Water Metabolism and Water Management
in Samothraki Island

Final Report

Surface and ground water quantities, water abstraction, water demand

and a

Preliminary water resources management plan

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The Fonias stream headwaters (*photo by N. Skoulikidis*)

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Forward

Samothraki is an island with significant water resources considering its area (Skoulikidis et al. 2014). However, as a result of unsustainable water management, some settlements and crops suffer from water scarcity during the summer period and a number of streams face artificial desiccation with adverse ecological consequences. Also, the island is vulnerable to floods since flood forecasting and respective abatement measures are missing. Currently, water management is carried out in old-fashioned, add hock and, frequently, individualistic ways that are often inadequate to satisfy the needs. Especially during extreme events, like flood sand prolonged draughts. In addition, the River Basin Management Plan of Eastern Macedonia & Thrace (2012) and its first revision (2017) do not identify concrete water resources management actions or measures for the island.

The present study has been assigned to the Hellenic Centre for Marine Research (HCMR - Institute of Marine Biological Resources & Inland Waters) by the University of Natural Resources and Life Sciences, Vienna in order to illustrate the existing water management system, estimate the available water resources, water uses and demands and propose a preliminary water resources management plan for the island.

According to the contract signed between the University of Natural Resources and Life Sciences and HCMR, the current report refers to water abstraction (WP2.1) and water demand (WP3), and focuses particularly to the: a) registration and mapping of all municipal abstraction points from surface and ground water resources under the supervision of the Municipality, and b) estimation of water demand, via calculations of water consumption for various water uses during the dry season. in collaboration with the Municipality.

1. General Aspects

1.1 Activities of the research group

During the initial phase of the project, we carried out an extended literature research to collect studies related to the water resources of the island. Furthermore, in order to collect information regarding water abstraction and water uses covered by the Municipality of Samothraki, we visited the Island in the third week of September 2018 up to the end of the month. During that time, we had several meetings with the personnel of the Municipality's Technical Service Department and the Mayor, we collected relevant information and we implemented field work activities. It should be mentioned that a major problem for implementing this study was connected with the collection of water resources management information and data; a related data base is missing, the data are only partly digitized, and the main information is scattered in paper or orally among different members of the staff of the Municipality’s Technical Service.

It should be underlined that, despite the contract commitment, which is limited on municipal data, efforts were placed on gathering data also from private water users.

Thus, during the first phase of the project, we: (i) collected information on the organizational structure of the Municipality of Samothraki regarding water resources management, (ii) collected information and data on municipal water abstraction points (springs and drillings) for domestic purposes, data on water used for irrigation from both municipal and private drillings or wells, as well as data on livestock and crop type and area, in order to calculate respective water needs, (iii) performed field measurements in order to estimate or correct the coordinates of all water abstraction points, and (iv) measured, where possible, the discharge of springs used by the Municipality for domestic water supply.

At that time, head of the Technical Services Department was Parthena Romanidou who greatly assisted the data collection and field working activities.

In the second phase of the project we: (i) continued the recording and correction of the coordinates of all water abstraction points used for domestic and irrigation needs, (ii) performed field measurements to estimate stream water discharge, and (iii) carried out a hydrogeological research to estimate the characteristics and quantities of ground waters.

As the island faces water shortages during summer, estimations on water availability and use and water management plans should particularly focus on the dry period of the year[1]. We thus decided to carry out field work activities during the dry season of the year since at that time freshwater resources reach annual minima; the timing of field working was ideal for the purposes of the study, since 2018 and 2019 were dry hydrological years with restricted snow fall. In fact, the annual rainfall for 2018 was 590.4 mm and for 2019 around 515 mm were substantially lower than the multiyear (2008-2017) average (706.4 mm) (Fig. 1).

[1]The management plan additionally focuses on floods.

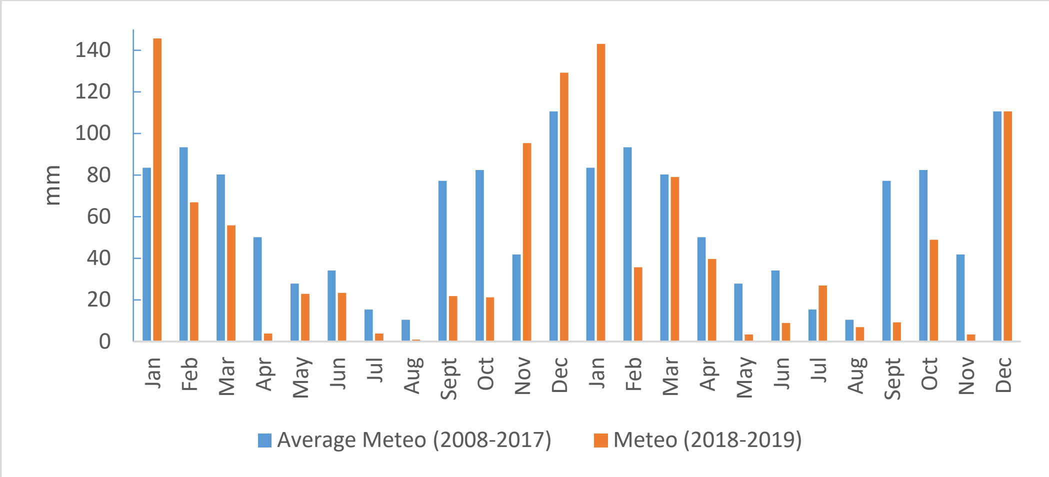

Figure 1. Comparison between monthly precipitation of 2018 and 2019 and the mean annual one (2008-2017) at the Samothraki meteorological station located in Chora.

1.2 Literature Research

A number of studies have been carried out on the island by the Institute of Geological and Mineral Exploration (IGME). In particular, in the framework of the IGME's project "Special hydrologic and hydrogeological research -Collection of long-term data", a hydrogeological research study has been carried out (Vergis 1984), in which hydrological data of 5 drillings and 40 springs have been reported for the dry and the wet periods of 1980. Data collection continued in the periods 1981-1990 on the same drillings and on a restricted number of springs (Vergis 1984, 1986, 1993; Tsanaktzis 1990; Romaidis et al. 2008, 2010). In addition, Romaidis (2006) conducted a hydrogeological study focusing on six springs. To obtain these studies was not that easy as one would expect.

1.3 Water resources management issues

Since 2011, the Municipality of Samothraki has, according to the law, a detailed internal organizational structure. According to this, the Municipality is responsible for carrying out water resources management. However, in the practice, citizens may independently cover their needs for households, touristic activities, or irrigation purposes.

Related structure of Samothraki Municipality

According to Decision 15240 (Government Gazette[2]Nr. 2279, 12.10.2011), the Municipality of Samothraki has an Internal Organizational Structure that includes a number of collaborating operational units. Here we describe units 2 and 6 which include activities relevant to the purposes of our study.

The Operational Services Unit (Unit 2), with the Independent Office for Programming, Informatics and Transparency, is actually the planning unit, supporting the Municipality regarding the outcomes of the 5-year Operational Programs and the Annual Action Programs. The responsibilities of this office include (among others) a) the collection, processing, documentation and updating of geographic, demographic, economic and social data, b) research and implementation of studies related to the development needs of the Municipality, c) investigation of the feasibility of developmental proposals and prioritization of projects,

[2]The official journal of the Government of Greece which lists all laws passed by Cabinet and President.

actions and measures, d) study and design of economic development programs through the exploitation of local natural resources, development of human resources, exploitation of municipal property, as well as creation and management of local economic infrastructures, and e) the integration of municipal plans and actions in developmental programs and monitors their implementation.

The Supporting Services Unit (Unit 6), which actually implements the planning objectives. It includes, among other departments, the Independent Department of Technical Services and Quality of Life. This Department is responsible for the execution and maintenance of all kinds of municipal technical works, the protection and upgrading of the natural, architectural and cultural environment, the collection and transport of waste, the separate collection and transport of recycled materials, etc. The Department includes the following Offices:

Technical Works Office

Office of Electromechanical Works and Transportation

Water-Sewerage Office

Office of the Environment, Cleanliness, Green Areas and Civil Protection

The Technical Works Office collaborates with Unit 2 in planning the Municipality's action programs and the implementation of technical projects, including hydraulic and land reclamation projects and checks related studies (preparation with the Office's staff or delegation to third parties).

The Water-Sewerage Office is responsible for planning expansion or renewal works for the water supply and sewerage networks, as well as for the repair, maintenance and good operation of drillings, water supply distribution systems, and water reservoirs, it controls the hydrometer records, etc.

Finally, the Office of Environment, Cleanliness, Green Areas and Civil Protection plans and proposes the implementation of policies, programs, actions and measures for protecting and upgrading the environment, ensures the protection and management of water resources and mitigates pollution, monitors the implementation of protected areas in cooperation with other authorities, ensures the establishment and proper operation of waste collection and management. It recommends the regulation of environmental protection issues, according to the jurisdictions of the Municipality, e.g. for the establishment and operation of slaughterhouses, regarding environmental remediation issues, for the establishment of industrial and business areas and related environmental impact assessment studies (referred in Article 5 Law 2545/1997, Government Gazette 254, A), for following up programs for the Environment, Energy and Climate Change. It finally studies, plans and monitors the implementation of alternatives solid waste management systems (recycling).

Despite the high responsibilities of the Department of Technical Services and Quality of Life, the number of the staff currently working is only14, of which only four are highly educated, three are technicians and the rest workers. The head of the Department is a civil engineer (Paschalia Pavlidou), one is architect (Parthena Romanidou), one is agronomist (Doukas Chailas), one is environmentalist (Panayiota Fotaki), two are hydraulic technicians (Yiannis Koletsas and Nikos Koutsouris) who are mainly focusing on water resources management, and one electrician (Panayiotis Maltezos) who is responsible for groundwater management issues.

2. Estimation of water abstraction

2.1 Registration and mapping of municipal and private water abstraction points

2.1.1 Historical and current water use

Water collection for domestic use in Samothraki can be traced back to the ancient times. In the area of the Sanctuary of the "Grate Gods" the Nike-fountain was found to the south of the ancient theatre. This was actually a water reservoir which was provided from springs of abundant supply. Excavations revealed a water supply network made out of clay material and an aqueduct with a pipe, both dated back to the Early Hellenistic period (323 - 220 B.C.). On the hill where the medieval fort of Gateluggi emerges, a rectangular aqueduct with a coating for sealing has been also excavated. Finally, an aqueduct with a dome form from the Roman times has been also discovered.

Nowadays, domestic water supply is carried out by surface and ground water abstraction by exploiting springs and wells/drillings, respectively. The increased use of surface water sources and the utilization of ground water sources in modern times is the result of the increase in population (especially in the touristic period), an increase of water use per capita regarding domestic use, and mainly due to high irrigation.

2.1.2 Water Abstraction Points

Regarding domestic use, the Municipality exploits a total of 18 springs, one well, and two drillings. In certain cases, when water shortage incidents occur during the summer period, spring water may be mixed with stream water, as in the case of the Varades water abstraction point. Apart from domestic use, water from these sources serves the needs of 13 hotels. Tables 1 and 2 provide the names of Municipal springs and drillings for domestic water use, their coordinates and the settlements that they serve.

