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Water Scarcity and Climate Change in Greece: Challenges and Opportunities for Agriculture in a CGE Framework

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List of Abbreviations

Abbreviation	Full Form of Abbreviations
CGE	Computable General Equilibrium
EEA	European Environment Agency
EIONET	European Environmental Information and Observation Network
ECMWF	European Centre for Medium-range Weather Forecasts
FAO	Food and Agriculture Organization of Nations United
GTAP	Global Trade Analysis Project
JRC	Joint Research Centre
ICES-W	Intertemporal Computable Equilibrium System - Water
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
WMO	World Meteorological Organization

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Abstract

Indeed, why is water scarcity, especially in sensitive areas with a dry climate and limited surface and groundwater, coming as a nightmare scenario of desertification and relocation of economic activities? Initially, the problem of water scarcity was occurring in the agricultural sector of developing countries, however, going through the era when Climate Change is not just a theoretical but a living phenomenon, it is suddenly noticed that it also affects developed countries to a great extent. The regions of southern Europe seem to be facing one of the biggest problems of climate change, water scarcity, in the coming years. In Greece, regions such as Thessaly, Central Macedonia, Attica, and Aegean islands face this major water scarcity challenge. Its plains and rivers are being intensively irrigated despite the already existing problem faced by the agricultural sector due to the dry river basin districts and the low rainfall, making difficult and unsustainable.

The thesis aims to demonstrate three issues facing Greek agricultural production: 1) what are the economic consequences of water scarcity in the agricultural sector, 2) how crop yields are fully dependent on climatic factors and 3) whether the traditional model of dryland crop production can be changed. The aim of this paper is to fully address these issues in a comprehensive scientific way through the Computable General Equilibrium (CGE) economic models, which provide a method for studying the role of water resources and water scarcity in the agricultural production sector and can yield important results. Finally, policy applications of sustainable and resilient practices are given, based on European examples.

Keywords: *Water scarcity, Climate Change, Agricultural production, Greece, CGE models*

Introduction

Water is the most important ingredient in shaping and sustaining life on the planet. Apart from its biological value, its influence in the developmental sectors is manifested by the first forms of civilization. It is no coincidence that larger societies developed near watercourses, productive activities were established alongside water resources, and agricultural activities were in the need of water adequacy in order to survive. Essentially, the role of water is transformed into part of economic activity, prosperity, and development. However, what happens in the case when societies consume huge amounts of water resources that the drainage system cannot provide?

In the 1940s with the advent of the Green Revolution, food production relied on new scientific methods to meet the food needs of the populations in developing countries. However, intensive agriculture and continuous food production were not sustainable at all. The continuous pumping of rivers and groundwater to cover the production processes ended up drying up entire runoff areas, leading to water scarcity (Falkenmark M, 2013).

As the world's population has grown exponentially since 1970, so has the need for food. Industrial and agricultural activities continue at an intensive rate in all parts of the world, resulting in significant water resources being in severe scarcity or in their quality being difficult to exploit. Another reason for water scarcity is the quality of water resources. In rural and industrial areas, producing activities usually deposit their waste in streams. Similarly, in livestock waste, the synthesis of nitrogen and phosphorus from chemical fertilizers, is not completely absorbed by the soil, therefore they remain partially in the surface and groundwater, turning them into dangerous and unavailable sources. In addition to the anthropogenic activities that have turned water areas into arid and potentially water-deficient states, the changing climatic characteristics of the planet are leading to a change in its geomorphological features. Specifically, through Climate Change, areas vulnerable to high temperatures and minimal rainfall are now facing desertification scenarios.

This study presents the case of water scarcity in the agricultural sector, within the economic impact that this sector has suffered and will suffer in the coming years due to climate change. It should importantly be noted that the financial costs caused by such damage, are difficult to reflect practically in economic variables. According to Damania R. (2020), absolute reliable data have not been substantiated through literature reports on the link between water and economic development. However, she supports a small group of scientists who believe in the connection between rainfall rates and the impact on the economy, that is, how climatic characteristics act as factors in shaping the economy. Similarly, this study will focus on how much Climate Change affects productive activities such as agriculture, through economic models.

The first chapter of the paper presents the whole literature review, during which many articles, research projects, and theories of climate cases and agricultural concepts were studied in order to base this paper on a strong background of theories. In particular, the concept of water scarcity as an impact of climate change is analyzed, followed by examples of economic consequences of this phenomenon specifically in the agricultural sector. And then, the general equilibrium ICES-W models and the GTAP frameworks that the CGE models are based on are presented.

In the next chapter, the whole current situation of Greece as a region directly affected by climate change is analyzed. All climate indicators are given in detail per Region and the hydrographic system is divided into River Basin Districts, according to which they belong to the respective administrative Regions. These parameters are important both in studying the phenomenon of water scarcity and in determining the needs of the agricultural sector.

