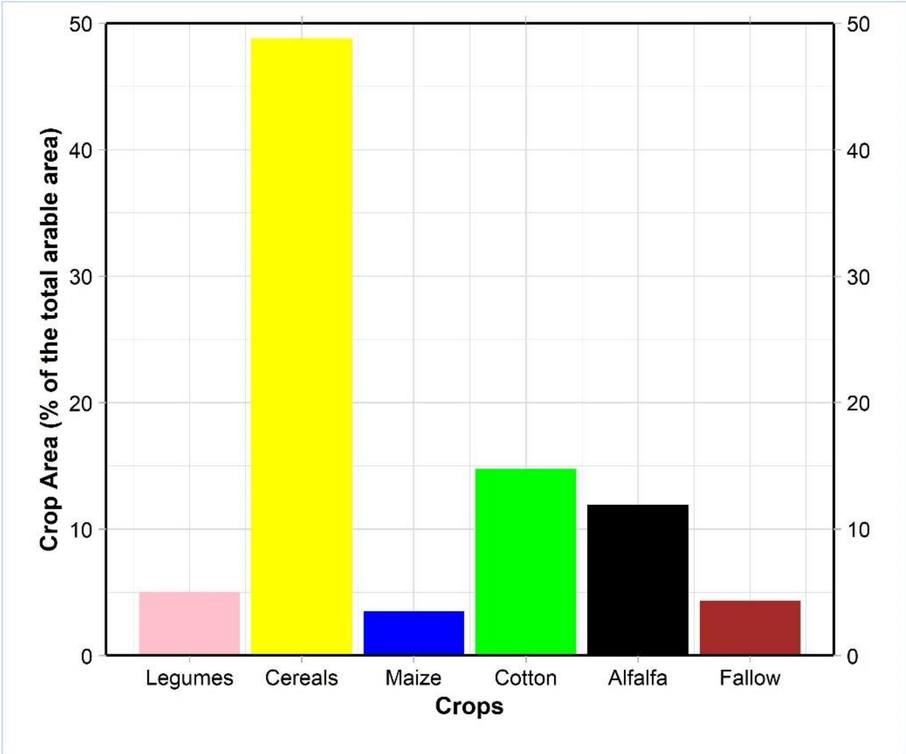

Figure 24. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2077 arable land.

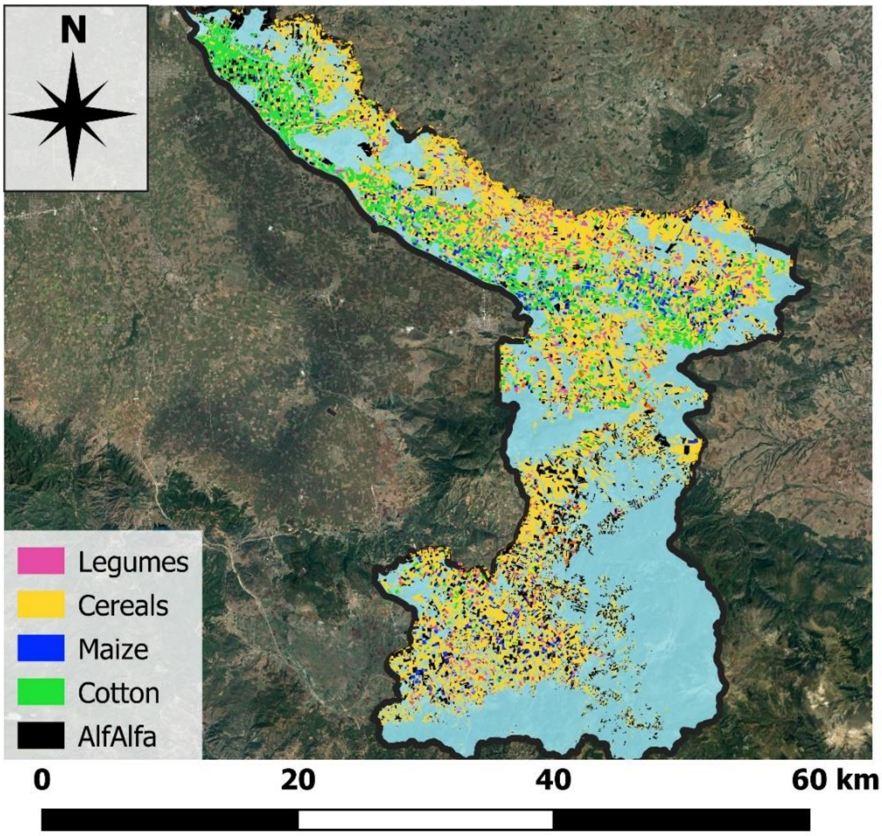

Figure 25. Main and arable-perennial crops spatial distribution in the sub-river basin 2077.

2.6.8. Arable and perennial crops distribution in sub-basin 2154

Surrounded by mountains in its' western, north and south borders, sub-basin 2154 is a small plateau of 167.8 km^2. Artificial lake Smokovou is located just 10 km to its east. Except the generally popular cereal and alfalfa crops, in sub-basin 2154 a significant portion of land (~ 15%) is cultivated with biodiesel crops (Table 17, Figure 26). Maize, legumes and nut trees are cultivated as well there but in a smaller scale. In 2017 roughly 5.5% of the arable land was let to lie fallow.

Biodiesel crops appear to be more frequently cultivated in the middle of the sub-basin, whilst cereals in its' eastern part and alfalfa in its' western part (Figure 26). The scarce nut trees fields are located in the perimeter of the region.

Table 17. Crops and their corresponding occupying area in the sub-river basin 2154.

Crop Name	Covering Area (ha)	Covering Area as a Percentage of the sub-district Total Arable Land (%)
	Arable Crops	
Tomatoes	42.6	0.42
Vegetables	12.7	0.13
Legumes	186.6	1.84
Alfalfa	2,262.4	22.36
Biodiesel	1,530.5	15.13
Cotton	38.1	0.38
Maize	558.0	5.52
Cereals	4,095.6	40.48
	Perennial Crops	
Olive Groves	-	0.00
Orchards	8.3	0.08
Nut trees	116.0	1.15
Vineyards	27.2	0.27

