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Exploitation of hydroelectric potential of the irrigation reservoirs in Eastern Crete

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ABSTRACT

Crete, one of the 5 largest islands in the Mediterranean Sea and the second largest in the Eastern Mediterranean, is facing water scarcity. The need to create water reservoirs is necessary, especially in the region of Eastern Crete where the problem is more intense. The National Water Commission of Greece in obligation to harmonized with the directive 2000/60EC, has located 3 points of creating a water dam or reservoirs for irrigation in the region, but these studies have not provided the possibility of utilizing hydroelectric energy. The study presents a water management plan and the resulting reduction in energy from the water drilling replacement in Eastern Crete and the additional proposal of hydroelectric utilization through approximate hydroelectric calculations.

Keywords: Eastern Crete; Hydroelectric potentials; Irrigation reservoirs

1. Part 1. The need of Crete for water through the prism of climate change

1.1. Crete, the place, the people

1.1.1. In short

Crete is the largest Greek island: 8.312 km^2 and the 5th largest in the Mediterranean Sea, at the same time is the most populated Greek island with about 650,000 people and also the 5th most populated in the Mediterranean Sea. It is discrete the (4th) Administrative Region of Greece of the 13th in total and it is separated in four (4) regional units (Lassithi, Heraklion, Rethymno, Chania).

1.1.2. Socioeconomic conditions

The region of Crete is considered a tourism hotspot and an important agricultural centre for Greece, where 6% (634,930 inhabitants in 2019) of the Greek population is concentrated. Regional gross domestic product (GDP) exhibited, over 2010–2018, has shown a decline by 14%. From 2010 to 2013, it steadily decreased, but it has been growing ever since, reaching €9,386 million GDP in 2018 [1], ranking as the sixth region with the highest GDP in Greece. Also during that period, regional GDP per capita in purchasing power standards (PPS) decreased from 18,400 in 2010 to 18,100 (2018), ranking the region in eighth place among the 13 Greek regions, below both the national (21,100) and the EU (31,000) averages [1].

The Region of Crete is included in the 6 regions of Greece that are characterized by a total high vulnerability to climate change. High vulnerability is characterized by all the sectors examined, with the exception of the sectors of Water Supply and Mining Activity which are characterized by moderate vulnerability.

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2. General climate data in Crete

The climate type of Crete is a transitional intermediate type between the land Mediterranean and the desert Mediterranean, which mainly includes the southeastern part of the island. The main feature of the climate is the sweetness and mildness. The cold season is mild and this is due to the frequent arrival in the area of hot and humid SW gas masses (Fig. 1).

In terms of mildness and change, the climate of Crete is considered privileged and is due to the central position of the island in the Eastern Mediterranean. Winter usually begins in mid-December and is mild. The average temperature is higher in the east than in the west and higher in the south than in the north. The picture differs significantly in the mountains, where the average temperatures are lower, the temperature deviations are more intense and the temperatures, especially in the winter months, are significantly lower. The warmest month of the year is August with an average temperature of 27.13°C. These temperatures largely determine the duration of the summer period, which in the whole study area covers at least 4 months (June, July, August and September).

The sunshine is very high throughout Crete. The average annual number of hours of sunshine is about 2,700 h in northern Crete (2,707 h in Heraklion, 2,699 h in Sitia, 2,765 h in Souda and 2,592 h in Rethymno (average 8 y only). In southern Crete, the average annual number of hours sunshine is at least 10% higher, amounting to about 3,000 h (3,068 h in Ierapetra and 2,948 h in Tympaki). The number of hours of sunshine in Ierapetra is the largest in Greece.

The average cloud cover is between about 5 eighths in January and 0.6–1 eighths in July. The average number of clear days (cloudy between 0 and 1.5 eighths) is between about 3 d in January and 28 d in July in the lowlands. In mountainous areas, the number of clear days during the summer months is 30% less. Fog (like frost) is also extremely rare in Crete. On the contrary, the appearance of water droplets on the soil surfaces is more frequent, the dew.

Crete generally presents a significant unequal distribution of the annual rainfall volume both geographically (from east to west) and physiographic (lowland to mountainous areas), showing rainfall (increase in precipitation with altitude) if not the largest in Greece: 61 mm/100 m. The average monthly rainfall is highest in December (97.30 mm) or January (106.87 mm) and low in July (0.04 mm) and August (2.95 mm) which are almost drought throughout the year plain Crete. The monthly number of rainy days varies between about 15 d in December and January and 0.3 d in July and August.