The last chapter describes all the economic impacts of the agricultural sector due to climate change and the reduction of water resources. Tables and charts are presented showing the reductions in production factors and crops. Tables with comparative annual amounts of irrigated areas and water resources, highlight the increasing tendency of agricultural producers to irrigate. Finally, examples of policy applications and sustainable practices for creating new resilient agricultural production based on new climate conditions are included.

CHAPTER I
LITERATURE REVIEW

1.1 Water Scarcity and Climate Change

Over the last few years, there has been noted an increase in water scarcity throughout the planet. The exponential demographic growth, food needs, and climate change led to the rarity of water resources, especially in agricultural production. According to the Food and Agriculture Organization of Nations United (FAO), water scarcity is due to the unequal relationship between the supply of water resources and their demand, which varies, respectively, with local conditions (climate, infrastructure, resource quality, and population). Specifically, it highlights that water scarcity is the extreme phenomenon of a supply and demand relationship since there is a growing demand for water resources and a rapid reduction in stocks and water quality.

One of the major factors contributing to water scarcity is the vulnerability of a region to drought. According to World Meteorological Organization (WMO), more and more people have been affected by the drought phenomenon from any other natural disaster. Rural families are the first to confront the impact of extreme climate change, as climate events directly affect food and land prices, resulting in the process production to shift in other forms or to migration of this community in other areas, the so-called climatic migrants.

According to UNESCO's World Water Assessment Program report (2009), agricultural production accounts for 70% of freshwater pumping, while this percentage reaches 90% in some developing countries. The growing demand for water resources in this sector, year by year, has far-reaching implications. In addition to the real changes in water availability and demand, the magnitude of uncertainty and the complexity of climate change science pose unique challenges in resource allocation and risk management (Tarlock, 1992). Practically, the changes in soil moisture, through climate change, become apparent in agriculture when the soil tries to store the minimal rain to return it to the plants. Rainwater used in agriculture, through this process[1] is called "green water" and is characteristic of the land to which it falls.

Liu et al. (2017) base their theories on that, reporting that green water refers to soil moisture due to rainfall. It is a purely dependent indicator on climatic data and directly affects agricultural production. Moreover, green water contributes 60% to the same food production without

[1] The UNESCO World Water Assessment Program (2009) attributes this process through photosynthesis, as the source of functions of all multicellular plant organisms in which soil water is pumped from plant roots, energy is collected from the sun, carbon dioxide is absorbed from the atmosphere and then diffuses through perspiration.
https://unesdoc.unesco.org/in/documentViewer.xhtml?v=2.1.196&id=p::usmarcdef_0000181993&file=/in/rest/annotaionSVC/DownloadWatermarkedAttachment/attach_import_ , (received for view 13.06.2022)

additional irrigation if the cultivated area does not need it (Rockström et al, 2009). It should be noted that the highest percentages of green water are found in non-cultivable areas, such as tropical forests. On the contrary, in areas where there is increased soil and atmosphere temperature (rise of hot and dry days) the percentage of green water is decreasing accordingly (Falkenmark M., 2013).

In contrast, the Nasa Global Climate Change Institute and the European Environment Agency (EEA) classify water content on the ground as soil moisture. This designation has been put as an important factor in plant growth because it affects the way soil temperatures exchange with atmospheric water vapor. This term and the data of the specific institutes are described and elaborated on in the second chapter of the present essay related to the specific case study that was selected.

Regarding blue water, Falkenmark M. (2013) emphasizes that the risks associated with its depletion are due to the competition of the economic system for water and the complexity of water management. He also states that climate-dry areas with high temperatures, a high rate of surface water evaporation, and a limited rainy season, it has the effect of shrinking watersheds. Especially if the above factors are combined, the increased water demand in areas that are vulnerable to dry and hot climates, then we are clearly referring to the reduction of river basins and groundwater.

Schewe et al. (2014)[2] having opposing theories, consider that the impact of climate change on water systems is quite uncertain for several reasons. The predictions of climate models regarding changes in the global average differ in size, and in many cases even in the sign, especially when converting data on a regional scale. In many cases, it must be borne in mind that aggregate estimates of water scarcity in the global setting, can potentially affect many areas that are more directly prone to water scarcity than others that indirectly do not have a significant problem. This is due to the fact that many regions or countries that do not have a high incidence of potential water scarcity, can "pull" the global index lower than the fewer countries that already have a serious water scarcity problem or will have one in the future. Furthermore, they point out that the way in which changes in rainfall rates only translate into changes in hydrological variables, such as surface runoff and river discharge (that is, runoff that accumulates along the river network), is wrong since it depends on many other biological characteristics of the areas (e.g., vegetation and soil properties).