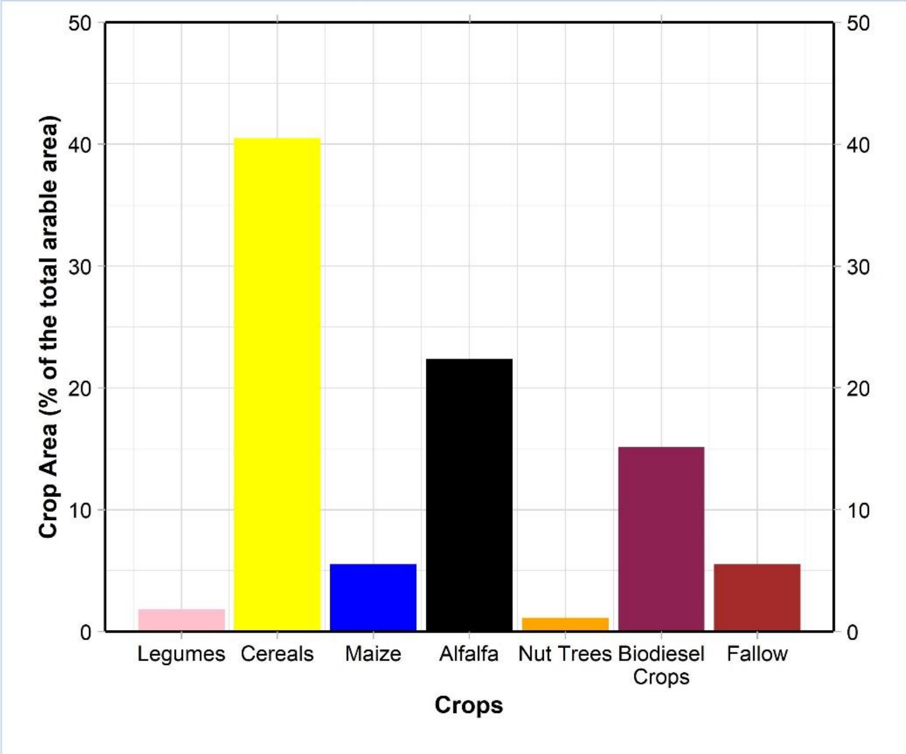

Figure 26. Main arable-perennial crops and fields that have been allowed to lie fallow land cover as a percentage of the total sub-river basin 2154 arable land.

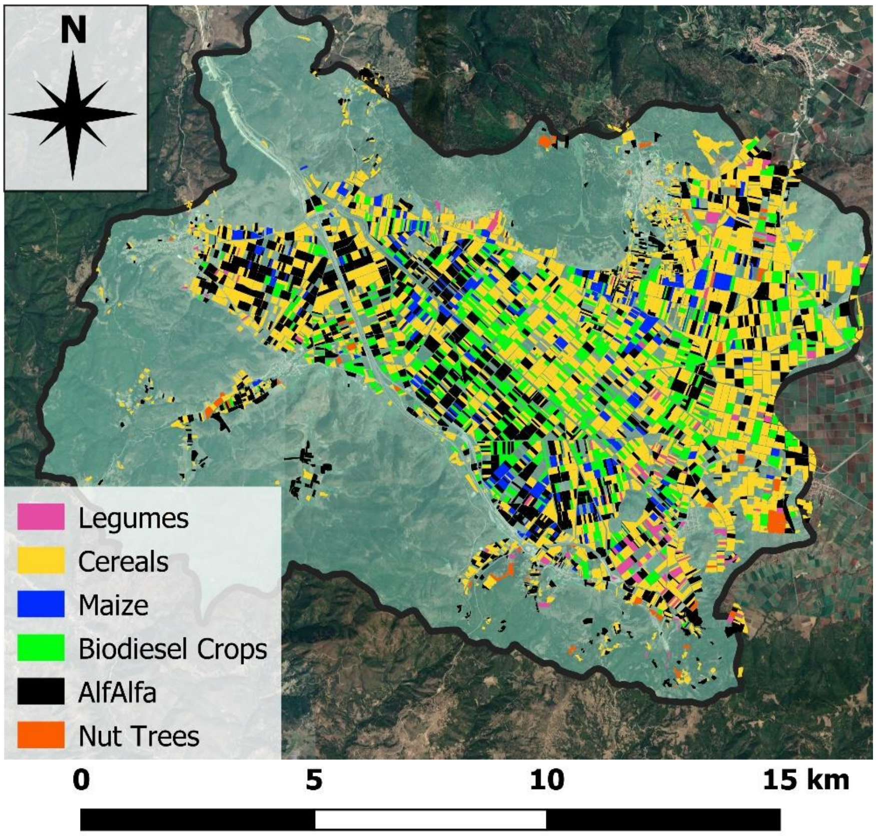

Figure 27. Main and arable-perennial crops spatial distribution in the sub-river basin 2154.

2.7. Potential irrigation water needs in Water District of Thessaly (EL08)

In the present situation, the net annual water requirements of the different arable and perennial crops are considered to be those proposed by the 2nd Update of river basin management plans (RBMP) (2019) for river basin district (RBD) of Thessaly. The water quotas for each crop are presented in Table 18. This means that a farmer can irrigate a maximum net amount of water equal to that defined in column 3 of Table 18. For instance, a famer that cultivates maize can irrigate throughout the crop season up to 5,562 m^3 of water per hectare of land. Due to the lack of real measurements regarding the amounts of water that individual farmers irrigate to their farms, in this study the potential net irrigation water needs for EL08 are estimated with the combined use of Tables 9 and Table 18. Specifically, the total area covered from each crop (Table 9) is multiplied by the maximum corresponding water quota (Table 18). Successively, the crop data that derived from the sub-basin level crop analysis were utilized and the potential water needs of each sub-basin were estimated.

In some cases, the crop data from OPEKEPE database do not concur with the crop categories of Table 18. Such are the cases of biodiesel crops and nut trees. The areas that according to OPEKEPE data are cultivated with biodiesel crops, can actually be cultivated either by sunflower or rapeseed, two crops with significantly different water requirements. Sunflower in included in Table 18, whilst rapeseed not. For the purpose of this study the rapeseed as a winter crop is considered to have similar water requirements with the winter cereals. Additionally, the total area that is cultivated with biodiesel crops according to OPEKEPE entries is assumed that is half cultivated with sunflower and half with rapeseed.

Similarly to rapeseed, the nut trees are not included to the crops list of Table 18. In the framework of the current work the water needs of nut trees are assumed to be equal to those of olive trees.