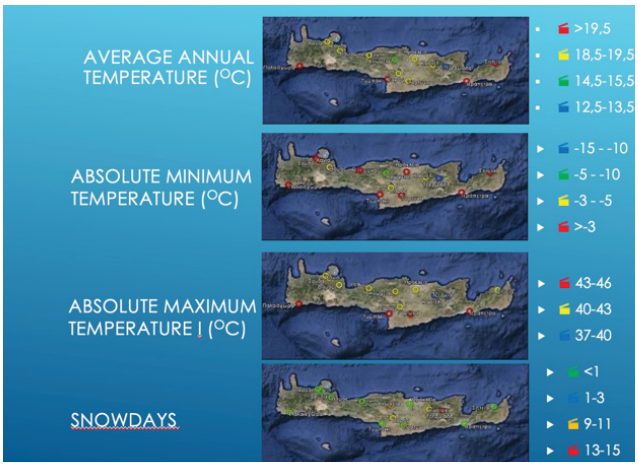

Fig. 1. Meteorological and colour maps of Crete [2].

The number of rainy days does not differ significantly between mountain and lowland stations. In mountain stations, in fact, the number of rainy days appears equal to or less than the number of rainy days in the lowland stations, especially during the winter months. The average number of rainy days in Crete is about 90 d (25% of the year).

3. Use of land in Crete

Land-use and habitat characterization is critical in government planning and definition of policy strategies. The region of Crete has a special geomorphology and geophysical characteristics. For the most part, it is covered by cultivated areas, natural habitats and generally low vegetation areas. The main categories of land use can be distinguished agricultural c, bushy grasslands, artificial surfaces, forest areas and open spaces with little or no vegetation. After 2000 we had a decrease of open spaces by 3.3% while a large increase is presented by the forest areas with a percentage of 27.4% and the technical areas with a percentage of 149% [3]. In general, the land uses on Crete are the following: 67%: agricultural land and pastures, 3%: wooded, 27%: crops, 2%: water surface, 1%: urban areas (Fig. 2).

4. Water resources in Crete

With the sub no. 706/16.7.2010 decision of the National Water Committee were determined [4,5], at country level, forty-five (45) river basins, which belong to 14 basin areas river basin (corresponding to the term Water Departments of Article 3 of Presidential Decree 51/2007). The Water Basin of Crete is the 13th of the 14 water basins of the country has Code EL13 and consists of 3 river basins. The physical characteristics of these basins are presented in Table 1.

Little water concentration from precipitation water (rain, hail, snow) due to the geophysical environment of the island. Geographical location (SE tip of Europe, east-west direction) and existence of high mountain ranges strongly determine the amount of annual water input (Fig. 3).

THUS: Rainfall sites occurring near the high mountain ranges (Lefka Ori and Psiloritis), Heavy rainfall at the western and central part, and light rainfall at the eastern part of the island [6].

5. Necessity for the existence of dams and reservoirs in Crete

The need to manage water resources is at the heart of the global debate. Not only those involved in regional development or the improvement and development of agricultural production but all those who realize that the effects of climate change are a fact [7]. Such discussions are common in Greece and concern not only the implications nationally but also internationally [8].