[2] Schewe J., Heinke J., Gerten D., Haddeland, Nigel W. Arnell, B. C. Douglas, Dankers R. et al., second published March 4, 2014 and first published December 16, 2013; https://doi.org/10.1073/pnas.1222460110 , (received for review 13.06.2022)

Fung, Lopes, and New (2011) find that the impacts of climate change differ significantly between river basins and that the seasonality of runoff may be more extreme in a +4 °C world than in a +2 °C.[3] But even when average annual runoff increases, dry periods can become more stressful. Schewe et al. (2014) identified that, with a 2 °C increase in temperature over present-day levels, the average annual runoff would be lowered, and water scarcity would be increased in several regions, including in the Mediterranean, the Near East and many regions of North and South America. As FAO (2020) reports, a recent project finds that 129 countries will be affected by increased drought, mainly as a result of climate change.

1.2 The Economic Consequences of Water Scarcity

The economic consequences caused by water scarcity are difficult to be captured in a single economic context. For example, rainfall reduction in an area where water is plentiful will impact economic costs less. While an equivalent reduction in rainfall in another area where water is scarce will result in an increase in economic costs. In fact, the number of rainy days and the availability of water show significant spatial and temporal variability. According to Damania R. (2020), the economic impact that one centimeter of less rainfall can have been not the same in a drought-prone area as in a wooded area. For this reason, when the data are collected at a country level, they may not be captured correctly, due to data overlap. As reported by Briant et al. (2010), it is known that the spatial average at national, regional, and international levels covers variability and prejudges the statistical conclusion. This can happen if one part of a country is affected by drought and another part is flooded, the average of the country may indicate normal rainfalls and will fail to record its spatial fluctuations. Therefore, in order to properly study the hydrographic systems of river basins, measurements should be done locally, especially when efforts are made to correlate them with the economic data.

To quantify the reduction of water resources, as well as water scarcity, Hanasaki et al. (2008), used a fraction ratio, which is expressed as the daily pumping of water from watercourses, rivers, lakes to the potential daily water demand from agricultural, industrial and urban production, for a given year. If the result of this ratio is less than one unit, then there might be future water scarcity.

In practice, such an example can easily be applied to the agricultural sector. In a period of intense drought, where the availability/supply of water is less than the demand of farmers and

[3] Fung F., Lopez A. & New M., (2011), *''Water availability in +2 °C and +4 °C worlds''.* Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 369(1934): 99–116.

water needs, then it can be reflected economically by the reduction of agricultural production. The reduction in the supply of agricultural products and food has consequently the rise in prices. This integral rise in prices will challenge the local market, which will contribute to the overall reduction of demand[4] for agricultural products and will focus on imported products. In the case of drought existing throughout most of the year, the current economic agricultural activity could undergo, theoretically, in depression.

According to Damania R. (2020), in the agricultural sector in cases of severe long drought, some insurance programs/compensations are given to farmers, which can create counterproductive effects or lead to non-utilization of appropriate drought management techniques, pushing the productive sector in a vicious cycle of improper management and dealing with these phenomena. Hertel and Liu (2009) provide a solution with a shift of production from traditional farms to other less water-dependent agricultural production sectors of the economy. Therefore, farmers should be freed from pumping groundwater and surface water, which increases the vulnerability of the water shortage phenomenon but also freed from seasonal compensation.

Additionally, through the Computable General Equilibrium (CGE) models we can draw several scenarios for the management of water scarcity and how much it affects the economic indicators. CGE models are based on a series of affairs, based on data availability and computational constraints, that provides a standardized representation of the economy. In short, a CGE model provides various conclusions on hypothetical study scenarios. For example, if most of the available water is distributed to the agricultural sector at no significant cost to the user, over-consumption would be inevitable. The marginal value of water in different uses varies greatly because the prices disbursed by the primary, secondary and tertiary sectors often have nothing to do with the opportunity cost of supplying water to them (Roson R. and Damania R., 2017). Thus, CGE models present the consequences of inequality as a function of market failures and institutions that do not distribute water based on economic value. The simulations of these models suggest that even if only a fraction of water use is distributed based on its economic value, it can balance the ratio between supply and demand, resulting in more benefits and an increase in rural GDP per year, but also to contribute to the prevention of serious water shortages.