The descriptive irrigation water potential requirements for each arable and perennial crop cultivated within EL08 and each of the sub-basins are presented in Table 19. The total net water requirements for EL08 and each of the basins are illustrated in Figure 27. It derives that the annual water net needs for irrigation purposes in EL08 are roughly 1,934.28 hm^3. Considering that the irrigation is performed via a drip irrigation system with a performance coefficient 85.5% (as that proposed in Table 18), the actual water needs are increased to 2,214.8 hm^3 per year. Alternatively, applying the required irrigation amounts with a sprinkler irrigation system (performance coefficient 80.75%)

(Table 18), the potential annual water needs are even more than that in the case of the drip system, equal to 2,306.6 hm^3. As it was mentioned in subsections *2.3.1 Surface water bodies* and *2.3.2 Sub-surface water bodies*, the annual withdrawals for irrigation from the rivers, lakes and groundwater systems of EL08 are estimated to be 1,674.4 hm^3, 64.98 hm^3 and 842.8 hm^3, respectively. Summing the abovementioned quantities, it derives that the estimated water withdrawals from EL08 water resources for irrigation are 2,582.2 hm^3. This amount is larger than the estimated potential irrigation water needs calculated according to maximum water quotas of Table 18. The difference was found to be roughly 367.5 hm^3 and 275.6 hm^3 in the case of drip and sprinkler irrigation systems, respectively. This difference can be attributed to some extend to the losses of the pipe systems that transfer the water from the surface water bodies to the irrigated fields. Nevertheless, these losses alone cannot gap the difference and thus the available data indicate that in some cases the water quotas are violated and the crops are over-irrigated.

More than half of the potential irrigation needs of EL08 are attributed to sub-basin 2066, equal to approximately 1,036.68 hm^3. Substantial are the irrigation requirements of sub-basins 2070, 2077 and 2061 as well, while the needs of the rest of the sub-basins are negligible. It's remarkable that the geographical borders of groundwater systems 3, 8, 9, 10 and 17 (Figure 8), whose water quantity status is considered as bad, are fully or partially contained within the sub-basins 2066, 2070, 2077 and 2061.

Looking into the irrigation requirements of each crop, among arable crops alfalfa and cotton are the two most water demanding crops, transpiring annually roughly 623.92 hm^3 and 563.47 hm^3 of water, respectively. From the rest of the arable crops maize and cereals estimated to consume annually 197.33 hm^3 and 177.22 hm^3 of water, respectively, while the needs of the rest of the crops are significantly lower.

It should be mentioned that despite the fact that within EL08 cereals occupy well more than double of the area occupied by alfalfa and cotton (Table 9), their water requirements are even less than that of maize which covers just 17.9% of the area corresponds to cereals This is attributed to the considerably lower water requirements of cereals when compared to that of alfalfa, cotton and maize (Table 18).

Regarding perennial crops, olives are found to be the most demanding crop followed by orchards with estimated potential net water requirements equal to 115,37 hm^3 and 74.15 hm^3, respectively.

Table 18. Irrigation water quotas per crop in water district EL08 according to the 2nd Update of RBMP – RBD (EL08) Thessaly.

Crop Categories According to Crop Coefficient K	Crops	Net Total Water Quota During Cultivation Period (m^3/ha)	Allowed Irrigation Consumption from a Drilling		
			Maximum Consumption (m^3/ha) via a drip irrigation system PC=85.50%	Maximum Consumption (m^3/ha) via a sprinkler irrigation system PC=80.75%	Maximum Consumption (m^3/ha) via a furrow irrigation system PC=50.00%
I K=0.55	Citrus	4,756	5,560		
	Olives	3,995	4,670		
	Vineyards	4,756	5,560		
II K=0.6	Tobacco	3,419		4,230	
III K=0.65	Cotton	3,918		4,850	
	Legumes	4,640		5,750	
	Orchards	5,208	6,090		
IV K=0.7	Sugar beets	5,656		7,000	
	Sunflower	5,656		7,000	
	Vegetables	6,133		7,590	
	Process Tomato	4,511		5,590	
	Potatoes	4,671		5,780	
	Melon fields	5,135		6,360	
V K=0.75	Winter Cereals	895		1,110	
	Maize	5,562		6,890	
VI K=0,80	Constructed Grasslands	3,507		4,340	
VII K=0,85	Alfalfa	7,510		9,300	
VIII K=1.2	Rice	10,149			20,300

PC=Irrigation System Performance Coefficient

Table 19. Potential net irrigation water requirements in Water District of Thessaly and its sub-basins for the different arable and perennial crops according to the water quotas proposed by the 2nd Update of RBMP – RBD (EL08) Thessaly.

Crop Name	Potential Net Irrigation Water Needs (×10^3 m^3/y)								
	EL08	2061	2062	2066	2067	2069	2070	2077	2154
Arable Crops									
Tomatoes	19,431.09	34.28	0.00	6,115.56	0.00	0.00	10,308.99	2,842.83	192.17
Vegetables	28,975.79	2,390.64	46.61	20,480.54	12.88	290.70	4,516.95	3,243.13	77.89
Legumes	58,278.49	513.18	91.41	8,025.81	70.06	2.78	35,849.10	17,849.62	865.82
Alfalfa	623,918.41	120,934.28	3,515.43	364,943.19	657.13	760.01	61,643.58	68,403.33	16,990.62
Biodiesel	6,010.15	45.53	0.00	3,780.25	12.77	0.00	1,243.38	2,320.36	5,013.15
Cotton	563,465.76	619.44	0.00	377,498.12	0.00	118.72	131,260.44	44,055.17	149.28
Maize	197,329.80	10,417.07	26.14	141,357.67	23.36	552.86	26,918.97	14,891.70	3,103.60
Cereals	177,216.44	14,650.52	385.30	56,524.17	476.95	1,037.04	65,937.60	33,248.53	3,665.56
Perennial Crops									
Olive Groves	115,369.05	5,682.09	0.00	20,742.44	0.00	4,533.53	4,529.13	182.17	0.00
Orchards	74,145.98	12,108.08	19.79	18,706.62	2.60	807.76	11,415.42	493.72	43.23
Nut trees	47,576.22	12,341.75	46.34	9,141.76	37.55	5,133.97	13,825.90	3,190.41	463.42
Vineyards	22,558.09	9,780.24	0.00	9,359.33	0.00	47.08	1,159.04	701.99	129.36
Total	1,934,275.26	189,517.11	4,131.02	1,036,675.47	1,293.31	13,284.46	368,608.50	191,422.96	30,694.10