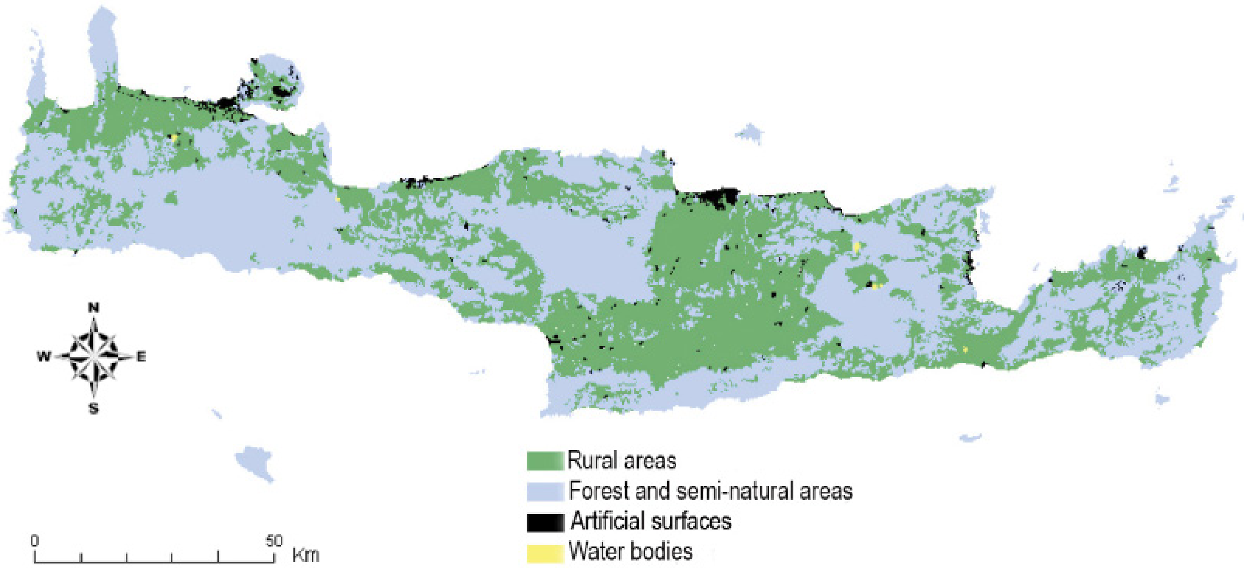

Fig. 2. Meteorological and colour maps of Crete [2].

Table 1
Physical characteristics of the Crete Region basins

Leasure code	Leasure name	Area (km²)	Altitude (m)		
			Middle	Maximum	Minimum
EL1339	Basins of North Part Chania–Rethimno Heraklion	3.64375	43,892	2.45209	0
EL1340	Basins of South Part Chania–Rethimno Heraklion	2.79803	47,515	2.44802	0
EL1341	Basins of Eastern Crete	1.88536	34,673	2.12266	0
EL13	Total water department of Crete	8.32710	48,051	2.45209	0

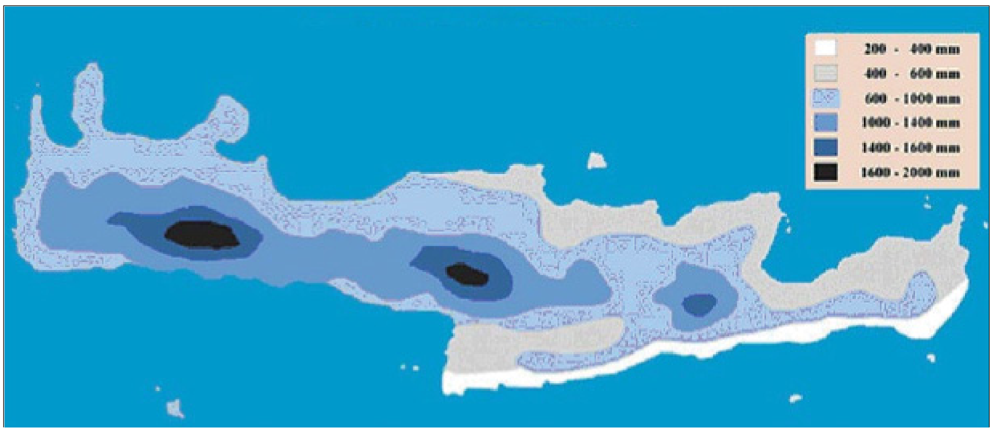

Fig. 3. Increase from east to west and increase (from south to north) and physiography and altitude (lowland to mountainous areas) [6].

Among the discussions related to sustainable development and related to infrastructure and in terms of costs, impacts and results is the construction of small or large dams and reservoirs. It is a fact that the construction of a dam is a complex technical project with many economic and other effects on society, the economy and the environment. Today the construction of dams can be more efficient since the scientific knowledge and the technological improvement of the means of construction are much better than in the past [9].

The utility of the dams is upgraded and focuses on the retention of water resources during the wet season and their performance during the dry season, in addition they can additionally contribute to the production of hydroelectric power, the settlement of torrents, flood prevention [10]. Issues that can prevent the construction of a dam or a reservoir are the high costs required for studies and construction work, possible changes in flora and fauna or the microclimate as an environmental impact but also possible social impacts that may arise from the destruction of arable land or residential settlements, which will force the population of the area to move. [10].