[4] Example of economic theory of supply and demand, through rising prices and falling demand, as reported by Parkin M., Powell M. and Matthews K., (2012), *"Essential Economics",* pp. 126-128, Pearson Education Limited

Ponce et al. (2016)[5] indicate that the economic consequences of changes in water availability must be considered, as it is an essential factor linking international trade with agricultural production. They conclude by saying that to calculate the impacts of climate change on the agricultural sector based on water availability, the general equilibrium approach is the most appropriate analytical framework. In their research entitled *"Climate Change, Water Scarcity in Agriculture and Economy-Wide Impacts in a CGE framework"*, they examine two modes of agricultural production, depending on how water is supplied, such as rainfed agriculture and irrigated agriculture. The current approach also includes irrigated activities as well as the role played by water endowment availability.

Through ICES-W they look at two different ways in which water flows affect the agricultural sector. The form of precipitation and the form of irrigation. As well as how climate change impacts affect both rain-fed and irrigated water systems. Ponce et al. (2016) emphasize despite the importance of water as a key factor in shaping agricultural production, it is also, a significant challenge to evaluate water as an economic indicator and a factor within the CGE system. Water does not have a price to reflect its marginal productivity. In this way, much empirical evidence suggests that the lack of a percentage competitive market price is one of the factors leading to inefficiency in the use of water resources.

With the current situation of Climate Change, where more and more areas are facing and will continue to face water management problems, reasonable questions arise: Should the use of water resources be made more stringent and controlled, cause when water is provided free of charge or below the opportunity cost in most cases, it seems that its value is not calculated and how the phenomena of resource depletion intensify? In such an economy where the limit of productive potential and the efficient use of resources are exceeded, the point of distributive efficiency is lost. According to Calzadilla et al. (2013) improving the efficiency of water management systems not only brings benefits to areas with water scarcity but also causes other areas to use water resources more wisely.

On the contrary, however, Expósito A., Beier F. and Berbel J. (2020) argue that Hydro-economic models (HEMs) are more appropriate as tools for evaluating water management than CGEs, as HEMs include multiple indicators of hydrological, climatic, geological, economic and political data, while CGEs give more basis to the levels of economy and economic equilibrium models. The question here, however, is not which model uses the most appropriate

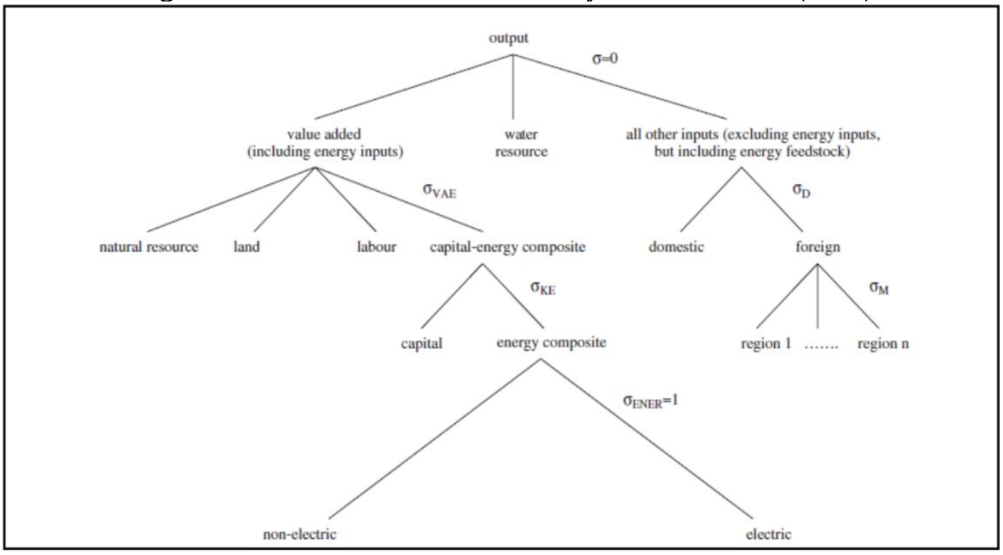
[5] Ponce R., Parrado R., Stehr A., Bosello F., (2016), "*Climate Change, Water Scarcity in Agriculture and the Economy Wide Impacts in a CGE Framework*", FEEM Working Paper No. 79.2016, Available at SSRN: https://ssrn.com/abstract=2887916 or http://dx.doi.org/10.2139/ssrn.2887916 (received for review 02.07.2022)

tools for the utilization of water resources, but which model gives realistic projections of the tradeoffs between economic and environmental costs and benefits of water scarcity in agricultural production.

1.3 GTAP-W and ICES-W model structure in CGE framework

According to Dellarole A. and Rarrado R. (2015)[6], few models explicitly focus on water resources with a focus on agriculture. The most useful model with respect to water is the Global Trade Analysis Project[7] - Water (GTAP-W) by Bernitella et al. (2005), which was characterized as an improved version of GTAP-E by Burniaux and Truong (2002) to include water resources in agriculture and water trade as indicators. In particular, the standard GTAP model is a multi-region, multi-sector, computable general equilibrium model with perfect competition and constant returns to scale.