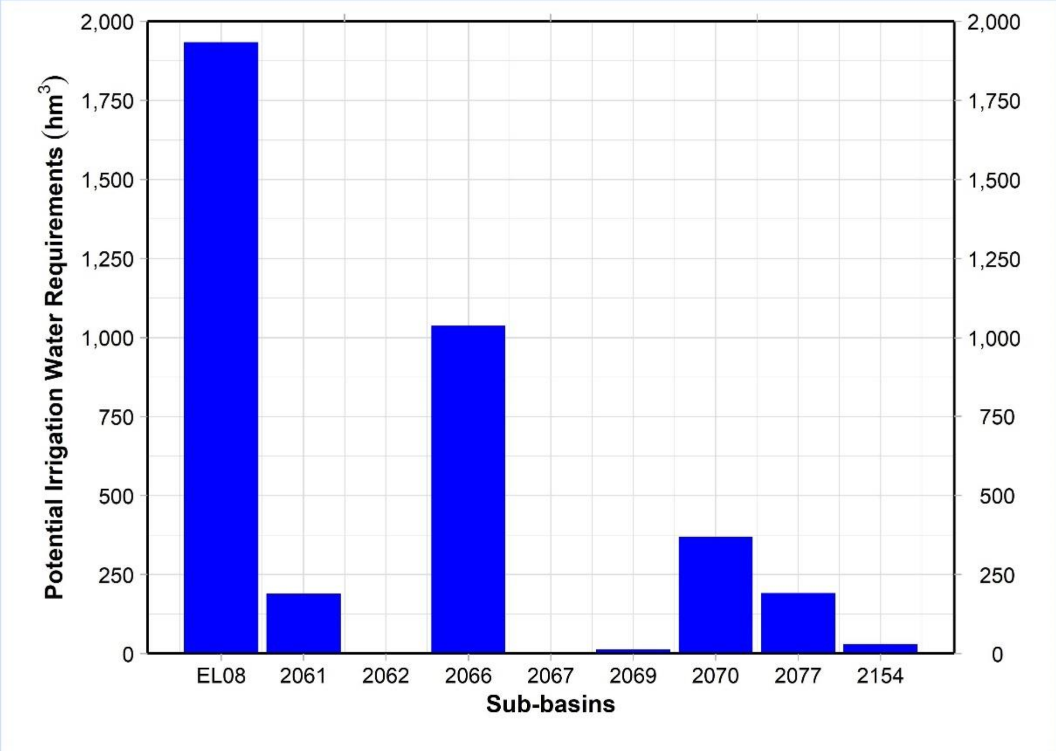

Figure 28. Potential total irrigation requirements for arable and perennial crops in Water District of Thessaly (EL08) and its sub-basins.

2.7.1. Potential irrigation water needs in sub-basin 2061

The overall potential irrigation water needs of sub-basin 2061 (189.5 hm^3) are considered as moderate. Overwhelmingly, alfalfa crop stands as accountable for almost 63% of the total potential irrigation water needs within the sub-basin (Figure 28). Cereals and perennial crops are responsible for the rest of the water requirements, while the needs of the rest of the crops are insignificant.

The annual water withdrawals for irrigation from the groundwater systems 4, 5, 6 and 16 that fell within the geographical borders of sub-basin 2061 (Figure 4, Figure8) are estimated to be 12.35 hm^3, 1.14 hm^3, 11.13 hm^3 and 1.44 hm^3, respectively (Table 8). Groundwater systems 19 and 20 are partially belong to sub-basin 2061 as well, but is hard to say which portion of the annual water withdrawals from these systems is caused agricultural activities in sub-basin 2016.

Despite the fact that rivers 38, 39, 40, 41, 42 and 43 are crossing the sub-basin (Figure 6), available data regarding withdrawals for irrigation there are only for river 44 and are estimated to be equal to 4.31 hm^3 (Table 7). In sum roughly 30 hm^{3}of water are estimated to be withdrawal from sub-basin's water resources for irrigation, whilst the potential net irrigation water needs are around 189.5 hm^3.

The lack of data about withdrawals from the rivers 38, 39, 40 and 43, as well as the weakness to define the amount of water withdrawals form groundwater systems 19 and 20, renders any further conclusions regarding the mismatch between sub-basins net irrigation water needs and withdrawals unfounded.

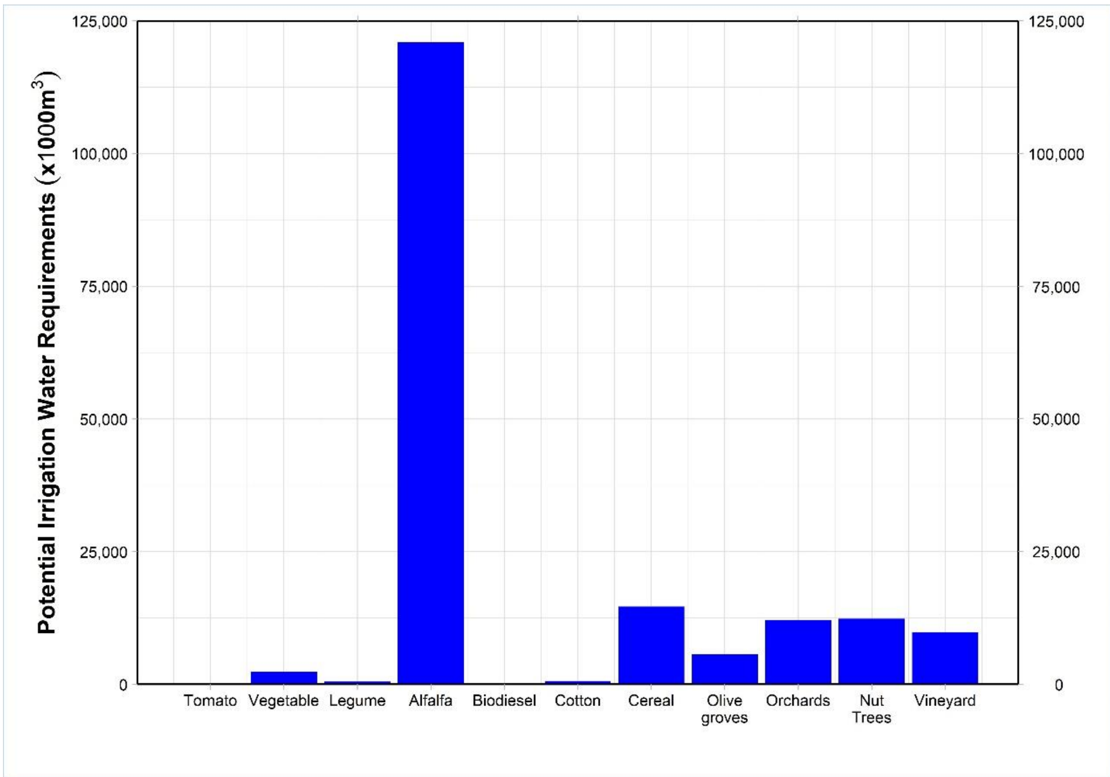

Figure 29. Potential irrigation water requirements for arable and perennial crops in sub-basin 2061.

2.7.2. Potential irrigation water needs in sub-basin 2062

The potential irrigation water needs of sub-basin 2062 are kind of insignificant when considered in the scope on total EL08 needs. The total sub-basin needs are approximately 4.1 hm^3 (just 0.21% of the total EL08 irrigation water needs) and are attributed mainly to alfalfa crop (Figure 29). In the absence of any surface water bodies the water needs of the sub-basin are covered through 20 groundwater system. (Figure 8). The estimated annual water withdrawals for irrigation from the EL0800250 are roughly 13.21 hm^3 (Table 8), an amount more than three times the potential irrigation water needs of the sub-basin. However, this is logical as groundwater system 20 spreads to sub-basins 2061 and 2066 as well and thus the excessive water is probably pumped within these areas.