For the Region of Crete, based on the scenario A1B of the 4th Evaluation Report of the IPCC (International Panel on Climate Change), an increase of the average annual temperature is foreseen, which ranges from 1.4°C for the period 2021–2050 to 3.1°C for the period 2071–2100. According to the Report of EMEKA (Climate Change Impact Study Committee (2011) of the Bank of Greece, a significant percentage reduction of the average annual precipitation is also predicted, which during the period 2021–2050 will approach 15%. The projected increase in temperature and the reduction of rainfall, are expected to lead to an increase in the duration of the dry periods, especially in the northern part of Chania–Rethymno–Heraklion where 20 additional days of drought are expected in the period 2021–2050 and up to 40 additional days in the period 2071–2100. As the temperature rises and droughts increase, the number of fires during the summer season is expected to increase, as well as the total area burned, while the distance between two consecutive fires is expected to decrease those of the southern mainland are expected to be most affected by forest fires.

6. Use of water as a basis of national legislation and policy of the region of Crete

The need for water security in Crete forced the political leadership at the central level (Ministry of Environment and Energy) and at the local level (Crete Region) to develop plans for the utilization of the island's water resources and address the effects of climate change. For this reason, goals were set which they present through actions that will be done or at least should be done and will be a priority in the near future. These actions are:

- Action 6.1. Actions to assess the effects of climate change on the water resources of the Region of Crete.
  The action includes the following measures:
- Measure 6.1.1. Preparation of a specialized study for the identification of the most vulnerable water systems of the Region of Crete, the assessment of the risk of unavailability of water resources and the investigation of the desalination phenomena of the aquifer at regional level due to the expected changes. Preparation of a specialized plan of measures for the protection of vulnerable water systems adapting to climate change regarding the risk of unavailability of water resources (surface and groundwater) and measures to reverse the effects.
- Measure 6.1.2. Implementation of a network for monitoring the effects of climate change on the main groundwater systems and reservoirs of the Region of Crete (development of a telemetric network for the continuous measurement of rainfall, level and flows in the most important water systems of the region).

Correlation with the basic measure of the relevant SDLAP (1st Revision) M13B0902. "Determination of the minimum level of natural lakes and determination of the maximum range of reservoir level variation", and the additional measure M13S1607 "Recording and monitoring of the operation of reservoirs at unknown ecological potential" [11].

- Action 6.2. Actions to save and use water efficiently.
  The action includes the following measures:
- Measure 6.2.1. Promoting water saving in all sectors and uses (agriculture, tourism, industry, housing). Indicatively through the installation of water saving equipment in houses and public buildings, rainwater recycling for irrigation, financial incentives for water recycling in industry, promotion and strengthening of pilot projects.
- Measure 6.2.2. Maintenance, repair and modernization of the water supply networks of the Region of Crete. Correlation with the basic measure of the relevant SDLAP (1st Revision) M13B0302. "Actions to strengthen, rehabilitate, modernize water supply networks and control leaks".
- Measure 6.2.3. Installation of low consumption water supply equipment in public buildings of Crete. Providing incentives for the installation of appropriate low-water water supply equipment in private companies and the household sector (e.g., provision of free equipment, subsidies, fee and tax deductions, etc.).
- Measure 6.2.4. Optimize existing surface water storage methods (e.g., dams) and create new ones (e.g., rain tanks), if required, in particular by replacing pumps during periods of low or zero flow [12].

7. Water balance in Eastern Crete

7.1. Basic elements

The construction of Water Reservoirs in Eastern Crete is of primary importance, due to the dependence of the local economy on water-related activity such as the agricultural production (agriculture and livestock), farming and tourism (grandly occurring in Q2 and Q3).

At the same time in the region there is low rainfall level (450 mm/y) and also low rainfall during Q2 and Q3 (88 mm/y). Under these conditions the need for water savers becomes more than imperative [13].

7.2. Focusing primarily on the Municipality of Sitia

The local water supply needs are currently met by: 81 wells of depths, of varying features (depth 70–512 m, capacity 20–80 m^3/h) which is an extremely costly process due to the great depth and the resulting damages, while at the same time from the excessive use have arisen issues of increasing the salinity of the water and degradation of the quality, it is important the existence of 8 low capacity springs (capacity 0.5–5 m^3), several of which are seasonal but all provide water with natural flow. Water pricing, as a result of all this data, is extremely high for both water supply and irrigation with the cost of the process being transferred to the citizen-consumer.