Regarding irrigation, the Municipality manages 16 groundwater drillings, of which two are nowadays inactive (Table 3). Since 2015, the Municipality applies a system with electronic hydrometers, where each farmer uses a card to activate water abstraction from the drillings. The time of water consumption is registered on the card. According to the former mayor Athanasios Vitsas, this system substantially reduced water use from the drillings, as users pay 2.6 Euro per hour. Unfortunately, the disastrous flood of September 2017 destroyed all respective files and thus data on groundwater abstraction are not available for the years 2015-2017.

A problem with the registration of the necessary information, is connected with terminology; regarding the water abstraction points, there are differences between the codes used by the Municipality and those existing in the studies of IGME. Moreover, the IGME's codes differ between older and more recent studies. There were also problems regarding the coordinates and the names of the Municipal springs and boreholes. Missing or wrong coordinates and data of water abstraction points exacerbated our efforts. In the frame of this activity, we attempted to cover these gaps in close cooperation with Parthena Romanidou. In fact, we compiled existing data and information, and, regarding the Municipality data, we measured and registered missing coordinates of springs and drillings (Figure 2), corrected wrong ones and produced respective GIS maps. However, corrections of the IGME abstraction points was not possible.

A problem with monitoring municipal spring discharges of springs used for domestic water supply is that the exploitation of most of them is facilitated by means of cisterns constructed directly at the spring outflow connected with closed distribution pipes (Figure 3). As a result, in most of the cases it was not possible to measure discharge at the springs’ outflow.

Figure 2. GPS measurements

Figure 3. Cistern installed directly at a spring outflow

Regarding domestic use, the Municipality exploits a total of 18 springs, one well, and two drillings (Figure 4). Apart from domestic use, water from these sources serves the needs of 13 hotels.

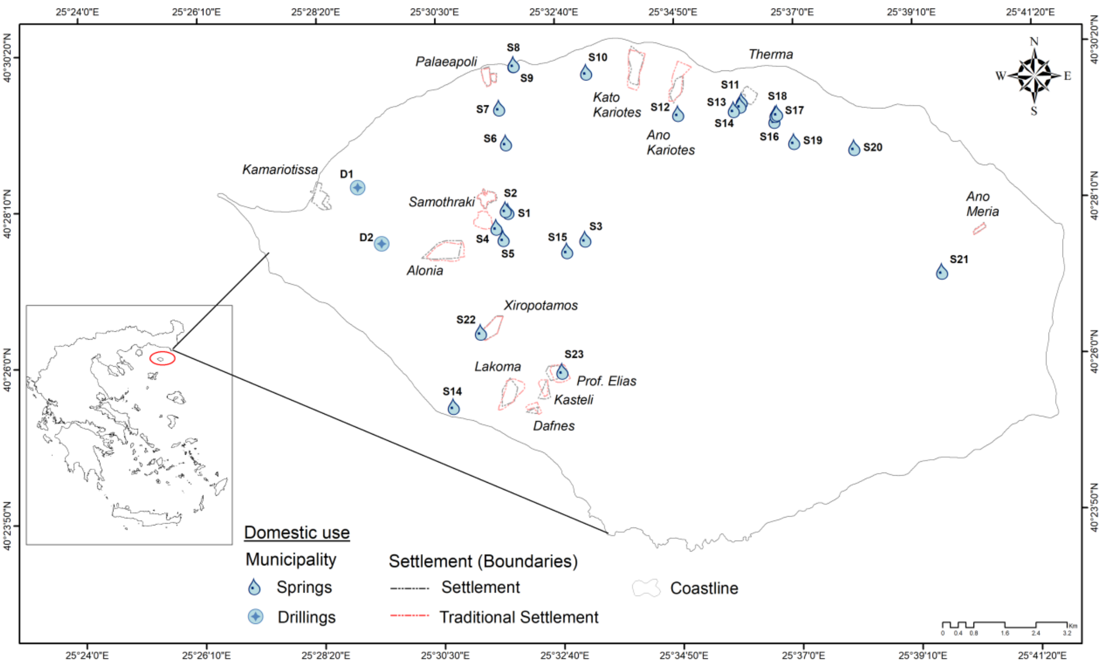

Figure 4. The springs and drillings that are exploited by the Municipality for domestic use.

To gain an overview regarding domestic water supply, details on the origin of water and the water supply system are given:

Kamariotissa and Paleapoli are supplied by two springs located at Kopsi and by a third one within the archaeological site. These springs supply a 100 m^3 reservoir, situated south of Paleapoli. Since the spring of the archaeological site has a lower altitude in respect to the reservoir, a pumping station with two pipes drives the water to Paleapoli and a third on to the Kamariotissa reservoir (200 m3). A new pipeline drives water from the Kamariotissa reservoir to Katsabas area to supply off-site areas. A drilling located east of Kamariotisa serves the increased needs of this settlement during the summer period. The area east of the Paleapolis archaeological site is supplied by the Vasilikos spring.

Chora and Alonia are jointly supplied from the Askamnes and Sotiros springs. Additionally, and especially in summer, Chora is supplied from the Vrysia springs and Alonia used to be supplied from the Agios Georgios spring.

Lakoma, Makrylies and Xiropotamos are mainly supplied from the Panagia Mandalo spring. In addition, Lakoma is also served by a well located 60-70 meters from the coast.Daphnes - Kasteli - Prophitis Elias are served by Panagia Mandalo spring.

Kato Kariotes and Ano Kariotes are supplied from different sources located at Voutiros Kapias, respectively.

Therma is mainly supplied by two springs, one south of the settlement and one east in the area Pera Therma, located near a stream. The Agios Antonios spring serves the municipal campsite. The Varades camping site is supplied by the homonymous spring.

Finally, Ano Meria is supplied by Karidies spring.

Tables 1 and 2 provide the names of Municipal springs and drillings for domestic water use, their coordinates and the settlements that they serve.

Table 1. Names (terminology according to the Municipality) and coordinates of municipal springs for domestic use and the settlements that they serve

Settlement	Spring	X	Y	Map code
Chora	Vrysia 1	629666.8497	4480856.464	S1
	Vrysia 2	629598.5171	4480904.358	S2
	Varades	631648.3359	4480143.912	S3
	Sotiros	629365.5367	4480450.611	S4
Alonia	Ag. Georgios (*not operating*)	629549.5219	4480159.543	S5
	Varades	631648.3359	4480143.912	S3
	Sotiros	629365.5367	4480450.611	S4
Kamariotissa	Ag. Theodoros	629608.8522	4482615.663	S6
	Kopsi	629432.5142	4483510.364	S7
	Skra (Axios 1)	629796.4439	4484621.645	S8
	Skra (Axios 2)	629802.2152	4484626.075	S9
Palaeapoli	Ag. Theodoros	629608.8522	4482615.663	S6
	Kopsi	629432.5142	4483510.364	S7
	Skra (Axios 1)	629796.4439	4484621.645	S8
	Skra (Axios 2)	629802.2152	4484626.075	S9
Vasilikos	Vasilikos	631665.3378	4484432.515	S10

Kato Kariotes	Voutiros	635664.0034	4483684.829	S11
Ano Kariotes	Kapias	634031.9095	4483370.863	S12
Therma	Therma	635627.3455	4483584.112	S13
	Milia	635462.5395	4483472.187	S14
	Askamnes	631178.9382	4479847.399	S15
	Road towards summit Fegari (pump)	636532.3608	4483345.313	S16
	Pathway towards summit Fegari (pipe)	636532.3608	4483345.313	S17
Pera Therma	Svotana	636569.0634	4483382.74	S18
	Grigorakis	637013.9572	4482648.999	S19
Varades	Ag. Antonios	638554.7755	4482494.196	S20
Ano Meria	Kandour (Kardies)	640808.3452	4479314.753	S21
Makrylies	Terzis' mill	628963.3713	4477756.516	S22
Xiropotamos	Panagia Mandalou	631059.7112	4476752.616	S23
	Terzi'smill	628963.3713	4477756.516	S22
Lakoma	Panagia Mandalou	631059.7112	4476752.616	S23
	Macrylies beach (well)	628269.1335	4475842.496	S14
Profitis Elias	Panagia Mandalou	631059.7112	4476752.616	S23
Kasteli	Panagia Mandalou	631059.7112	4476752.616	S23
Dafnes	Panagia Mandalou	631059.7112	4476752.616	S23

Table 2. Names (terminology according to the Municipality) and coordinates of municipal drillings for domestic use and the settlements that they serve

Settlement	**Drilling**	**X**	**Y**	Map code
Alonia	Sklavouna	626407.72	4480006.55	D1
Kamariotissa	Lagada (Trypa)	625791.43	4481454.14	D2

Regarding irrigation, the Municipality manages 16 groundwater drillings, of which two are nowadays inactive (Table 3, Figure 5). Since 2015, the Municipality applies a system with electronic hydrometers, where each farmer uses a card to activate water abstraction from the drillings. On each card the time of water consumption is registered. According to the former mayor Athanasios Vitsas, this system substantially reduced water use from the drillings, as users have to pay 2.6 Euro per hour. Unfortunately, the disastrous flood of September 2017 destroyed all respective files and thus data on groundwater abstraction are not available for the years 2015-2017.

Table 3. Names (terminology according to the Municipality) and coordinates of municipal drillings for irrigation and the settlements that they serve

Settlement	**Drilling**	**X**	**Y**	**Map Code**
Kamariotissa	Aj. Kara	624827.677	4479927.1	D3
	Lagada (Trypa)	626097.944	4481032.5	D2
	Mavrou (not operating)	624544.175	4480137.5	D4
Alonia	Ag. Dimitrios 1	625580.418	4479554.8	D5
	Ag. Dimitrios 2	625872.386	4479457.1	D6

	Tzigkounas	626310.14	4478996.8	D7
	Panagouda	625968.562	4478967.2	D8
Alonia	Sait Arch	627351.74	4479470.4	D9
	Sykia	625421.535	4479255.9	D10
Lakoma	Apatsanades	626683.269	4477985.5	D11
	Ochtos	627227.849	4477447.4	D12
	Alanoudia	627741.0	4476470	D13
Makrylies	Tiganouria	628013.0	4476298.6	D14
Pachia Ammos	Koitada 1	631597.584	4473869	D15
	Koitada 2	631775.781	4473900.4	D16
	Mellagki (not operating)	626270.188	4481869.4	D17

Besides municipal drillings used for irrigation, farmers install their own boreholes or dig wells within their properties to irrigate their fields. They may additionally install km-long PVC pipes to transfer water from neighbouring springs or streams. To obtain the rights for exploiting water resources, farmers are obliged to submit a statement that includes, among others, the source type of water used, the coordinates of the water abstraction points, the type and area of cultivation to be irrigated, the irrigation system, the irrigation period, and the minimum and maximum water use. Nevertheless, illegal surface water abstraction is considered immense. According to the respective licenses, farmers abstract privately water from 9 wells, 7 drillings, and two stream reaches, whereas in two cases there are no data on the source and the amounts of water used.

Table 4 provides data on the private water abstraction points.