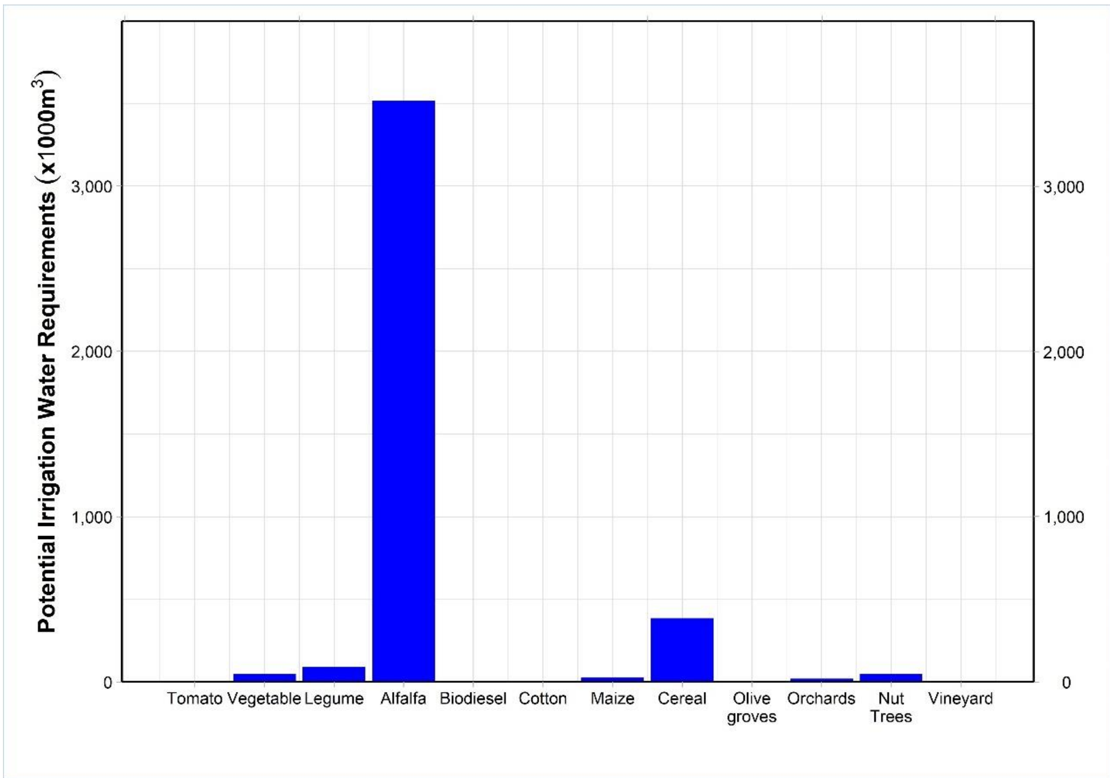

Figure 30. Potential irrigation water requirements for arable and perennial crops in sub-basin 2062.

2.7.3. Potential irrigation water needs in sub-basin 2066

With roughly 1,036.7 hm^3 estimated net irrigation water needs, sub-basin 2066 counts for 54% of the total EL08 requirements. Cotton and alfalfa are by far the most demanding crops with annual needs that reach the 377.5 hm^3 and 364.9 hm^3, respectively (Figure 30). From the rest of the crops, maize appears as the most considerable with annual needs up to 141.4 hm^3.

The geographical borders of sub-basin 2066 includes entirely the groundwater systems 3, 18, 14 and 27 and partially the systems 7, 12, 19, 17, 20 and 21 (Figure 4, Figure 8). Moreover, the sub-basin is crossed by the rivers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 29, 30, 31, 32, 33, 36, 37, 45, 46, 47 and 48 (Figure 6), including among them the main course of Pineios river. The estimated annual water withdrawals from the groundwater systems that belongs entirely to sub-basin 2066 are 354.1 hm^3, while the corresponding amount from the river is 1,628.6 hm^3. In total roughly 1,982.7 hm^3 of water is abstracted from the sub-basins available water resources for irrigation, whilst the net potential irrigation water requirements are calculated to be 1,036.7 hm^3. Even when the losses due to irrigation systems imperfections are included to the potential needs (1,187.0 hm^3 and 1,236.3 hm^3 for drip and sprinkler irrigation systems respectively), the estimated water withdrawals are remarkably larger. This is attributed to the following facts a) potential losses to surface water transfer pipe systems, b) over irrigation and c) transfer of surface water to the non-boring sub-basins, where there is a lack of water availability.

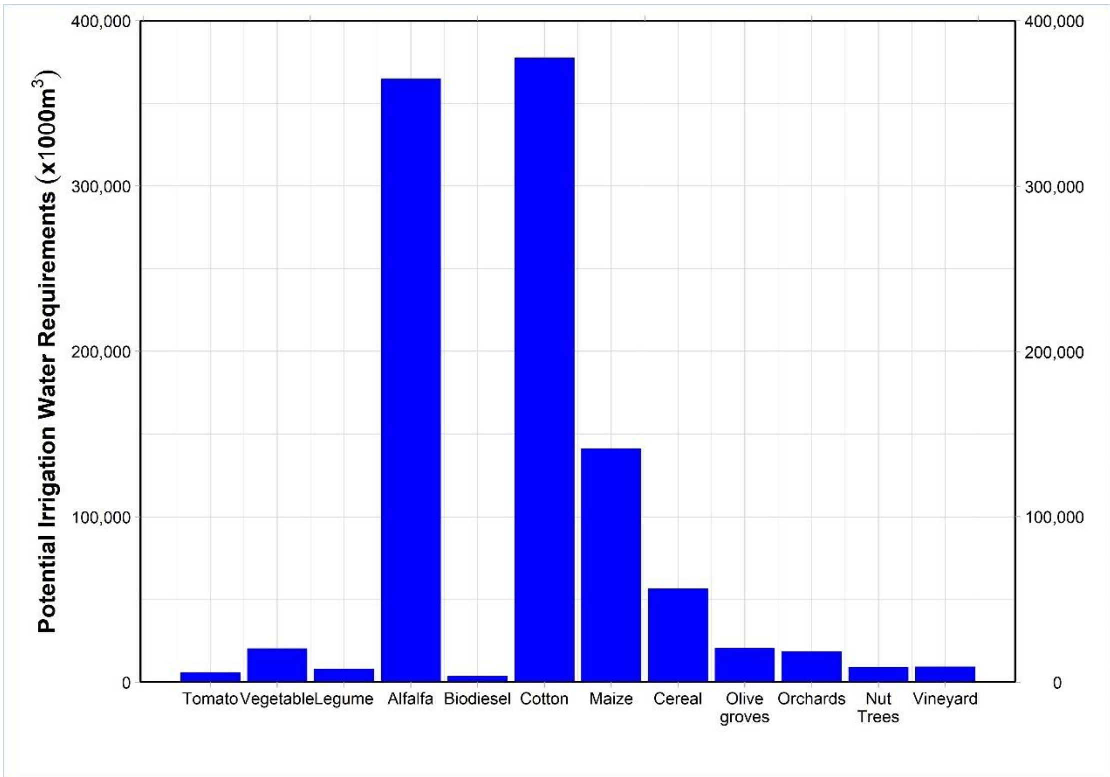

Figure 31. Potential irrigation water requirements for arable and perennial crops in sub-basin 2066.