The cost of maintenance and operation of the drillings for the municipality of Sitia for 2020 was approximately more

Table 2
Hydro dams (under development) in Eastern Crete

	Lithines	Chochlakies	Zou
River/stream name	Maroulas	Flega	Padelis
Dam crest length (m)	465	108	527
Dam height (m)	58	14	8
Dam crest elevation (m)	122	211	58
Active reservoir capacity (m^2)	9.000000	1.500000	450.000
Irrigation area (ha)	2.000	1.000	250
Budget (M€)	69	16	4.5

than 150.000 €, an amount allocated exclusively for drilling without including the cost of maintenance of the water supply and irrigation network.

8. Part 2. The irrigation reservoirs in Eastern Crete and the additional proposal for hydroelectric use

From now on, this work has a calculation content, since to date in Eastern Crete no works have been carried out for the creation of dams and water reservoirs while there are no studies regarding the possibility of generating hydroelectric energy. For this reason, the plans for the creation of three dams and water reservoirs designed in the area (1 dam, 2 reservoirs) were studied. From the first calculations, it was found that the case of the two reservoirs cannot have substantial potential for the use of hydroelectric energy since the volume of water is low. The possibilities for such a use are seen more in the dam where the study will focus through rough hydroelectric calculations (Fig. 4).

8.1. Hydro dam of Zou

Its construction has joined with no. 10641/8-12-2009 Decision to Measure 125A1 of the Rural Development Program (PAA) 2007-2013, as amended by No. 2533/19-2-14 (APA: VIBEB-L16) with expiry date for expenditure eligibility at 31/12/2015. The total budget of this project is €4,146,189.28. The design and implementation of the project has been undertaken by the region of Crete. The project was first designed in 1994, in 2005 it was stopped due to lack of riparian material for the completion of the embankments and the completion of the project (Fig. 5). The project was announced at the end of June 2021 from the region of Crete that the project will continue till the end of next year.

8.2. Hydro dam of Chochakies

Its construction with the no. 4692/27-7-2010 was included in Measure 125A1 of the Rural Development program (PAA) 2007–2013. The study of this project was commissioned

Fig. 4. Hydro dams (under development) in Eastern Crete localisation.

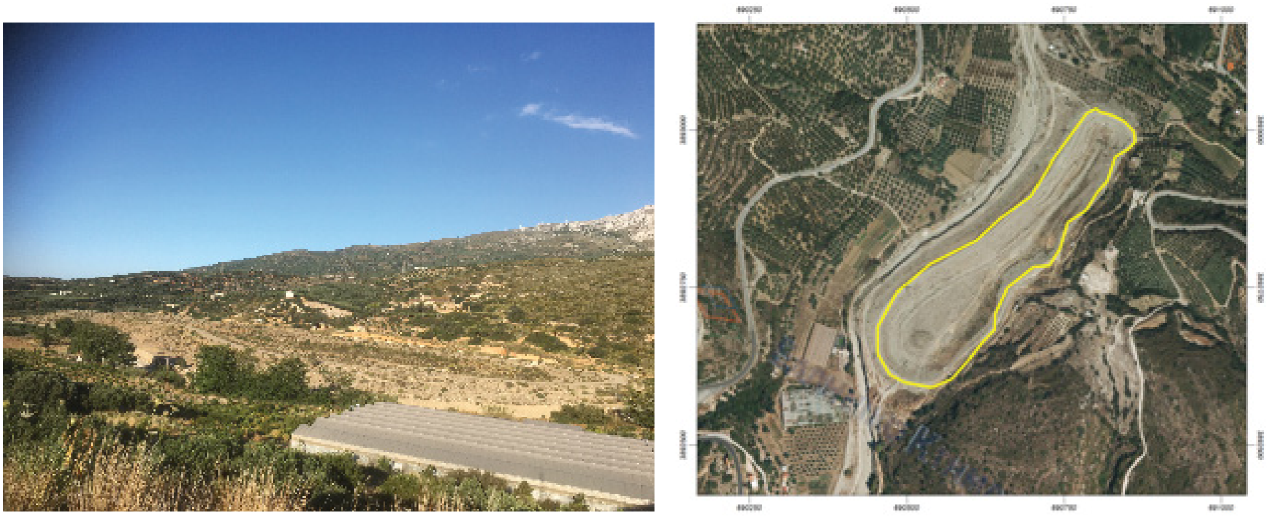

Fig. 5. Zou region.

under no. 4732/143889/21-11-2013 decision (ΑΔΑ: ΒΛ1ΦΒ-ΚΙΠ) in the partnership of design offices.