Table 4. Ground and surface water abstraction points used privately for irrigation. their coordinates. the irrigation system applied and the type and area of cultivation served (1 acre = 1000 m^2 - data according to water use licenses provided by the Municipality)

Source of water	X	Y	Map code	Type of cultivation	Irrigated area (acres)	Irrigation system
well	626157.48	4478926.8	PR1	barley	0.71	Canals, artificial rain
drilling	625633.93	4478117.7	PR2	barley-wheat. vetch. alfalfa. olive groves		surface irrigation
drilling. well	626094.37	4478807.1	PR3	olive groves	5.5	canals
well	629672.21	4475882.4	PR4	vineyard and olive groves	1 & 2	drip irrigation
drilling	625043.58	4480962.5	PR5	olive groves	2.5	artificial rain
well	626772.63	4478873.8	PR6	barley	0.48	not irrigated
-	-	-	PR7	olive groves	5	free flow
-	-	-	PR8	alfalfa and wheat	5 & 10	sprinkler irrigation
well	634356.91	4484494.4	PR9	olive groves	6	surface irrigation
well	632910.55	4483510.5	PR10	olive groves		canals - pipes
well	631466	4484927	PR11	-	4	not irrigated
drilling	624669	4480406	PR12	vineyard and olive groves	1 & 8.5	drip irrigation
drilling	625419	4478776	PR13	cereals	27.7	sprinkler irrigation
drilling	628031.52	4476682.1	PR14	alfalfa. corn and cereals	16. 4 & 30	sprinkler irrigation
well	625435	4479171	PR15	vegetables	8	drip irrigation
well	626901	4477239	PR16	Vineyard and olive groves	0.79 & 0.48	drip irrigation
drilling	628502.75	4475835.6	PR17	olive groves	25.5	surface and drip

stream	626681.88	4479046.3	PR1	olive groves	4.5	surface irrigation
stream	630747.14	4475543.3	PR2	olive groves and vineyard	28.1 & 13.2	drip irrigation

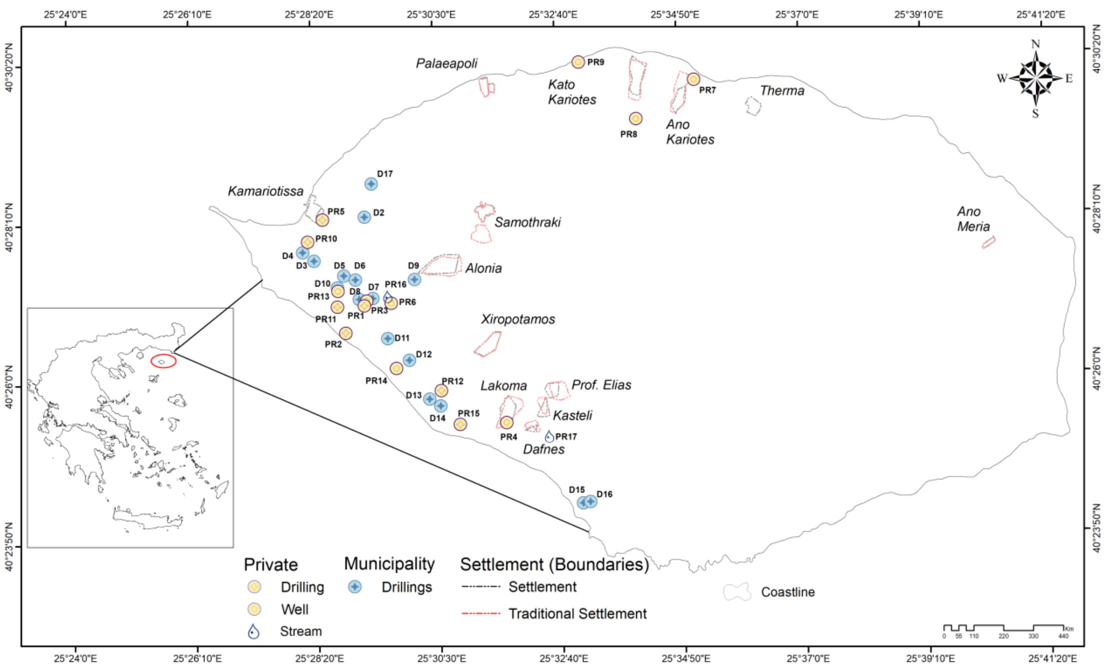

Figure 5. Water abstraction points (drillings, wells, streams) that used for irrigation on Samothraki Island.

2.2 Estimation of water uses/needs

2.2.1 Domestic water consumption and needs

Domestic water consumption data were provided by the Municipality for the year 2016 (Table 5). According to these data, the total annual domestic water consumption for 2016 was 371,160 m^3. Note that 2016 was a particularly dry year with water shortages during summer. As a result, the long-term annual domestic water consumption should be higher.

Table 5. Water consumption in the island's settlements for 2016

Settlement	Water consumption in m^3/year
Chora	120.395*
Kamariotisa	101.308
Lakoma	36.803
Alonia	29.557
Therma	25.528
Profitis Elias	19.090
Palaeapoli	14.942
Kato Kariotes	12.914
Xiropotamos	9.413
Ano Meria	7.072
Makrylies	6.742
Ano Kariotes	4.577
Total	**371.160**

*31.206m^3/year are from flowmeter measurements and 89.189 m^3/year from estimations by the Municipality

Furthermore, the domestic water consumption has been compared with the domestic water needs. Considering a mean daily water use of 250 L/capita and the population of the island (2,859 citizens in 2011), the total water needs of the permanent population is estimated at 260,884 m^3/yr. Tourist arrivals are estimated to 36,000 per year (for 2015) with an average stay of 4.79 days (Schwaiger 2017). According to these numbers, touristic needs reach 43,110m^3/yr. Hence, the total domestic water needs are estimated to 303,994 m^3/yr. However, if we consider a more realistic domestic water consumption per capita of 129 L/day, as reported for the city of Alexandroupolis (Gratziou et al. 2006), the total domestic water needs in Samothraki decreases to 156,860m^3/yr. This number is not much different from the estimations of Schoder et al (2016), i.e. 178,523 m^3/yr. From the above estimations, it may be concluded that domestic water consumption on the island overwhelms the respective needs by a factor of ~2.3.

Based on data of the Municipality, Romaidis (2006) reported a domestic water use of 425,955 m^3/yr and calculated the needs at 323,390 m^3/yr (using 250 L/day*capita). According to the RBMPs of Thrace Hydrological District, the groundwater abstraction for domestic use alone is estimated to be about 860,000 m^3/yr. This number is considered not realistic. Finally, Karavitis & Kerkides (2002) provided an indicative water demand for domestic use of 500,000 m^3/yr.

2.2.2 Irrigation water use and needs

Figure 6 presents the land use map according to CORINE (2006). As a result of the mountainous relief of the island, agricultural land is restricted. Cultivated area numbers vary depending on the literature source[3]. According to the data of the Municipality for 2017, the total cultivated area reached 29.69 km^2 (16.7% of the island's area), of which 29.66 km^2, i.e.99.9%, is irrigated.

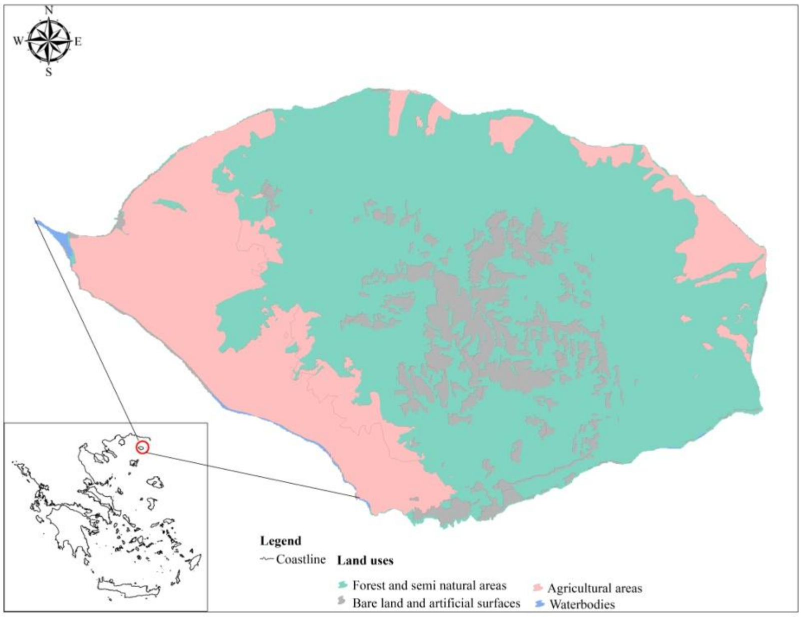

Figure 6. Land use map of Samothraki Island according to CORINE (2006)

Data on real water uses for agriculture are missing. Regarding Municipal drillings serving irrigation needs, existing information refers to the discharge of each drilling (Table 6) and the

[3] 24.6 km^2 (CORINE. 2006), 30.8 km^2 (NoSI, 2011) and 45.7 km^2 (Hellenic Statistical Service. 2011)

operation time of all drillings together. Regarding private water uses for irrigation, data on water withdrawal, obtained from the respective licenses, are only theoretical (Table 7).

For Municipal boreholes, the total operation time of all drillings together in 2018 was 3,716 hours. Groundwater abstraction for irrigation from Municipal drillings during 2018 is estimated at 1,631,324 m^3. This number derives from the data of Table 6, by multiplying the average discharge of the drillings (31.4 m^3/h) with the number of operating drillings (14)and the total operation time (3,716 hours).

Regarding private with drawls, irrigation requirements range between 106,069 and 147,948 m^3/yr (average 127,008 m^3/yr), of which 82,029 to 127,458 m^3/yr (average 104,743 m^3/yr) derive from groundwater sources (Table 7).

As a result, the total (municipal and private) mean annual water abstraction for irrigation purposes (focusing on 2018) reaches 1,758,332 m^3/yr, of which 1,736,067 m^3/yr refers to groundwater.

According to the RBMPs of Thrace Hydrological District, the total mean annual groundwater abstraction for irrigation is 1,660,000 m^3.

Keeping in mind that, in common practice, stream or spring runoff are substantial sources of unregistered irrigation water on the island, an effort has been made to estimate total irrigation water abstraction needs by employing the area of the different cultivation types applied on the island (respective data were provided by the Municipality for 2017) considering the irrigation needs of each crop type. The calculation procedure is presented in the Appendix I (Tables 1A-7A). The water requirements for different crop categories are defined in Law 16/6631/89. particularly for the Thrace Hydrological District. Since irrigation on the island is largely applied by a mixture of surface water application, sprinkler, and drip irrigation, the irrigation efficiency was set to 85% according to respective data provided by the Law. Water distribution in Samothraki is applied either through traditional open channels or via PVC pipes. To calculate irrigation losses due to the water distribution system we used the numbers provided in Law 16/6631/89, i.e. 5% losses for pipes and 10% for open irrigation channels, and assumed (after discussions with the Municipality's Technical Service staff) that 75% of irrigation on the island is carried out through pipes. Finally, the irrigation period according to the Municipality is June-September and irrigation covers the entire months.

According to this approach, the annual water requirements for irrigation range between 13.93and 16.93 hm^3 [4], with an average of 15.43 hm^3. Schoder et al. (2016) estimated the potential water demand for irrigation at7.22 hm^3/yr. These numbers are immense compared to the estimated annual water use for irrigation (1.76 hm^3), which is 8.8 times lower than the theoretical crop needs.