2.7.4. Potential irrigation water needs in sub-basin 2067

The sub-basin 2067 net potential irrigation water requirements are trivial compared to total EL08 needs, roughly equal to 0.07% of them. They are attributed to alfalfa crop and cereals cultivation (Table 19). The water needs are covered completely by groundwater system 20 (Figure 4, Figure 8).

2.7.5. Potential irrigation water needs in sub-basin 2069

With total net potential irrigation water requirements equal to 13.3 hm^3, sub-basin 2069 counts for just 0.69% of total EL08 estimated needs. Nut trees and olive groves are the crops with the highest water needs but they are closely followed by cereals and maize crops. There are no surface water bodies within the sub-basin and the irrigation water needs are covered via groundwater system 21 (Figure 4, Figure 8). The estimated annual water amount that is abstracted from system 21 is roughly 24.22 hm^3 (Table 8), almost the double of the sub-basin's potential irrigation water needs. The excess of abstracted water is probably used to cover the needs of sub-basins 2066 and 2070.

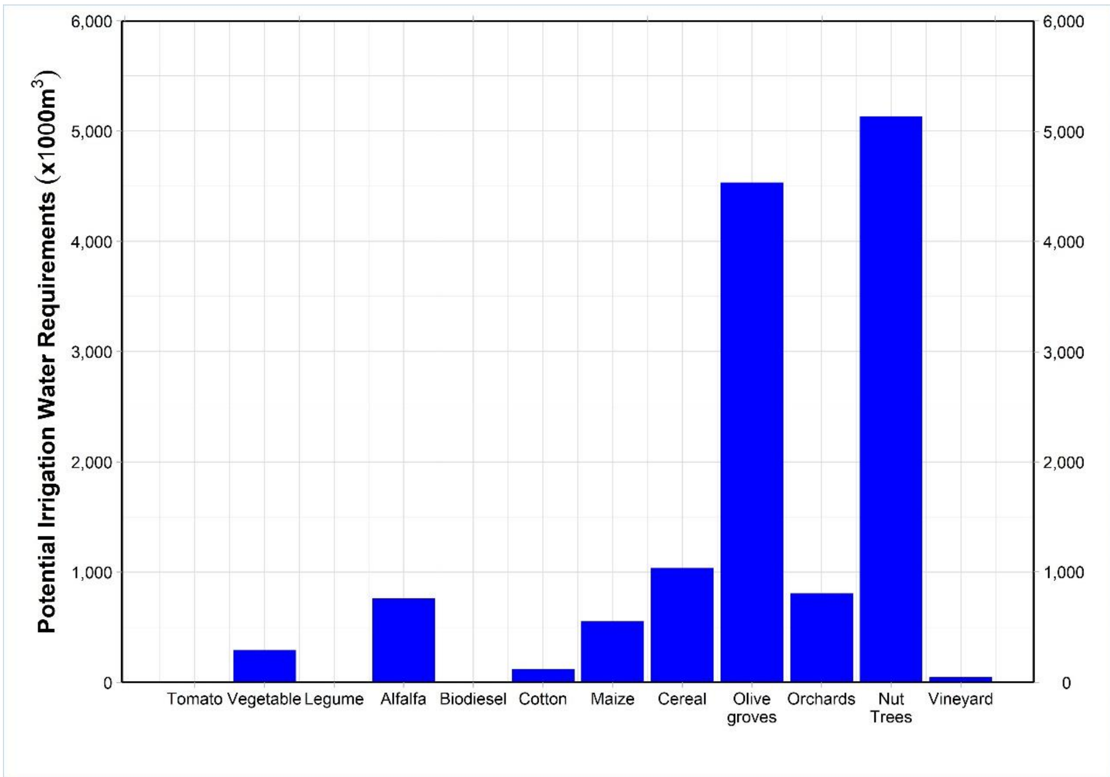

Figure 32. Potential irrigation water requirements for arable and perennial crops in sub-basin 2069.

2.7.6. Potential irrigation water needs in sub-basin 2070

Sub-basin 2070 is the sub-basin with the highest net potential irrigation water needs after sub-basin 2066. The calculated irrigation water needs are roughly 368.6 hm^3, with cotton to be the crop with the highest water needs followed by alfalfa and cereals. (Figure 32).

The water needs of the basin are covered by the artificial lakes Karla, Kalamakiou and Namaton, rivers 49-50 and the groundwater system 10 (Figure 4, Figure 6, Figure 8). Moreover, water is pumped from the groundwater systems 12, 17 and 22, but as these systems belongs to other sub-basins too it's unfounded to assume how much of the abstracted water it is used to cover the needs of sub-basin 2070. The water that is abstracted from lake Karla is estimated to be 64 hm^3 (Table 8), but there is a luck of data regarding the withdrawals from the rest of the lakes and rivers 49- 50. The annual withdrawals from groundwater system 12 are approximately 42.24 hm^3. It's obvious that just these two water resources (lake Karla and groundwater system 12) are not enough to provide enough amounts of water to fully cover the sub-basin needs. Nevertheless, the lack of data regarding water abstractions from lakes Kalamakiou-Namaton and the rivers 49-50 renders impossible to estimate if the within sub-basin water resources are adequate to fully cover the water needs or water is transferred via other sub-basins.