With the no. 4527/13-6-2016 (ΑΔΑ: ΩΨ4Χ4653ΠΓ-Τ9Ο) it was decided to continue the operation in Measure 4, subproject 4.3, Action 4.3.1 "Infrastructure of Land Improvements" of RDP 2014-2020 as it was amended with no. 9869/10-11-2016 (ΑΔΑ: 6Π5Ζ4653ΠΓ-Η32). With the no. 4132/28-11-2016 (ΑΔΑ: 7ΕΛΞ4653ΠΓ-3ΞΝ) the 2nd SP of the study was approved. The total budget of the project is 11,600,000.00 €.

The project has been completed in design and is ready for auction. In September 2020, the mayor of Sitia informed that the project has entered the reintegration process, but so far there is no new information on the completion process. This year at an event in Athens in the presence of Prime Minister Kyriakos Mitsotakis, the minister Lebanos presented the first 8 of a total of 21 irrigation projects, with a total construction cost of 1.6 billion euros, which will cover more than 1.3 million acres throughout the country. One of the projects that was officially announced was the Sitia Hochlakia Reservoir and water supply network in an existing irrigation network (Lassithi Prefecture). The data announced for the project are: construction cost with PPP: 18,518,362 €, new reservoir capacity (m^3): 840,000, irrigated acres: 4,125 acres. The beneficiary farmers will 500 (it is noted that the population of this area is about 1,500 people) (Fig. 6).

8.3. Hydro dam of Lithines

The construction of the dam of Lithina and the wider area of Pilallimata of the Municipality of Sitia, budget €69,150,000.00 is the largest planned project regarding water in the area.

It is a chronic request of the Municipality, the construction of which was included with the no. 5751/6.9.2010 decision in Measure 125A1 of the Rural Development program (PAA) 2007–2013, but was rejected with the no. 7939/30-04-2015 decision (ΑΔΑ: ΩΓΠΧ465ΦΘΗ-Μ9Β) due to the excessive overbooking of the projects included in Measure 125A1 that concerned "Land improvement projects and actions" (Table 3).

8.4. Lithines Dam: case study

The Andromylos river basin extends between the Libyan Sea downstream and the ridges of Mount Ornos and Krimiani upstream (Table 4). It is located in the southern

Table 3
Hydroelectric exploitation

AVG Forebay water level	+91 masl	
AVG Tailrace water level	+52/27 masl	(dep. on detailed design)
H_{gross}	39/64 m	(<<)
H_{net}	35/60 m	(<<)
Specific consumption	12/7 m^3/kWh	(<<)
Total electricity production	1.4/2.4 GWh(/y)	(<<)
Hydroelectric tariff	€90/MWh	
Annual electricity production	110/200 k€	(<<)
Hydropower capacity	250/400 kW	(<<)
Capacity factor	64%/68%	(<<)