Table 6. Municipality irrigation drillings and their discharge in m^3/h

Drilling	**Discharge** (m^3/hour)	**Settlement**
Ag. Kara	20	Kamariotissa
Trypa*	50	
Mavrou	not operating	
Ag. Dimitrios 1	25	Alonia
Ag. Dimitrios 2	50	

[4] 1 hm^3 = 1,000,000 m^3

Tzigkounas	50	Alonia
Panagouda	35	
Sait Arch	40	
Sykia	40	
Apatsanades	35	Lakoma
Ochtos	45	
Alanoudia	15	
Tiganouria	10	Makrylies
Koitada 1	12	Pachia Ammos
Koitada 2	12	
Mellagki	not operating	

***** gas station

Table 7. Maximum and minimum water withdrawal from private boreholes, wells and surface water (data according to water use licenses. GW: groundwater. SW: surface water). The additional details are provided in Table 4.

Source of water	**Maximum annual water withdrawal (m^3/yr)**	**Minimum annual water withdrawal (m^3/yr)**
well	284	213
drilling	-	-
drilling. well	400	200
well	200	150
drilling	200	100
well	0	0
well	4176	3488
well	-	-
well	-	-
drilling	4160	3408
drilling	21408	3700
drilling	80000	60000
well	4000	500
well	200	150
drilling	12430	10120
SUM GW	**127.458**	**82.029**
	Average 104.743	
stream	2490	2040
stream	18000	22000
TOTAL	**147.948**	**106.069**
	Average 127.008	

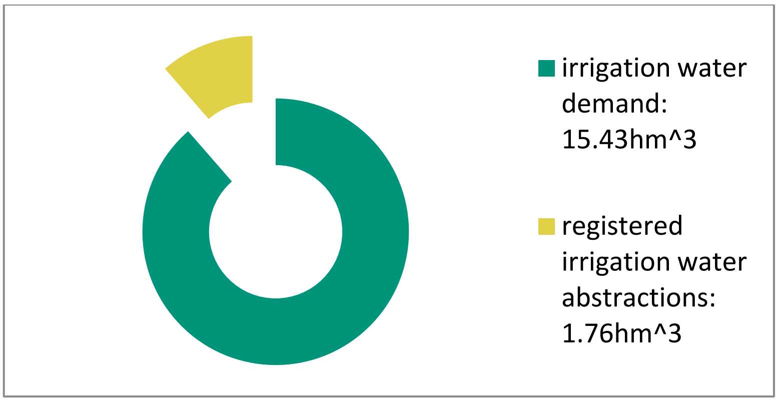

Figure 6. Comparison between irrigation water use (estimated according to data provided by the Municipality of Samothraki) and the theoretical irrigation demand, estimated according to the area and the water requirements of the different cultivation types, the irrigation period, the irrigation systems applied, and the theoretical irrigation losses.

2.2.3 Livestock water needs

Data related to water use by livestock are missing. We thus calculated livestock water needs. According to http://provata-assaf.blogspot.com/ 2013/05/blog-post_7.html, the mean water consumption for sheep has been estimated to 5 L/day. For goats, a mean value of 2.54 L/day has been applied according to the average of different literature sources summarized in Anthitsa et al. (2017). The latter authors provide a value of 37.5 L/day for horses. Considering the number of animals according to data from the Municipality for 2017, the estimated water consumption for livestock reaches 60,444 m^3/year (Table 8). According to the RBMPs, the annual groundwater use for livestock is estimated at 90,000 m^3.

Table 8. Water consumption according to livestock type (data Municipality of Samothraki for 2017)

Livestock type	Livestock number	Average water consumption per livestock type (L/day)	Total Water consumption (L/day)	Total Water consumption (m^3/year)
sheep	18,735			
small sheep	1,220			
rams	581			
sum	**20,536**	5	102,680	38,505
goats	20,920			
small goats	1,188			
mail goats	544			
sum	**22,652**	2.5	56,630	21,236
horses	50	37.5	1,875	703
Total				**60,444**

2.2.4 Total water needs

By summing up the water needs for irrigation, domestic and livestock, results an average total figure of 15.65 hm^3/yr, whereas irrigation demands make up around 98.6% of the total water needs (domestic and livestock needs comprise 1 and 0.4%, respectively).

3. Estimation of water resources availability

The design and management of water resources necessarily needs a preliminary assessment of water demands and water availability. Estimation of water resources availability is an essential step for devising efficient water resources management strategies.

3.1. Springs

IGME registered 42 cold springs located at low and mid altitudes of Samothraki Island. Despite their low permeability, the magmatic rocks of the island (predominately ophiolites and secondarily granites and volcanic rocks) host 33 springs[5] (Vergis 1984, 1986) developed within cracked type aquifers (see 3.2.1). This is the result, of intense tectonic activity which caused rock fracturing and cracking enabling the formation of small ground water aquifers within rock fractures and valleys and ravines filled up with weathered material of these rocks.

The majority of these springs (18) are located within ophiolitic rocks. They are predominately contact springs between ophiolites and the Quaternary deposits (such as Π-3 to Π-9 and Π-11, Π-13 and Π-14, see Fig. 7). Some springs (located between Chora and Profitis Elias, i.e. Π-20 to Π-24) also draining ophiolites are overflow springs, while 11 small springs located within granitic (Π-31 to Π-40) and two within volcanic rocks (Π-16 and Π-19) are fracture type springs (Vergis 1986). The mean annual discharge of springs developed within ophiolites range between 0.65 and 19.5 l/sec and show low seasonal variability. The mean annual discharge of springs located within granite rocks range between 0.1 and 6.5 l/sec, while volcanic rock host two springs with 0.3 and 5.4 l/sec (Vergis 1984, 1986).

In addition, 9 contact springs are connected with sedimentary groundwater aquifers located at the western lowland parts of the island (IGME), the so called "Xiropotamos ground water system" (RBMP 2017, see 3.2.1). These aquifers are located within Neogene and alluvial sediments. IGME speculates that the alluvial aquifers are laterally fed by the cracked aquifers. The mean annual discharge of these springs range between 0.6 and 15.5 l/sec. Most important ones (in terms of discharge) are the Panagia Mandalo (Π-30) and the Ano Panagia (Π-29) with mean annual discharges of 15.5 and 9.5 l/sec, respectively (Vergis 1984).

Figure 7 presents the georeferenced and registered springs according to the results of this study. It additionally shows the locations of springs studied by IGME. It should be mentioned that, since IGME did not provide coordinates, we transferred the spring sites from an IGME map. Due to technical reasons, it is possible that a number of Municipality springs may be identical to IGME springs.

Table 9 presents the spring discharge measurements according to IGME.

[5]The RBMPs provide a total number of 35 springs.

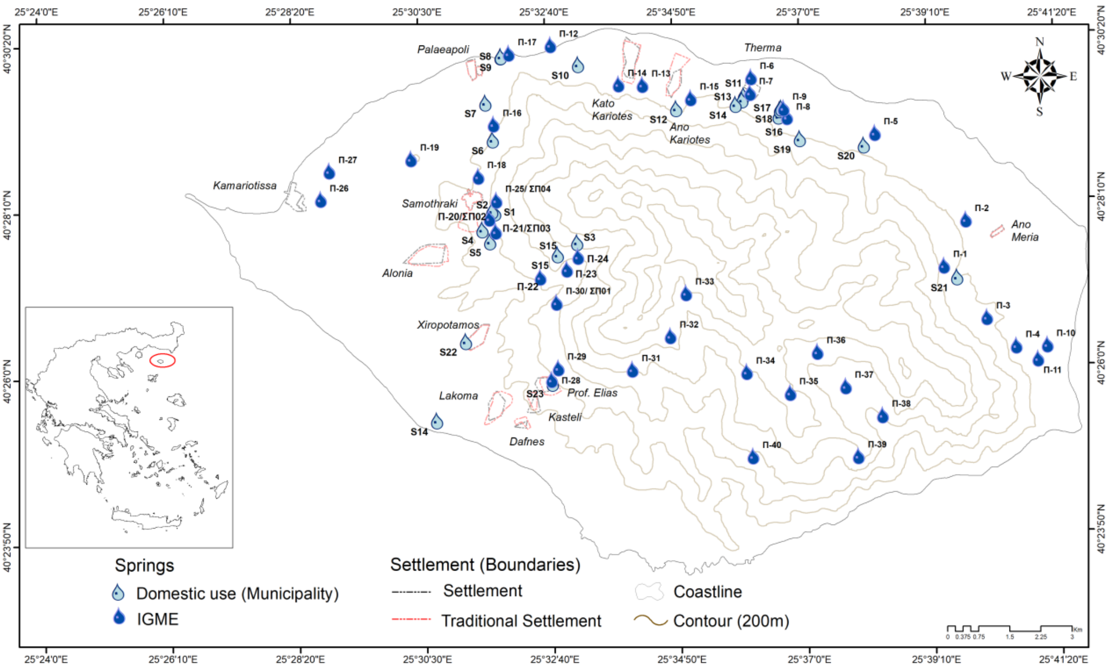

Figure 7. Topographic map of Samothraki with the location of springs exploited by the Municipality for domestic use (georeferenced and registered in the frame of this study) and the spring sites studied by IGME. Note that a number of Municipality springs may be identical to IGME springs.

Table 9. Spring discharge measurements according to IGME

Map Code	Location	Spring Name	Geology at spring outflow	Mean discharge (hm^3/year) 1980-1990
Π-1	Ano Meria	Kandaradika	Diabases	0.683
Π-2	Ano Meria	Isomata	Quaternary	0.084
Π-3	Ano Meria	Kerasia	Diabases	0.499
Π-4	Ano Meria	Lithari	Diabases	0.145
Π-5	Fonias	Fonias	Diabases	0.030
Π-6	Therma	Therma	Diabases	0.020
Π-7	Therma	Sklithros	Diabases	0.155
Π-8	Therma	Svopana	Diabases	0.150
Π-9	Therma	Svopana	Diabases	0.319
Π-10	Ano Meria	Lagadiotis	Quaternary	0.114
Π-11	Ano Meria	Askamnia	Quaternary	0.039
Π-12	Palaeapoli	Pyrgos	Quaternary	0.019
Π-13	Kato Kariotes	Potami	Diabases	0.084
Π-14	Kato Kariotes	Voutiros	Diabases	0.139
Π-15	Ano Kariotes	Vathra	Diabases	0.161
Π-16	Palaeapoli	Kopsi	Dacites	0.167
Π-17	Kamariotissa	Lanii	Diabases	0.381
Π-18	Chora	Platanos		
Π-19	Chora	Psychonero	Dacites	0.027
Π-20/ ΣΠ02	Chora	Sotiras	Diabases	0.613
Π-21/ ΣΠ03	Alonia	Ag Georgis	Diabases	0.261
Π-22	Therma	Askamnes	Diabases	0.095
Π-23	Alonia	Loutskia	Diabases	0.022

Π-24	Alonia	Varades	Diabases	0.365
Π-25/ ΣΠ04	Chora	Vrysia	Diabases	0.032
Π-26	Kamariotissa	Solinari	Quaternary	0.025
Π-27	Kamariotissa	Lagada	Quaternary	0.087
Π-28	Prof. Elias	Ano Panagia	Quaternary	0.147
Π-29	Prof. Elias	Kato Panagia	Quaternary	0.311
Π-30/ ΣΠ01	Xiropotamos	Panagia Mandalo	Quaternary	0.410
Π-31	Pachia Ammos	Ag. Banti	Granites	0.003
Π-32	Vatos	Katsgourou	Granites	0.114
Π-33	Vatos	Bachadouri	Granites	0.024
Π-34	Vatos	Krio Nero	Granites	0.020
Π-35	Vatos	Latzari	Granites	0.006
Π-36	Gyali	Stravoxilo	Granites	0.205
Π-37	Gyali	Platia	Granites	0.076
Π-38	Gyali	Adriomeni	Granites	0.030
Π-39	Gyali	Ag. Thekla	Granites	0.013
Π-40	Vatos	Vasilitsi	Granites	0.032
Π-41	Pachia Ammos	Karavi		
Π-42	Platia basin	Kalamithria		
Total mean annual spring discharge				**2.916**

According to the data of IGME for 42 springs monitored for their discharge, the total annual discharge of theses springs reaches 2.92 hm^3.