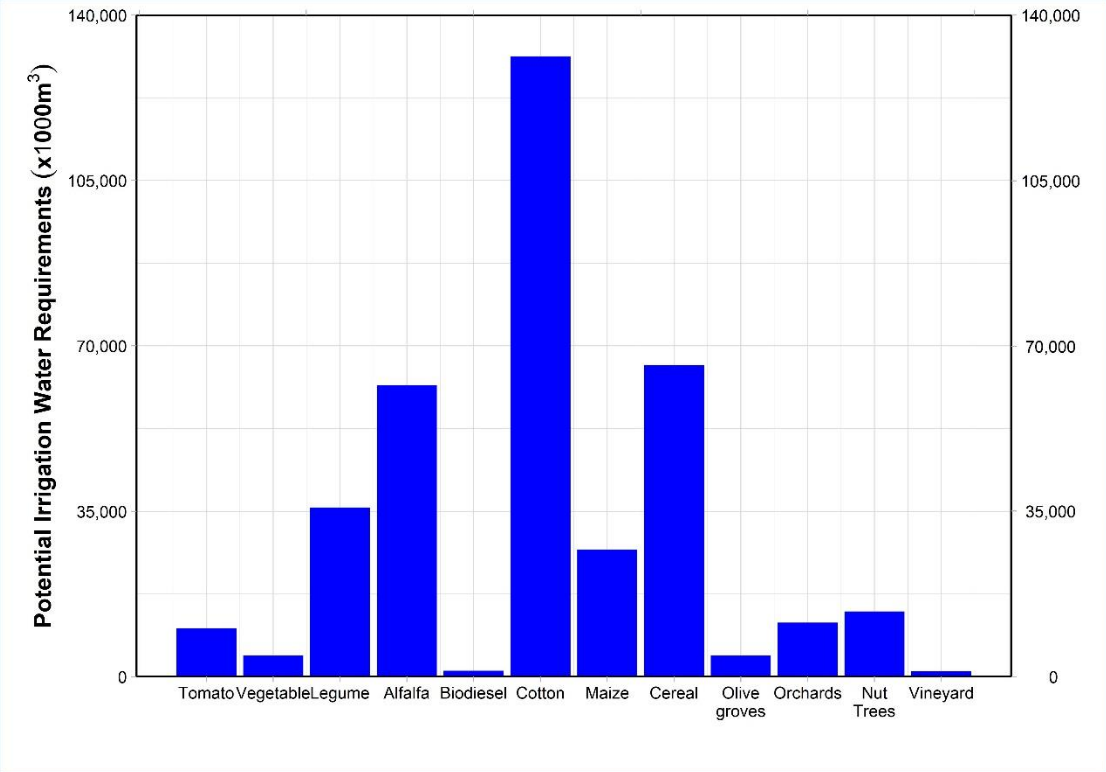

Figure 33. Potential irrigation water requirements for arable and perennial crops in sub-basin 2070.

2.7.7. Potential irrigation water needs in sub-basin 2077

A considerable amount of water is required to fully cover the net irrigation water needs of sub-basin 2077, equal to 191.4 hm^3. Alfalfa, cotton and cereals are the crops with the highest irrigation water needs, but legumes and maize require a considerable amount of irrigation water too.

Rivers 26, 27 and 28 (Figure 6) are crossing the sub-basin. Moreover, within the sub-basin's geographical borders are fully included the groundwater systems 8 and 23 (Figure 4, Figure 8), but small parts of other groundwater systems are included as well (e.g. part of the groundwater systems 3, 12). From the rivers are abstracted for irrigation roughly 15 hm^3 of water (Table 7), whilst from the groundwater systems 8 and 23 roughly 22 hm^3

(Table 8). Consequently, more water is probably abstracted from the partially included groundwater systems to fully cover the sub-basin net irrigation water needs.

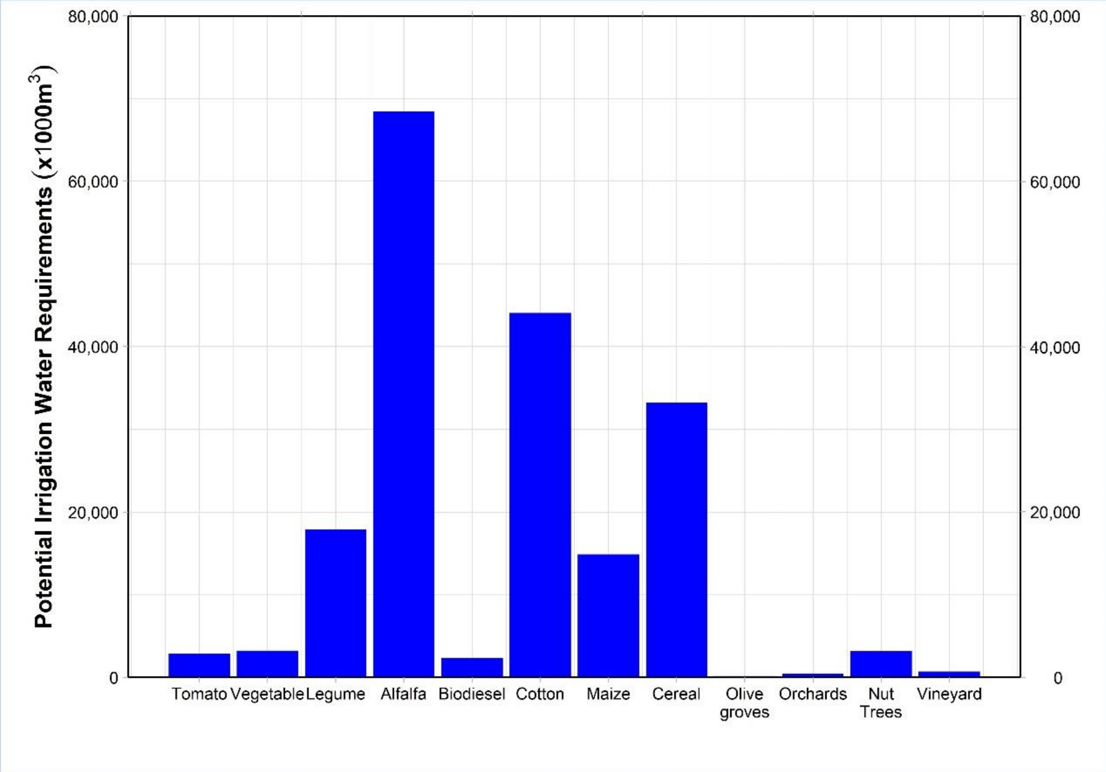

Figure 34. Potential irrigation water requirements for arable and perennial crops in sub-basin 2077.

2.7.8. Potential irrigation water needs in sub-basin 2154

The net irrigation water needs of sub-basin 2154 are considerably low, approximately equal to 30.7 hm^3. Alfalfa in the crop with by far the highest water needs, followed by biodiesel crops, cereals and maize.

The sub-basin can cover its irrigation water needs through water transfer from artificial lake Smokovou, which is just 10 km from the sub-basin's west edge, or via pumping through the groundwater systems 9, 15 and 24 (Figure 8). The annual abstractions from the groundwater systems are roughly 22.13 hm^3 (Table 8), and thus the rest of the water needs is assumed that are covered from artificial lake Smokovou.