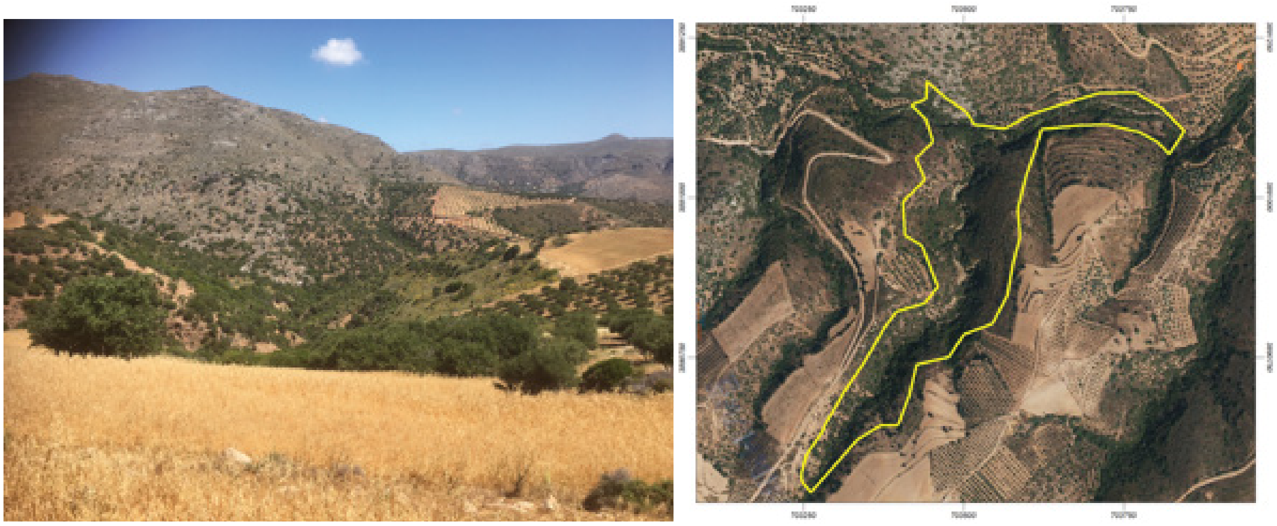

Fig. 6. Chochlakies region.

Table 4
Technical characteristics of Lithines Dam [14]

Hydrology	
Catchment basin	52 km^2
Average annual runoff	16.60×10^6 m^3
Reservoir	
Water level	+78/+104 masl
Active storage capacity	8.25×10^6 m^3
Total storage capacity	9.1×10^6 m^3
Area @ 104 masl	55 ha
Dam	
Type	Earth – filled, with central impermeable core
Height	58 m
Crest elevation	+110 masl
Crest dimensions	465 (L)/10 (W)
Spillway	Side overflow, without gates
Intake	Concrete tower – hexagonal trash rack scree arrangement

and central part of the prefecture of Lassithi in the province of Sitia, at the geographical location 26th 02' A.M. and 35th 04' B.P. about. The basin has an opioid shape and orientation of the main axis N-S (Fig. 7).

The mouth of the basin at the site of the project has an altitude of about 60 m. To the N the peaks of Krimiani (+751) Plati Sopata (+929) and Megali Mouri (+1179). To the W the peaks Gypsos (+649) Romaneti (+937) and Salamakos (+326) (Fig. 8). The eastern and western hydrocrites contribute south to the location of the projected dam. The mountain basin consists of two sub-basins:

- The East that is crossed by the river Kalypra that comes from the settlements of Sykea and Papagiannades and;
- The west that is crossed by the river royal passage that comes from the area of Krya and Dafni purpose of dam construction.

9. Conclusion

The construction of hydro dams at Eastern Crete is a major and urgent issue for the environment and the economy, considering the major role of the primary sector and the tourism and the lack of the adjacent water resources.

Hydro dams are prominent projects, of multiple role (irrigation, water supply, electricity production, flood protection, leisure, fire protection, local infrastructure, etc.) The construction of a dam in Lithines will be a key infrastructure project in an area where the main structure of economic activities is the agricultural and tourism sectors. Both of these sectors are more in need of such projects, especially since the area is dry. The creation of the project will greatly change the local economy and will be a substantial intervention for the region of Crete, in the effort it makes to address the consequences of climate change.

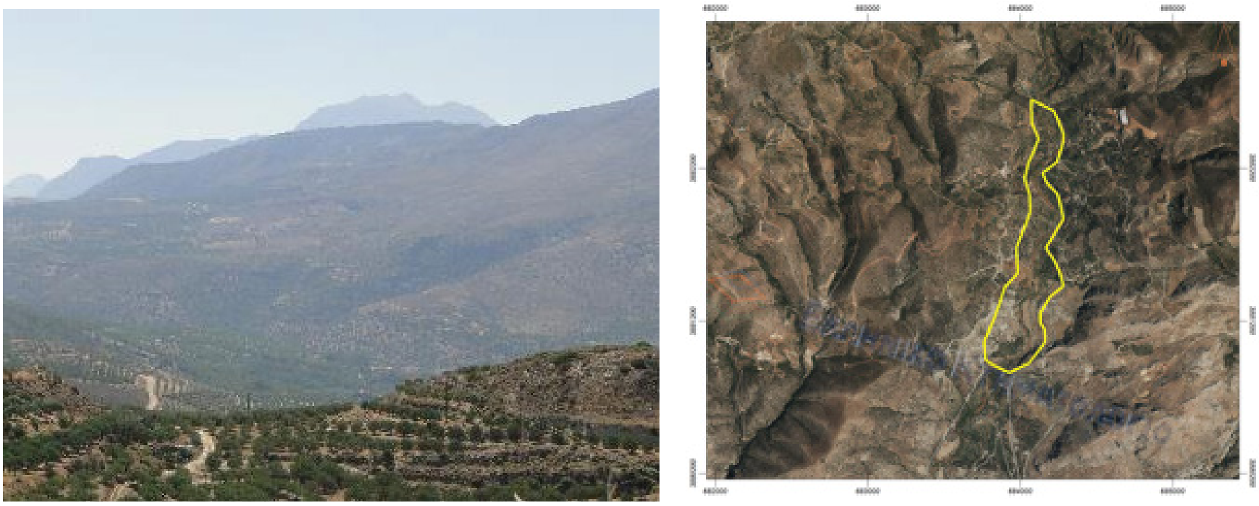

Fig. 7. Lithines region.