Figure 1. GTAP-W Production Tree by Bernitella et al. (2007)



As Ponce R. D. & Parrado R. F (2012) state that in order to include water, the CGE modeling framework requires a value system. Under the assumption that water has no price for the agricultural sector, the authors simulate price systems through the occurrence of economic

[6] Dellarole A. and Rarrado R., (2015), Chapter 3 The implications of irrigation as a planned adaptation measure on an economy wide context, *"ESSAYS ON ECONOMIC MODELLING OF CLIMATE CHANGE IMPACTS AND ENVIRONMENTAL POLICIES",* Universita degli studi di Milano, Department of Economics, Management, and Quantitative Methods (DEMM), Lombardy Advanced School of Economic Research (LASER), Ph.D. COURSE IN ECONOMICS XXVII cycle.
https://air.unimi.it/retrieve/handle/2434/352870/517308/phd_unimi_R09436.pdf#page=86 (received for review 03.07.2022)

[7] Specifically, the GTAP (Global Trade Analysis Project) is a global network of researchers and policy makers conducting quantitative analysis of international policy issues. GTAP aims to improve the quality of quantitative analysis of global economic issues in an economy-wide context. (For more information: https://www.gtap.agecon.purdue.edu/about/project.asp , received for review 03.07.2022)

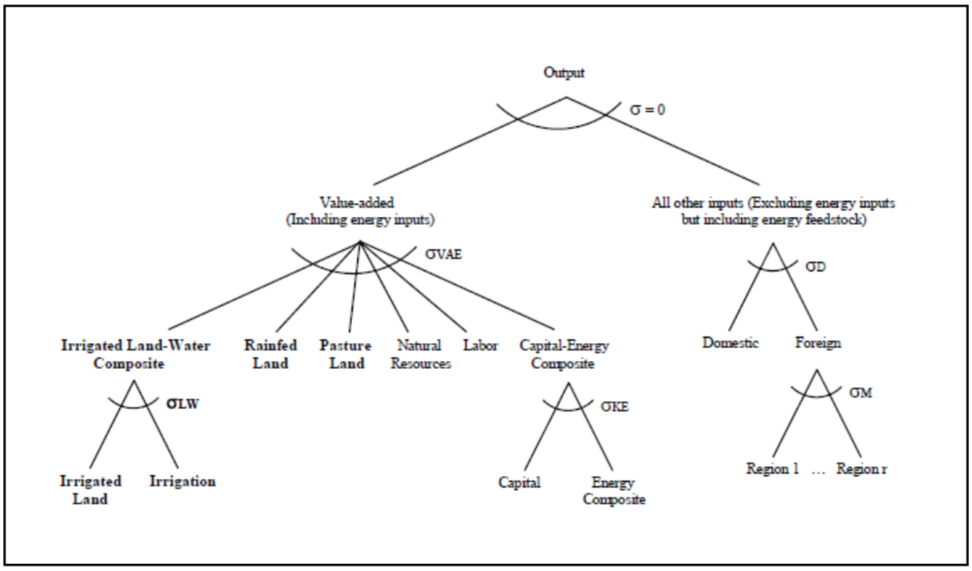
gains due to water scarcity. For example, if the water supply does not meet water demand, producers would be forced to pay a price in order to access water resources. This model assumes that the water resources are owned by individuals or collective entities, to whom a water scarcity event would result in the occurrence of economic rent. According to the model, when water supply decreases, assuming negative water price elasticity implies an increase in water prices, which simultaneously leads to a decrease in water use. The GTAP-W model has been applied to the analysis of virtual water, water pricing and water supply (figure 1).

As reported by Calzadilla A., Rehdanz K. and Tol S.J R. (2011)[8], in all CGE models, GTAP-W is used to present the Walras perfect competition case to simulate the adjustment processes. The sectors are simulated through a surrogate firm that maximizes its profits in perfectly competitive markets. The production functions are determined by a set of nested constant elasticity functions. In the original GTAP model, the land is combined with natural resources and capital in a value-added model. In their framework, Calzadilla et al. (2008) incorporate the GTAP-W model into the GTAP 6 database and information from the IMPACT model[9] (Rosegrant, Ringler, Msangi, Sulser, Zhu, & Cline, 1998). The model they use is based on 16 regions and 22 sectors, 7 of which are related to agriculture. They briefly report that land types differ in that rainfall is available, but irrigation development is costly and yields per hectare are higher. Given that land that is equipped for irrigation is generally more valuable, they refer to the separation of the value of land as capital and the value of irrigation (Figure 2).