Since the Municipality lacks data on discharge measurements at the spring outflows of its interest, and recent monitoring data from IGME are missing, we undertook respective measurements (see Figure 8). However, as aforementioned, this was not possible in most of the cases. Table 10 presents the discharge of the springs measured.

Table 10. Measured capacity of springs (in m^3 per hour) that are being exploited by the Municipality (21 and 22 September 2018)

Springs	**Time (sec)**	**Water quantity (L)**	**Discharge (L/sec)**
Kopsi	3.45	12.5	3.62
Aj. Theodoros	4.6	7.2	1.57
Voutyros	4.25	12.5	2.94
Kandour	2.47	9.0	3.64
Varades (Aj. Antonios)	21.23	10.0	0.47
Panagia Mandalou	13.9	7.5	0.54
Askamnes	11.99	10.0	0.83

Figure 8. Spring outflow facilitating discharge measurements

Springs where discharge measurements have been performed both by IGME and HCMR were used in order to examine any long-term variations. For that purpose, we compared the old IGME measurements with the recent ones carried out in the same month. Table 11 presents the results of this comparison. According to this Table, a substantial spring discharge diminishing is clearly visible. Since the number of common springs is limited, to draw any conclusion on the possible impact of climate change or other factors (e.g. tectonic movements or human impact) on spring discharge diminishing, more measurements should be considered. However, this may be not be possible for the majority of the springs used by the Municipality as they are not accessible.

Table 11. Comparison of spring discharges between old measurements (IGME) and recent ones (HCMR)

	Spring discharge (l/s)	
	IGME	HCMR
	Average Sept 1981-83/Sept 2005-08	*September 2018*
Panagia Mandalou	5.43	0.54
	September 1981	*September 2018*
Kopsi	6.3	3.62
Varades	11	0.47

3.2 Streams

Flow and wetted cross-section measurements were carried out near the stream outflows at the end of June 2019. The wetted cross-section was divided to subsections based on the width of each examined stream. The area and the flow of every subsection were measured and then the two measurements were multiplied in order to estimate the discharge of the corresponding subsection. To find the mean discharge of each examined stream we used the summed up the discharges of each subsection. Despite the fact that autumn and winter 2019 were rainy and snowy, a number of streams were dry. Figure 9 presents streamflow and cross-section measurements and Table 12 the results of stream discharge measurements and additionally includes discharge measurements carried out in May 2014.

Figure 9. Streamflow and cross-section measurements

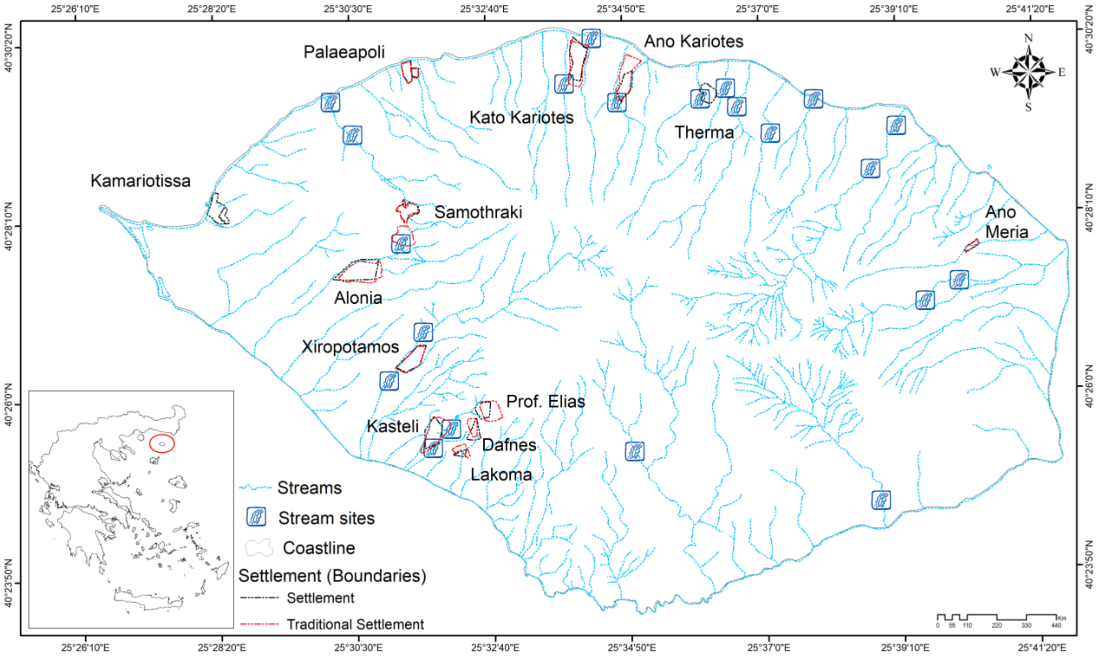

Figure 10. Stream sites were discharge measurements have been carried out.

Table 12. Stream discharge measurements (June 2019 and May 2014).

River name	Site name	X	Y	Discharge (m^3/s)	
				May 2014	June 2019
Fonias	Fonias 1	639300.31	4481826.6	0.396	-
Fonias	Fonias 2	639871.6	4483162.1	0.481	0.077
Platia	Gria Vathra1	636401.33	4483385.2	0.140	0.011
Xiropotamos	Xiropotamos gorge	629348.22	4478176.7	0.389	0.027
Xiropotamos	Xiropotamos estuaries	628622.7	4477093.6	0.035	-
Agkistros	Agistros 1	639969.02	4478746.3	0.359	-
Agkistros	Agistros 2	641217.72	4479516.8	0.308	0.026
Polupoudi	Alonia	628820.78	4480207.5	0.018	0.005
Vatos	Vatos	635241.58	4473556.3	0.409	-
Giali	Giali	639637.28	4474405.7	0.360	-
Kardelis	Grigorakis	637082.31	4482675.9	0.047	0.015
Katsambas	Chora	628580.6	4481937.4	0.049	0.009
Katsambas	Katsambas estuaries	627280.51	4483302.5	0.037	-

Lakoma	Lakoma 1	629927.41	4476024.4	0.926	-
Lakoma	Lakoma 2	629530.18	4475598.8	0.024	0.007
Arapis	Ano Kariotes	633901.96	4483020.4	0.196	0.013
Aga (Vouturos)	Agas	632911.46	4483640.5	0.061	0.002
Tsivdogiannis	Nekrotafeio	636229.48	4483812.7	0.120	0.001
Thermiotis	Therma	635678.19	4483506.1	0.052	0.004
Mantzar	Kato Kariotes	633091.41	4484768.8	-	0.002
Varades	Varades	637968.62	4483192.3	-	0.001

Stream discharge differences between June 2019 and May 2014 are immense. In fact, the average stream discharge in May 2014 (0.16 m^3/s) is one order of magnitude higher than the June 2019 one (0.016 m^3/s). This is not caused by the meteorological conditions of the specific years; the total rainfall of the period January – May for both years is almost identical (300.2 mm for 2014 and 300.6 for 2019). The dramatic discharge diminishing from May to June is attributed to the specific properties of the cracked groundwater aquifers which are developed on magmatic rocks (see 3.3.1). These groundwater aquifers are small and shallow. As a result, only a small portion of precipitation water is stored in the subsurface and the vast portion flows as surface runoff. Thus, as rainfall inputs diminish during summer, groundwater reservoirs are rapidly exhausted and stream discharge shows a dramatic decline (Skoulikidis et al. 2019). This particular feature of the cracked groundwater aquifers of Samothraki is clearly visible during extreme rainfall events; even in summer, when groundwater aquifers are exhausted, rainfall events may cause severe floods, while soon after the event, stream flow and water level reach pre-event conditions.

Using the results of Table 12, the total annual stream discharge has been estimated. For that purpose, the average discharge of May and June of each stream has been used as an estimate of the stream's mean annual discharge. To validate our assumption, we compared the long-term mean annual discharge of Fonias and Xiropotamos provided by the Public Power Corporation (monthly measurements, period 1986-91) with our results; in both cases the discharge was the same, i.e. 0.28 and 0.21 m^3/s, respectively. Thus, the assumption made is realistic. By summing up the mean annual discharge of all streams, the total mean annual discharge of Samothraki streams was calculated at 62.82 hm^3. Nevertheless, the outflows of Giali and Vatos are situated at the southern inaccessible part of the island and it is not possible to exploit their runoff. Hence, the total exploitable annual stream discharge of Samothraki lies by 49.43 hm^3. Koutsogiannis et al. (2008), estimated the surface runoff of Samothraki at 48 hm^3.

3.3 Groundwaters

3.3.1 Groundwater types and distribution

Unfortunately, it was not possible to conduct pumping tests. This was because during our field work activities the municipal drillings were frequently operating to cover irrigation needs, and this would be misleading regarding the results of the pumping tests. In addition, the drillings from IGME were locked and not accessible. Thus, we based on published estimates on the available ground water resources.

According to the RBMPs groundwater is distributed within two types of aquifers:

a) a 66.2 km^2 cracked aquifer (called according to the RBMPs, “Samothraki ground water system”) that covers ¾ of the island. It is located within the weathering zone of magmatic rocks (primarily within ophiolites and secondarily within granites). It has a maximum length of 11 km and a maximum width of 8 km. According to IGME (Romaidis & Favas 2010), the cracked groundwater aquifer covers 64 km^2 and receives annually 610 mm precipitation, and
b) a 25.6 km^2 alluvial aquifer, located at the western part of the island, the so called “Xiropotamos ground water (GW) system” (RBMPs). According to Romaidis & Favas (2010) the sedimentary groundwater aquifer covers 14 km^2. The aquifer has a maximum length of 8 km and a maximum width of 5 km. The alluvial aquifer is shallow, reaching up to 15 m depth (Romaidis 2006).

In autumn, groundwater tables reach annual minima. The latter is caused by a delay between minimum precipitation and minimum runoff by one month, according to data of IGME (Romaidis2006).

Figure 11 presents all municipal and private drilling and wells found on the island. It includes those registered by the Municipality and those included in IGME database.