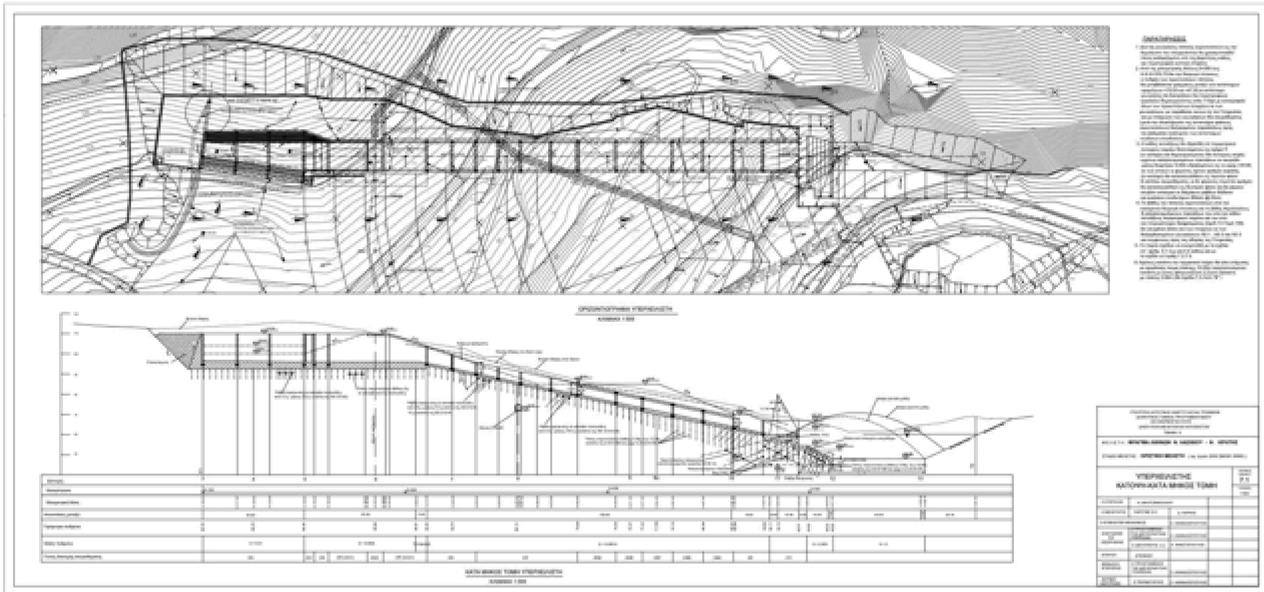

Fig. 8. Overflow, floor plan along section [14].

The Lithines Dam, under development by the Hellenic Ministry of Agricultural Development and Food, is due to commence construction within the next years. The dams are classified as small hydroelectric dams since, as we have pointed out, large hydroelectric dams are not options for European countries. It is extremely important to note that this project is not designed as a hydroelectric dam but as an irrigation. This means that the accompanying work of electricity generation, in addition to the positive imprint on the environment, offers the investor the possibility of economic exploitation of the production process. In other words, in addition to saving water, the operation of fire protection, the road network that will be created, the development and improvement of biodiversity also offers a small economic profit from the exploitation of water for energy production.

According to the data of the final study, the construction of a small hydroelectric power station, downstream of the dam, is techno-economically feasible. The return of the annual Electricity Production to the level of 110 to 200 k € in an area of the country with a high price of MWh of electricity, along with the increase of energy needs, is a key promising investment in the irrigation project (total electricity production 1.4 GWh/2.4 GWh/y).

At a time when renewable energy sources are at the centre of the debate, Crete must highlight projects that contribute to tackling climate change in a dry region and projects of this kind must have in their environmental background and the potential for energy use. The Lithines Dam is not just a construction irrigation project, but a development opportunity in a regional level, and in the same time a renewable plan with respect for the environment, sustainable development combined with energy production.

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