[8]The GTAP-W model: accounting for water use in agriculture by Alvaro Calzadilla, Katrin Rehdanz and Richard S.J. Tol No. 1745 | November 2011, Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany *https://www.researchgate.net/publication/254426905_The_GTAP-W_model_accounting_for_water_use_in_agriculture*

[9] International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). *IMPACT-WATER - through the combination of the IMPACT and WSM models - incorporates water availability as a driving variable with observable flows and storage to examine the impact of water availability on food supply, demand and prices. This framework allows exploration of the relationship between water availability and food demand at trade at a variety of spatial scales - ranging from river basins, countries and more aggregated regions to the global level.* (for more information see Tingju Zhu, Mark Rosegrant, Siwa Msangi, (2008), International Food Policy, *https://www.academia.edu/14126896/International_model_for_policy_analysis_of_agricultural_commodities_and_trade_IMPACT_Model_description*

Figure 2. GTAP-W Production Tree by Calzadilla A., et al. (Calzadilla, Rehdanz, & Tol, 2008)



According to the authors, the new production infrastructure, as well as the data used, allows this model to estimate differences associated with the type of water used for the agricultural sector, i.e., differences between blue and green water. This is possible because the IMPACT model accounts for the amount of green water used in irrigated production and the amount of green and blue water used in irrigated production. Calzadilla et al. (2008)[10] analyzed the consequences of innovation in irrigation management at the economic level. The model has been implemented in the analysis of irrigation improvement, sustainable water uses and climate change. The results showed that higher levels of irrigation efficiency will have a significant impact on water use, production and crop productivity. In some areas, water use increases for some crops, while in others it decreases. Due to increased water use efficiency, the rainfed sector is disadvantaged, but the welfare losses are compensated for by the total benefits to the economy.

Regarding the Intertemporal Computable Equilibrium System (ICES), Ponce R. et al. (2016) refer to it as a multi-dynamic and multi-regional CGE model developed by Fondazione Eni Enrico Mattei[11]. This model was based on the GTAP model format. To better conduct research on water issues, they developed ICES-W which was expanded from its original form to explicitly consider the role that both the irrigation sector and water resources in each region play in addressing the impacts of climate change on the agricultural sector. As mentioned by

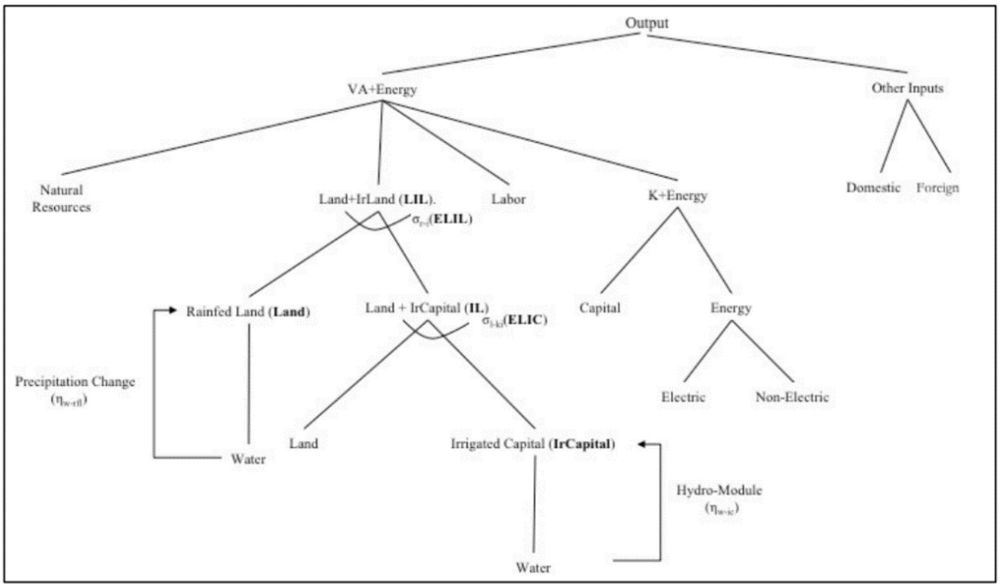
[10] Calzadilla, A., Rehdanz, K., & Tol, R. (2008). Water Scarcity and the Impact of Improved Irrigation Management: A CGE Analysis. Kiel Institute of the World Economy, Working Paper 1436, Kiel University

[11] Ponce R., Parrado R., Stehr A., Bosello F., (2016), "Climate Change, Water Scarcity in Agriculture and the Economy Wide Impacts in a CGE Framework", FEEM Working Paper No. 79.2016, Available at SSRN: https://ssrn.com/abstract=2887916 or http://dx.doi.org/10.2139/ssrn.2887916 (received for review 03.07.2022)

Bates et al. 2008 and Parry et al. 2007, this model approach does not consider climate impacts, changes in temperature, carbon dioxide levels, changes in growing seasons and extreme weather events. This model follows the example of GTAP-W which considers two types of agriculture depending on how the water is supplied, i.e., rainfed agriculture and irrigated agriculture. Thus, ICES-W is based on these two ways of developing methodology, irrigation and precipitation.