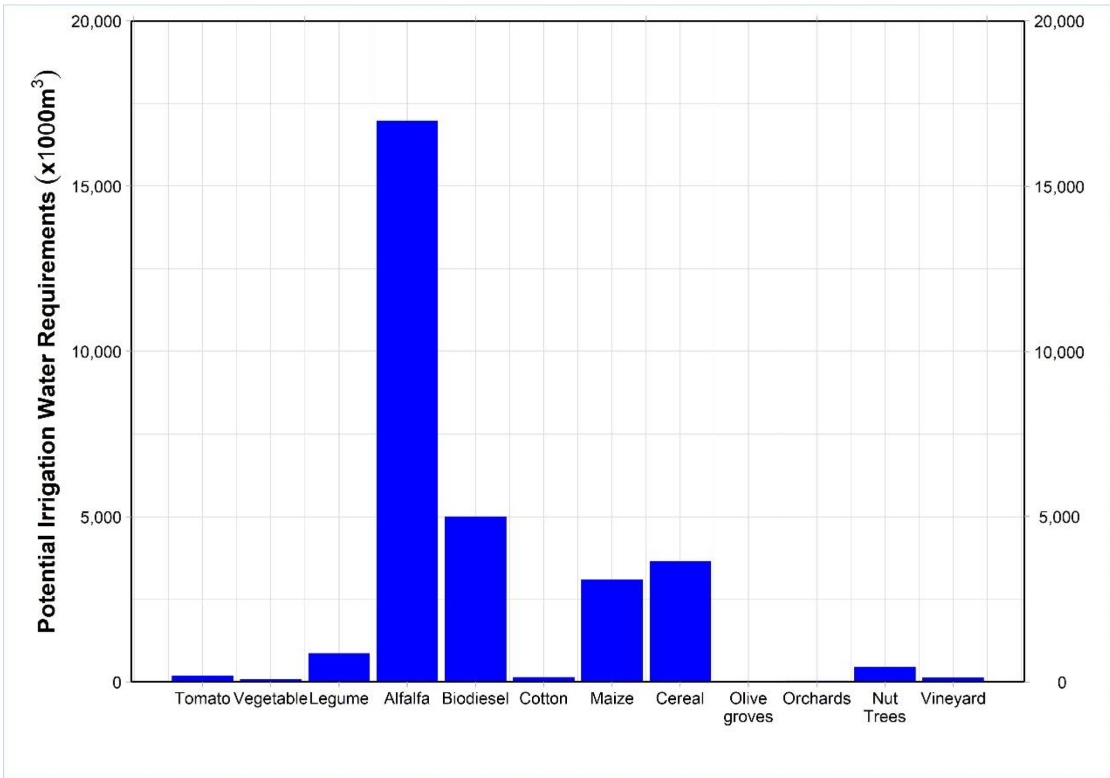

Figure 35. Potential irrigation water requirements for arable and perennial crops in sub-basin 2154.

3. Conclusions

In the extended data review performed in the framework of the Re-Source project to the available data regarding water resources management in the EL08, it was found that roughly 2,582 hm^3 of water is consumed for irrigation purposes annually. The required water amounts are withdrawn from surface water bodies (rivers, lakes) and groundwater systems. Nevertheless, the estimations of the potential net irrigation water requirements based on the proposed maximum allowable irrigation water quotas for each crop in combination with the data regarding the individual crops' area within EL08 in 2017, indicated that the consumed water amounts are larger than the needed ones (1,934.3 hm^3). This difference is mainly attributed a) to the irrigation systems imperfections, b) to water losses from canal and pipe transfer systems and c) the overexploitation of the available water resources by the farmers empirical irrigation scheduling in combination with the absence of a robust water withdrawal monitoring system which leads, as a result, to the over-irrigation of the crops.

The difference between the reported water withdrawals (2,582 hm^3) and the estimated net irrigation water requirements (1,934.3 hm^3), results in an average water use efficiency, within EL08, equal to 74.9% and can be considered as quite satisfactory. However, this average efficiency may vary significantly within EL08. For instance, the water use efficiency is expected to be even higher a) to areas with limited water resources, where the farmers are forced to follow deficit irrigation strategies, or b) to areas where contemplate irrigation systems with increased efficiency are used. On the contrary, water use efficiency is regarded to be substantially lower than 74.9%, to areas with abundance of water, where farmers tend to violate water quotas and over-irrigate, or where furrow and gun-sprinkler irrigation systems are used. This uneven distribution of water use efficiency within EL08 is highlighted to some extent in the discussion of potential irrigation water needs in sub-basin level that was performed from sub-section *2.7.1 Potential irrigation water needs in sub-basin 2061* to sub-section *2.7.8 Potential irrigation water needs in sub-basin 2154*. Nevertheless, lack of specific data regarding water withdrawals from each sub-basin renders the quantification of this uneven water use efficiency infeasible.

Moreover, the available historic weather data indicated different patterns of precipitation height and ETo demands within the region. These patterns are implying that the water needs of the same crop (e.g. cotton) may vary substantially within the EL08. Specifically, the water needs of a crop are expected to be lower in areas with low ETo demands and higher in areas with high ETo demands. Moreover, the water amount supplemented by the precipitation events that fall more often in some areas compared to the others during the cultivation season may mitigate the irrigation water need in some areas compared to others.

The available geological data unveiled the existence of fundamentally different geological formations, from alluvial deposits to dolomites and limestones, within EL08. These different formations can have as a result potentially different characteristics of the arable soils such as different textural classes, different saturated hydraulic conductivities, variable organic matter contents etc. Thus, the capability of the soils within EL08 to hold water, named field capacity, as well as the soils drainage rate may vary remarkably around the district.

Taking into consideration all the above it is obvious that the water quotas that are proposed for each crop according to the 2nd Update of RBMP – RBD (EL08), seem to be inadequate to integrate the unique climatic conditions and soil properties that are founded in EL08. Consequently, these quotas may be smaller or larger for some areas than others. Setting as a main unit the sub-basins delineated in the framework of ISPIRE directive and continue with an even lower-scale separation if the geological and meteorological conditions advocate for it, new water quotas for each crop should be defined.

Consequently, if a transition from the empirical, unsustainable agriculture that at the moment is implemented in EL08, is to be triggered, the use and integration of operational precision irrigation algorithms in the irrigation scheduling process seem to be mandatory. The implementation of these algorithms is expected to ameliorate the threat that is imposed by the agricultural sector to the district's available water resources, while at the same time will guarantee high crop yields. These algorithms will integrate the soil properties of each field as well as the micro-climatic conditions that prevail in the area, in order to calculate the exact amount of potential transpirable and evaporable water, the available water in the crop's root zone, and based on these info are going to generate an optimum irrigation schedule.

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