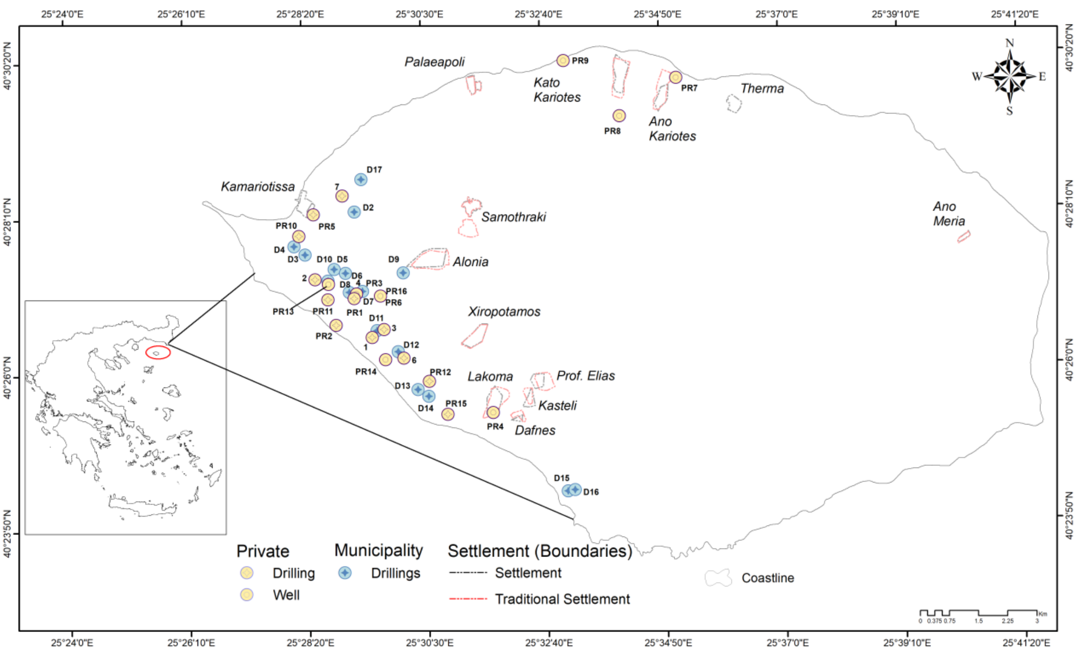

Figure 11. Total drillings on Samothraki Island (private and municipal, according to data from the Municipality and IGME. Since IGME did not georeferenced the locations, it is possible that a number of Municipality and IGME drillings are identical).

3.3.2 Groundwater quantity

The average annual supply of cracked aquifer is estimated at ~19.8 hm^{3}and the average annual supply of the “Xiropotamos GW system” aquifer is estimated at ~1.14 hm^3 (RBMPs).

3.4 Total available water resources

By summing up the annual the total annual discharge of springs and streams and the annual supply of the groundwater aquifers it results that the total annual available water resources in Samothraki reach around 79.13 hm^3. This number is close to the 65 hm^3 estimated by Schoder et al. (2016) for surface runoff. Finally, it seems that the annual water supply of 90 hm^3 provided by the RBMPs is overestimated.

4. Estimation of water resources quality

4.1. Domestic water disposal and treatment

The quality of water resources is essential for their allocation to various uses, i.e. potable, irrigation or industrial use. In Samothraki water is used to cover domestic and irrigation needs. Only a local beer production plant uses water from Kamariotisa water supply system.

The Samothraki settlements are mainly served by septic cesspits. Waste water networks partly serve Chora and Lakoma. However, WWTPs do not exist yet and waste waters of these settlements end up untreated in Katsambas and Lakoma streams, respectively (Operational Program of Samothraki Municipality 2013-14).

4.2. Water resources quality

After an incident of contaminated drinking water, small chlorination facilities have been added to disinfect the cisterns used for domestic water supply (Schoder et al. 2016). The Municipal Water and Sewerage Corporation. Region of Eastern Macedonia & Thrace in Alexandroupolis monitors the quality of the water supply system. Occasionally, the Municipality of Samothraki or private users may assign water analyses from the distribution system to state (Dept. of Medicine, Democritus University of Thrace; Municipal Water and Sewerage Corporation in Komotini) or private laboratories.

The vast majority of springs present excellent drinking water quality and taste, and may be used as bottled water appropriate for sodium-restricted diet and diet-preventing calcium nephrolithiasis (Skoulikidis et al. 2019). The exceptionally low solute concentrations of Samothraki streams and springs is attributed to a combination of geological, morphological, and hydro(geo)logical factors. Stream basins are predominately mountainous and steep and are mostly composed by weathering resistant magmatic rocks (58.4% on the average). Low solute concentrations result from low-reactive bedrock and due to steep gradients and low travel time, and thus limited interaction between water and bedrock. Particularly, streams draining granitic terrains present minimum solute concentration as a result of their low weather ability, compared to the other rock types of the island. Moreover, the cracked groundwater aquifers developed in magmatic rocks are small and shallow and are composed by coarse material initiating low residence times and poor solute concentrations in subsurface flow. Thus, springs present remarkable low salt content.

4.2.1 Springs

A part of domestic and irrigation uses are covered by cracked type aquifer springs which reveal, according to data of the IGME and the Ministry for Development, a good quality considering major ion and nutrient concentrations[6] (RBMPs). According to Romaidis (2006), spring waters are characterized soft, with low solute concentrations and are poor in metals, and thus appropriate to be used for special diets. Regarding occasional heavy metal analyses performed in the water distribution system of several settlements, the levels of Fe, Mn, Cu,

[6]Analyses of dissolved oxygen, Cr, Ni, Pb, Cd, Al and As were not included in the RBMP reports

Cd, Ni, As, Pb and Cr were far below the drinking water standards (Common Ministerial Decisions 2600/2001 and 38295/2007). Regarding nitrate and ammonia, the concentrations found in the water distribution systems were low.

According to the results of a number of microbiological analyses carried out in water samples of the domestic distribution system (provided by the Municipality of Samothraki), in some instances microbial contamination was found. For example, in July 2016, microbiological parameters (total coliforms, E. coli, enterococci, etc.) in the water distribution systems of Therma, Kato Kariotes, Alonia and Lakoma were not compliant to drinking water standards, according to the Common Ministerial Decisions 2600/2001 and 38295/2007. A second set of analyses carried out in August 2016, showed microbial contamination in the water distribution systems of Palaeapoli, Kato Kariotes, Lakoma and the camping.

HCMR examined 21 cold and two hot springs for their physicochemical and chemical characteristics (in hot springs heavy metals were additionally measured). Efforts have been made to access high altitude cold springs since they were not included in previous studies by IGME.

Table (Appendix II) presents the chemical properties of the springs examined. Cold springs were characterized by exceptional low mineralization; average total dissolved ion (TDI) concentration (excluding the outlier springs Dafnes that presented exceptionally high mineralization. and Palaeapoli that was affected by slight marine water intrusion) were several times lower compared to the mean values of 75 potable spring brands scattered throughout Greece. Moreover, when comparing average TDI of Samothraki springs with potable water springs of several European countries, it appears that the Samothraki springs reveal of the lowest mineralization in Europe. Low mineralization of Samothraki springs results from the particularly low concentrations of earth alkali and hydrogen carbonate ions; they show more than 4 times lower average total hardness than Greek potable water springs. On the contrary, as a result of abundant granitic rocks, concentrations of alkali ions, sulphate and chloride are only slightly reduced in Samothraki springs. The spring Dafnes presents an exceptional composition with high concentrations of earth alkali ions, sodium, bicarbonate, sulfate and nitrate. At the outlet of this spring salt formation is visible. In addition, the Palaeapoli spring may be occasionally affected by sea water intrusion as its relative high content in sodium and chloride indicate.

Finally, thermal springs revealed an average water temperature of 42.3^{o}C, an average conductivity of 18 mS/cm and an average TDI of about 9.95 g/L, of which 8.13 g/L was represented by sodium and chloride, indicating mixing with sea water. Thermal springs that are commonly used for drinking, since it is believed that their effects are curative, exceed the drinking water quality standards regarding manganese (Table 13).

Table 13. Heavy metal concentration of thermal springs (Skoulikidis et al. 2014)

	Mn (μg/l)	**Fe (μg/l)**	**Co (μg/l)**	**Ni (μg/l)**	**Cu (μg/l)**	**Zn (μg/l)**	**Cd (μg/l)**	**Pb (μg/l)**	**Sr (μg/l)**
T (A)	346.3	94.7	0.771	1.515	2.086	2.148	0.032	0.347	13880
T (B)	312.3	159.5	0.651	1.345	1.642	6.424	0.028	0.289	12420
DWS	50^c	300^d	20 ^{c}	20^a	20 ^{c}	500 ^{c}	1 ^{c}	50 ^{d}	-

T(A). T(B): thermal springs, DWS: Drinking Water Standards, a: COUNCIL DIRECTIVE 98/83/EC, c, d: category A1, b: guide, c: mandatory, COUNCIL DIRECTIVE 75/440/EEC

4.2.2 Streams

Like springs, streams present lower mineralization compared to Greek mainland and island rivers and streams. Like most island streams, they are enriched with sodium, chloride and silicate compared to the mainland. However, they present lower ion concentrations than other islands. Regarding nutrients, the Samothraki streams show substantially lower levels of nitrite, ammonia and phosphate, and slightly lower nitrate and total phosphorus concentrations compared to the Greek average. Table (Appendix III) presents the chemical properties of the streams examined. The physicochemical quality of Samothraki streams, according to the WFD prescriptions, is generally high. Only the Katsambas downstream Chora and the Lakoma, downstream the homonymous settlement, present a moderate quality (thus requiring remediation) due to the impact of untreated domestic wastewaters. Further downstream however, the Katsambas reaches a good quality as a result of self-purification. Finally, stream headwaters that are not affected by any pollution source, i.e. Giali and Kremasto, exhibit unexpected elevated nitrate concentrations and reveal a less than high (i.e. good) physicochemical quality. It is speculated that the high stream water nitrate levels in Samothraki result from rain water inputs which are laden with high nutrient concentrations, as scattered rainfall analyses indicated (Skoulikidis 2019). However, this assumption should be validated by capturing and analyzing additional rain events.

4.2.3 Groundwater

According the RBMPs, the hydrochemical parameters of 11 drillings and two wells located in the alluvial sediment aquifers reveal low average levels, despite drilling ΣΓ01 (IGME) which shows elevated mean chloride concentration (215.6 mg/l Cl), while the sulfate one (350.6 mg/l SO_4) overwhelms drinking water standards (250 mg/l SO_4). IGME (Romaidis & Favas, 2010) speculates that high sulfate concentrations may be connected with the geothermal field of Therma. However, this assumption seems not realistic since other ions of geothermal origin reveal low concentrations.

The drilling used to supply water to Kamariotissa, located within Miocene sediments, reveals high nitrate concentration. Measurements carried out on demand of the Municipality presented 43.8 and 47.6 mg/l NO_3 in the water distribution system and, according to Romaidis (2003), 51.2 mg/l NO_3 in the drilling used for domestic water supply whereas drinking water threshold is 50 mg/l NO_3. The same drilling may be occasionally contaminated by ammonia of anthropogenic origin, as the IGME analyses indicated (0.205 mg/l NH_4, Romaidis 2003). Also, the drilling ΣΓ03 (IGME) shows elevated mean nitrate concentration (40.3 mg/l NO_3) (RBMPs).

Based on the results of three drilling (IGME) for the period 2005-2008, the groundwater level variation follows seasonal trends and there were no over-pumping indications. Thus, within the RBMPs, the quality of “Xiropotamos GW system” has been classified as “good”. The RBMPs propose to extend groundwater monitoring by establishing two operational groundwater monitoring stations within the “Xiropotamos GW system” and one surveillance monitoring station within the cracked aquifer as the later comprise a drinking water source.