The fact that there is a clear distinction between irrigated and crop rotation agriculture is because water affects agricultural productivity depending on the type of agriculture. Concerning areas with the irrigated agriculture characteristic, productivity depends directly on rainfall, while in areas with the main characteristic of irrigated agriculture, productivity depends on specific investments made in the provision of irrigation services and the supply of water-to-water tanks (FAO 2011). Important factors other than water that determine significant percentages of agricultural sector development are three new factors which are: Irrigation capital, and irrigated land (Ponce R., et al. 2016). The production structure in the standard ICES version is expressed as a series of nested CES output functions. The main changes in ICES-W are included below the third level as shown in Figure 3. At the fourth level, the model distinguishes between rainfed and irrigated land to account for productivity as well as the effects of climate change.

Figure 3. ICES-W Production Tree by Ponce R. et al. (2016)



According to Ponce R. et al 2016, the production structure presented above applies only to the agricultural sector, which includes the following products: rice, wheat, cereals, vegetables and fruits, oilseeds, sugar cane, sugar beet and fibre. As a clear distinction is made between rainfed and irrigated soils and capital adequacy, such as irrigation capital (IrCapital) and physical capital (Capital) as indicated in Figure 3. In addition, they note that in order to allow for substitution between new inputs, the Rainfed Land-Irrigated Land elasticity of substitution (ELIL) is larger than the elasticity of Land-Irrigated Capital (ELIC). Finally, the model hypothesizes that the productivity of capital invested in irrigation and the productivity of rainfed land depend on the water supply and the level of rainfall, respectively.

In the research by Ponce et al. 2016, both the static ICES model and the ICES-W model have similar results in terms of output change and impact on global GDP. Specific results showed that agricultural production, in the ICES model decreases by 1.8%, while in the ICES-W model the reduction is 1.82%. However, at the regional scale, the differences in production are marginal. The use of the ICES-W model represents a broader assessment of the economic impacts of climate change than previous global CGE models dealing with water emissions. In addition, the ICES-W model as an adaptation strategy could be used to evaluate the economic impact of increased investment in irrigation in the agricultural sector.

Finally, as Ponce et al. 2016 point out, the model does not consider specific geographical conditions that could improve the results. The ideal solution is to operate with river basin scale data, but this information is very difficult to collect. For the above reasons, this essay is based on multifaceted evaluation indicators, i.e., geomorphological, hydrographic and climatic, as well as both at local and regional level, in order to obtain reliable results. However, the model presupposes a relationship between water and agricultural productivity by including water for each area and individually response functions for agricultural productivity, following the same model structure, it would be feasible to obtain more detailed outputs. Furthermore, as stated in FAO (2020)[12], water accounting and water auditing should be the basis for any effective strategy to address water scarcity, as they can form the basis for proportionate, effective, and equitable water management.

[12]FAO, (2020), " *The State of Food and Agriculture 2020* ", Rome, Italy, ISBN: 978-92-5-133441-6