Table 14 presents the data of IGME for a number of municipal and private boreholes. It is noteworthy that in all cases the depth of the drillings, which are close to the sea, exceeds the sea level (Z). This makes the groundwater vulnerable to sea water intrusion as a result of overpumping. In fact, according to Romaidis & Favas (2010), the alluvial groundwater aquifer of Samothraki has started to show salinization characteristics.

Table 14. Elevation, depth and distance to the sea of drillings from IGME database.

ID	Name used by Municipality	Map Code	X	Y	Z (m)	Location	Depth (m)	Discharge (m^3/h)	Distance to the sea (km)
ΣΓ01		1	626557	4477810	22	Alonia	80		0.5
ΣΓ02		2	625091	4479294	12	Alonia	120	50	0.8
ΣΓ03	Mavrou		624480	4480151	12	Kamariotissa	100	50	0.7
236		3	626863	4478012	50	Alonia	100		0.9
317	Alanoudia		627731	4476470	35	Makrylies	100		0.4
1128	Ag. Dimitrios 2		625875	4479445	30	Alonia	71	90	1.3
1137		4	626309	4478988	30	Alonia	117	80	1.3
1139	Trypa		626056	4481031	45	Alonia	102	150	1.4
1144	Tiganouria		628016	4476309	40	Kamariotissa	54	10	0.5
1145	Ochtos		627225	4477453	45	Alonia	111	40	0.7
1147		5	625732	4478907	15	Alonia	117	90	0.8
1149	Ag. Dimitrios 1		625573	4479567	25	Alonia	102	120	1.2
1152	Mellagki		626328	4481876	38	Kamariotissa	104	15	1.0
2160	Aj. Kara		624811	4479931	30	Alonia	18	80	1.1
2161	Sait Arch		627397	4479530	55	Alonia	140		2.3
2162	Sykia		625427	4479255	25	Alonia			0.9
3334		6	627372	4477276	20	Alonia	100	10	0.7
3422		7	625781	4481447	65	Kamariotissa	80	30	1.0
3594		8	625817	4482168	15	Potamia	60	20	0.5
Average					**33**		**93**	**59**	

Groundwater extraction at rates exceeding up-stream recharge by freshwater allows the salt/fresh water interface (Figure 12) to progress inland and may cause locally increased upward and landward flow of saline seawater. Future sea level rise connected with climate change may act synergetic. Fresh water that is contaminated by only 5 % of seawater renders it unsuitable for many uses. Once seawater intrudes and causes coastal salinization, it is almost impossible to remediate.

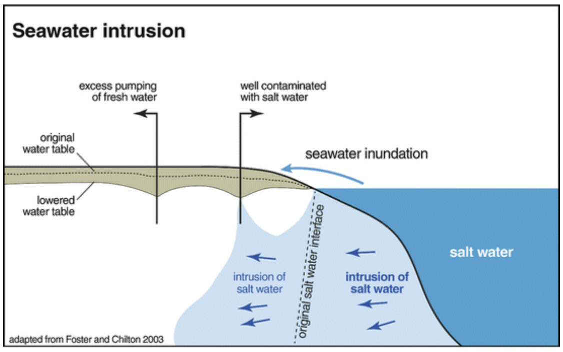

Figure 12. Salinization process of fresh groundwater in coastal aquifers due to the intrusion of salt water from the sea as a result of over pumping.

5. Preliminary Water Resources Management Plan

5.1 Description of the current situation

5.1.1 General aspects

Within the Regional Planning Framework and Sustainable Development of Eastern Macedonia & Thrace (2014), Samothraki is recognized as a “Landscape of International Importance”. A strategy to highlight, protect and sustainably manage the island includes:

- The creation and promotion of a distinct identity of the island in Greece and internationally, by promoting exclusively mild, alternative tourism, including nautical tourism, in combination with primary production and the organization of activities targeting to recreation, culture and science.
- The sound and sustainable management of the island's natural and cultural environment by restricting tourist development facilities in specific, limited areas of the island.

The management aspects of the Open City Spatial and Residential Planning of Samothraki Municipality include the:

- Rational and integrated water resources management.
- Maintenance and restoration of a free zone along the banks of all streams.
- Protection and preservation of exceptional and rare landscapes under pressure.

In addition, the streams and their riparian zones are defined as areas for protection and sustainable management; in these areas, the plane forests should be conserved and the previously existing forest vegetation should be restored.

5.1.2 Specific aspects

Besides the fact that the estimations within this study basically base on theoretical water demand data (as real data on actual water uses are largely missing) which may refer to different hydrological years (lying however between 2016 and 2018), thus including a relative uncertainty, it is safely to conclude that the registered water uses (1.76 hm^3) are far less than real water demands (15.65 hm^3 on the average). As the registered water uses for irrigation largely comprise groundwater sources (registered surface water sources make up only 1.3% of water used for irrigation), it is concluded that the difference is mainly covered by illegal surface water abstraction (either from streams or springs) for irrigation.

Our estimations on the total annual available water resources (~76.21 hm^3) and the total annual water demands (~15.65 hm^3), show that that the island has more than adequate water resources. In order to expand irrigation, a small reservoir is being constructed at Xiropotamos stream, foreseen to store the winter flow of this intermittently dry watercourse behind a 15 m high dam shortly upstream of Xiropotamos village. The reservoir with a storage capacity of 315.000 m^3 was designed to irrigate 70 to 100 ha of land (Vardoulakis 2011).

Despite high water availability, water shortages may occur during the summer period; for example, during the dry summer of 2006, settlements located at high altitudes faced frequent water interruptions for specific hours of the day, while according to Athanasios Vitsas, available water resources decreased by 50%. The mayor called for restricting irrational use of water and attributed the appearance of water scarcity on inadequate enrichment of the aquifers due to the dry winter (low rainfall and snow cover) and, predominately, to water resources mismanagement in previous years. The mayor stated that, due to the island's abundance of water, during the last 20 years much of the water supply was used to irrigate crops, which was the main cause of the observed decrease in water availability, and argued that 30% of the inhabitants illegally use water resources. To mitigate water scarcity the Municipal Council took following immediate actions to: a) shut down all municipal faucets, b) sue everyone responsible for illegal use of water from the water supply network of the Municipality and, c) implement immediately the provisions of the water regulation, in particular those relating to illegal water supply, i.e. the imposition of penalties for illegal water abstraction, and the ban of water supply for irrigation from the municipal network. Similar but less severe situations faced the island in following summers.

From this description it becomes obvious that, as result of high availability of good quality water on Samothraki, appropriate water management actions in case of droughts are not preventive and are implemented ad hoc. The same approach holds true in case of floods. The cracked groundwater aquifers are shallow with low storage capacity forcing precipitation to flow predominately overland. Thus, even during the dry season, when groundwater aquifers are nearly exhausted, rainfalls may cause disastrous flash floods. Moreover, a too high number of undernourished free grazing animals exploit and degrade pastures, thus magnifying naturally occurring soil erosion[7] (Panagopoulos et al. 2019). In September 2017, an extreme flood event triggered several landslides, demolished buildings (even the Medieval Fonias tower located at the mouth o Fonias stream) and covered large parts of Chora, including the town hall, with rocks and debris. Flood forecasting infrastructure and respective precautionary measures are missing, thus only post flood remedial actions are being implemented.

Water abstraction from streams and springs do not only affect domestic water supply during particularly dry years. It additionally affects steam flow downstream abstraction points. Thus, a number of perennially or nearly perennially streams (i.e. that naturally desiccate near their outflow to the sea) may cease to flow from their outflow to several km upstream. As a result, the ecological integrity and quality of downstream stream reaches is threatened and estuaries receive less fresh water, thus affecting coastal habitats and limiting nutrient inputs to the sea.

The domestic water supply network covers the settlements of the island, buildings outside settlements, municipal campsites and other productive activities taking place throughout the island. However, it is in a bad condition and leakages occur frequently. In addition, it needs further expansion (Operational Program of the Municipality of Samothraki 2013-2014). The Region of Eastern Macedonia & Thrace (2012) anticipated 1.000.000 € to repair the network. However, according to the Operational Plan of Samothraki Municipality 2014-19, a 750,000,00 € project foreseen to improve the domestic water network, has been cancelled. Recently, the domestic water supply pipe between Palaeopolis and Kamariotisa has been replaced, while further improvements of the networks are anticipated by the Municipality.

Most of the traditional cement canals used for irrigation are outdated and, even if they are operational, users commonly neglect them. Nowadays, irrigation is mostly carried out with

[7]Naturally occurring erosion derives from tectonically deformed bedrock, steep slopes, and restricted groundwater aquifers creating flash floods.

PVC pipes. Users place their own pipes to abstract water for irrigation and commonly several pipes run along the stream banks, thus negatively affecting the aesthetics of the landscape.

A WWTP for Kamariotissa has been integrated into the planning of the Municipality. The respective study has been completed and the construction of the plant is foreseen to start soon. The plant will be built on a 2,700 km^2 location west of the settlement, near the Akrotiri lagoon. In its initial phase it will serve 3,000 people and in the final phase, in 2025, 9,000 people. The prolonged ventilation system was chosen as the treatment method. The treated sewage will be disposed of in the sea, SW of Akrotiri. The possibility to transfer the waste waters of Chora to the Kamariotissa WWTP is being studied. For Lakoma and Prof. Elias, the sites for the construction of a WWTP have been selected. For Lakoma, the study for the transport and disposal of waste water has been completed, whereas a compact WWTP is anticipated to serve the needs of 1,500 inhabitants of the settlement (Eastern Macedonia & Thrace Region 2012). Finally, regarding the Municipal campings, the location near Kardelis stream for wastewater treatment/disposal and the construction of wastewater and drainage networks inside the camping and of sewage pipelines to a WWTP have been approved.

5.2 Proposed management measures

To ensure sustainable water use on the island, an integrated Water Resources Management Plan (WRMP) should be implemented. The WRMP should consider current and future water uses, and should anticipate the ecosystems requirements as well as future climate change impacts. In addition, it is necessary to connect water management aspects with the long-term socio-economical sustainability of the island (e.g. Rau et al. 2014, Petridis & Fischer-Kowalski 2016). Institutional improvements such as the upgrade of the Water and Sewerage Office within the Department of Technical Services and Quality of Life of the Municipality, improved maintenance, and better coordination of communication would ensure the success of the WRMP.

According to our estimations the vast majority of water needs (98.6%) comprise irrigation demands. Thus, water resources management should predominately target on irrigation water. To combat water shortages occurring during the summer period on the island, it is necessary to include within the WRMP the real current and future water needs of the island. For that purpose, it is essential, as a first basic step, to apply a monitoring system primarily targeting on water consumption (metering system) and secondarily on fresh water resources availability. Simultaneously, a long-term sustainable socio-economic strategy should be determined, on which the WRMP should be adapted.

Irrigation systems and agricultural production should be compliant to climate change issues. Respective measures may include the replacement or repair of damaged networks for domestic supply and irrigation, exploring the possibility of selecting crop varieties requiring less water, selection of varieties that thrive off-summer, ban free supply of irrigation water, explore possibilities to irrigate with reused water, and manage/control water abstraction according to specific hydrogeological studies (Ministry of Environment & Energy 2016). During the last years a seed mixture developed in Portugal for “sown biodiverse pastures” with a high share of legumes has been introduced to the island to serve as animal feed. The crops are less water demanding than existing pasture[8]. Experimental fields properly tended yielded between 20 and 50% higher productivity than the neighbouring fields (Fischer-Kowalski et al. 2019). Moreover, expanding irrigation for olive trees is not necessary when focusing not on quantity, but on quality of the harvest.

Measures concerning irrigation practices can help to save vast amounts of fresh water. Most important measure is to control illegal water abstractions from spring and streams. Today only two farmers have licenses to abstract water from streams. Thus, farmers, especially those owing large fields and use high amounts of water, should apply for licenses. Nevertheless, the total water abstracted form streams should be compliant with the demands of the WFD. Thus, the amounts of water abstracted should ensure the integrity and ecological quality of stream ecosystems. This, in turn, requires ensuring ecological (or environmental) flows (e-flows). The establishment of e-flows is ecosystem specific and requires the implementation of special studies targeting stream reaches affected by water abstraction. These studies will indicate the maximum water withdrawal to be allocated for irrigation for each stream.

All users, particularly those irrigating large land areas, should apply for water abstraction licenses. In total, the licenses for surface water abstraction should be adapted to the overall permissible water withdrawal per stream (according to the e-flows study). To control overuse, a metering system should be installed by each user. The Municipality should apply for regional funds to cover the installation of flow meters. Also, it is recommended to restore the traditional cement canal irrigation network and use PVC pipes instead only when it is absolutely necessary. The numerous PVC pipes that run parallel to the stream banks should be ban. A central PVC pipe may be placed to distribute water through smaller pipes to individual users.

As the “Xiropotamos GW system” aquifer shows signs of salinization (Romaidis & Favas 2010), water withdrawal should be strictly controlled and excess pumping should be avoided. Manual or automatic monitoring of groundwater levels and conductivity to control extraction is additionally recommended.

In some places, inefficient irrigation technologies are used (e.g. travelling guns involving high evaporation). Failure of the public system to supply sufficient amount of water to all users leads to illegal water abstractions or to maintenance of improvised and outdated irrigation structures. Pressures on surface and groundwater could increase in the future due to expansion of irrigation, e.g. for watering olive trees. The planned Xiropotamos reservoir would solve this problem only for part of the island.

It is a need to apply sustainable irrigation water use on the entire island. This requires knowledge on how much water in the soil profile is available to the crops and how much water the crop needs. Measuring and monitoring soil water status should be essential parts of an integrated management program. In addition, irrigation water use should strictly adapt to the plant needs and farmers should follow the recommendations of the state (e.g. Law 16/6631/89). Moreover, expert agronomists should be hired by the Municipality to advise farmers on irrigation water use according to the plant needs and the soil moisture status.

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[8] According to Schoder et al. (2016), legumes used as fodder for livestock in Samothraki contribute to almost 1 hm^3 of potential irrigation per year.

In order to increase exploitable fresh water resources in the future and cover the irrigation needs for the whole island, it is recommended to explore the possibility, instead of reservoir constructions, to store winter and spring stream flows into groundwater aquifers (natural enrichment of groundwater aquifers) or in underground reservoirs. It is easy then to exploit the stored water with shallow wells. Through this method evaporation losses will be minimized. This solution is preferred compared to the installation of new drillings. It is less energy demanding and will protect groundwater aquifers from future salinization. A geological/ geotechnical study may indicate appropriate areas in terms of dimensions, grain size characteristics of the aquifers and storage volumes.

However, new drillings do not have to be completely excluded if appropriately designed. With an improved well system, distributed reasonably over the island and constructed for the total irrigation demand, several advantages can be expected, including easier coordination, better spatial distribution (shorter pipe network), as well as minimal evaporation losses and impact on stream flows. Going for an extended groundwater exploitation, the positioning of wells has to be considered very carefully and further research including an updated hydrogeological study should be carried out, in order to protect groundwater aquifers from salinization (Schoder et al. 2016).

Considering domestic water supply, Romaidis (2003) proposes that waters of best quality should be allocated for drinking purposes. Thus, springs still exploited for irrigation purposes should be exclusively allocated for domestic use, since their supply is sufficient for that purpose. Only excess water should be used for irrigation. There is a need to cover all water needs for domestic purposes from springs and skip drillings. For example, the aquifer supplying Kamariotissa is probably contaminated by irrigation return flows and domestic waste waters from permeable cesspits as the high concentrations of nitrate and ammonia indicate. It is thus necessary to skip this drilling and target spring or stream water to cover domestic needs of that settlement.

Regarding qualitative issues, the vast majority of springs present excellent characteristics and can be used for drinking purposes and bottling. Even stream water may be used for drinking purposes after primarily treatment (settling, filtration and disinfection) to combat any microbial pollution, that may derive from e.g. dead animals. Incidents of domestic water microbial pollution may appear as a result of damaged water distribution systems that may be affected by permeable septic tank inflows.

The existence of protection zones around water abstraction points that serve domestic water supply is necessary for the protection of public health. These protection zones are designated in accordance with the provisions of the law, i.e. the law 1650/86 for the environment and the regulations for the management of water resources (Ministerial Decision 51/2007 and law 3199/03) and the RBMPs. However, such zones are missing in Samothraki and it is needed to be established. These zones should be fenced in order to protect them from any human activity and keep free grazing animals away. Any households in the vicinity of these zones should strictly use impermeable septic tanks, while owners of fields surrounding these zones should avoid to apply agrochemicals.

In order to establish high quality for domestic water supply with minimum costs and risks and avoid leakages, the existing old pipe network should be repaired and/or replaced. A monitoring (metering) system for all water reservoirs used for domestic supply and for all water users should be installed. Finally, the quality of all water abstraction points for domestic use, i.e. springs, cisterns, wells and drillings, should be secured by establishing protection zones.

To control flood hazards, a flood early warning system is required. HCMR recently installed a meteorological station at Koufouklio and an automatic water level recorder at Fonias stream outflow. Using the weather forecasting data in combination with the recordings of local rainfalls and stream water levels it is possible to develop a flood early warning system that will be used by the Municipality to take appropriate measures in advance.

To control erosion, the number of free grazing animals should be reduced and grazing has to be managed sustainably by establishing spatially and temporally controlled grazing areas. However, a really effective erosion mitigation plan would additionally require reforestation to the greatest possible extent along with protection against wildfires, as well as constructive practices, e.g. building of terraces. The latter could prevent soil loss if applied in the hilly vulnerable areas by increasing the retention of soil resources in the upland catchments. At the areas where farming is practiced, the newly introduced Sown Biodiverse Permanent Pastures may act toward both controlled grazing and soil erosion abatement (Panagopoulos et al. 2019).

Finally, education and awareness raising for all water users (e.g. farmers, tourists, school children) would be a step towards more efficient water usage.

6. Conclusions

6.1 Current situation

- Samothraki has more than adequate water resources; the total annual available water resources (~76.21 hm^3) exceed by around 5 times the total annual water demands (~15.65 hm^3).
- Registered water uses (1.76 hm^3) are by far less than the estimated real water demands (15.65 hm^3 on the average). The difference is mainly covered by illegal surface water abstraction for irrigation (either from streams or springs).
- As a result of illegal water abstractions and inadequate management, despite high water availability, water shortages may occur during the summer period, even for domestic consumption. In lack of a long-term water resources management strategy in combination with the availability of freshwater resources on the island, respective management actions are implemented ad hoc.
- Water abstraction from streams and springs do not only affect domestic water supply during particularly dry years. It additionally substantially affects steam flow, turning particular stream reaches from perennial to temporary, with adverse effects on their ecological quality and integrity.
- Due to the nature of the cracked groundwater aquifers, the island is prone to flash floods. Flood forecasting infrastructure and respective precautionary measures are missing, thus only post flood remedial actions are being implemented.
- As a result of natural factors (tectonically deformed bedrock, steep slopes, and restricted groundwater aquifers) and a disproportionate number of free grazing small ruminants, erosion rates on the island are immense.
- Parts of the domestic water supply network are suffering from leaks, causing water losses and occasional microbial contamination, and need to be repaired or replaced.
- The traditional cement irrigation networks are largely destroyed and irrigation takes place using PVC pipes.
- The groundwater aquifer of the drilling used to supply domestic water to Kamariotissa is polluted, as the high concentration of nitrate and ammonia indicate.

6.2 Proposed water management measures

- To ensure sustainable water use on the island, a long-term integrated Water Resources Management Plan (WRMP) should be implemented, including socio-economical sustainability aspects, aquatic ecosystems' requirements, and future climate change impacts.
- Irrigation systems and agricultural production should be compliant to climate change issues. It is recommended to select less water demanding crop varieties (e.g. "sown biodiverse pastures"), and varieties that thrive off-summer. To ensure high quality of olive oil produced it is recommended not to irrigate olive groves
- In the WRMP, the stream ecosystems' summer water requirements should be integrated and maximum withdrawal for each stream should be estimated.
- All users, particularly those irrigating large land areas, should apply for water abstraction licenses.

- The number of licenses for surface water abstraction should be adapted to the overall permissible water withdrawal per stream (according to a e-flows study). To control water overuse, a metering system should be installed by each user. The Municipality should apply for regional funds to cover the installation of flow meters.
- It is recommended to restore the traditional cement canal irrigation network and use PVC pipes only when it is absolutely necessary. The numerous PVC pipes that run parallel should be banned. A central PVC pipe may be placed to distribute water through smaller pipes to individual users.
- Inefficient irrigation technologies, such as travelling guns, should be banned.
- An irrigation scheme within the WRMB should be based on soil moisture and the real water needs per crop type. This requires soil moisture monitoring and agronomical know how that should be provided by the upgraded Water & Sewage Office of the Municipality.
- To avoid salinization of the “Xiropotamos GW system”, it is recommended to regularly monitor water level and conductivity of drillings and adapt water abstraction accordingly. These actions should also be arranged by the Water & Sewage Office of the Municipality.
- New drillings do not have to be excluded if appropriately designed. An improved well system, distributed reasonably over the island and constructed for the total irrigation demand offers several advantages. In this frame, the positioning of wells has to be considered very carefully and further research including an updated hydrogeological study should be carried out, in order to protect groundwater aquifers from salinization.
- In order to increase exploitable fresh water resources in the future, it is recommended, instead of reservoir constructions and opening of new drillings, to explore the possibility to store winter and spring flows underground, if this agrees with the results of geological/geotechnical studies.
- To avoid leakages and contamination, the domestic water supply network should be repaired or replaced, where needed.
- A monitoring (metering) system for all water reservoirs used for domestic supply and for all water users should be installed.
- Domestic water demands should be covered by springs and domestic water use from drillings should be skipped. Spring use for irrigation should be banned, and only excess water should be used for irrigation. It is recommended to shift water demands of Kamariotissa from ground water to spring or stream water. Stream water may be used for drinking purposes after primarily treatment to avoid microbial pollution.
- Protection zones around water abstraction points should be established to secure an excellent drinking water quality and minimize chlorination.
- An early warning system for catastrophic rain events and flash floods should be developed and applied.
- To combat erosion, there is an urgent need to drastically reduce free grazing animals, manage grazing sustainably by establishing spatially and temporally controlled grazing areas, assist forest regeneration, perform reforestations, and build terraces on hilly vulnerable areas to prevent soil loss. The newly introduced “sown biodiverse pastures” may act toward both controlled grazing and soil erosion abatement.

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