CHAPTER II

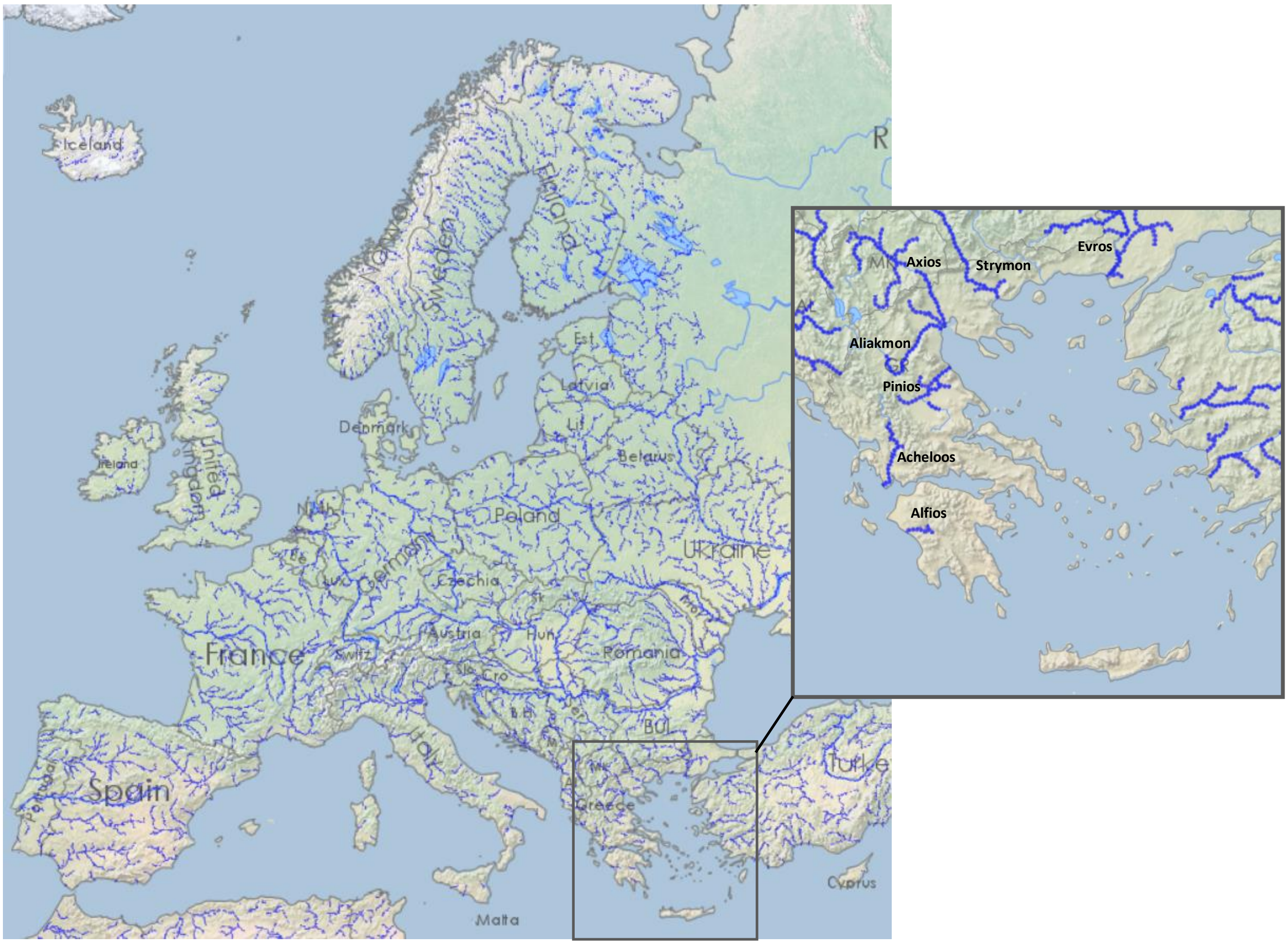
CURRENT SITUATION OF STUDYING AREA

2.1 Hydrological Data

This paper specifically studies the impact of water scarcity in the agricultural sector for the region of Greece. The main data to be analyzed are the changes in the hydrographic network and the desertification of the small and medium rivers of the country, as well as the intensity of their effect on agriculture. The most important rivers are located in the northern part of the country and flow from north to south and are cross-border rivers. The largest rivers in Greece are the Axios, Aliakmon, Acheloos, Pinios, Evros, Strymon, Nestos and Alpheus (see Map 2). Each of them contributes from a separate catchment area with many tributaries, streams and creeks, which are responsible for the development of habitats, the maintenance of fauna and the overall ecosystem. The map below illustrates the hydrographic system of Greece as extracted from the geospatial data of geomorphological features.

The main source of most of the country's water resources is the Pindos Mountain range. Western Greece is considered mountainous, with the Pindos range keeping most of the aquatic ecosystems alive (see Map.1). However, it is also the reason for problems in the utilization of the country's water resources, as the distribution of water resources in the geographical area of Greece is uneven. In fact, the western part of the country, covering 24% of the country, receives 36% of the total atmospheric precipitation.

Map.1 The hydrographic system of Greece *(Source: Map of the Department of Geology AUTH)*



Map.2 The rivers of Greece in correlation with the total number of rivers in Europe. *(Source: European Environment Agency,* [*https://www.eea.europa.eu/data-and-maps*](https://www.eea.europa.eu/data-and-maps) *)*

According to the Hellenic Geological & Mineral Exploration Authority[13], the total annual water resources in Greece are 29 billion m3. The above quantities do not include the water that flows into Greece from neighboring countries via the Evros, Strymon and Axios rivers (see Map.2), which are estimated at approximately 15 billion m^3. Also not included are the permanent groundwater reserves, which are huge and should not be used on a permanent basis, except as a reserve in particularly dry periods. Greece therefore has, overall, sufficient surface and groundwater resources. However, over the last 50 years, due to the impact of human activity on nature, various reasons have significantly reduced the quantity available and made it difficult to use them. As shown in map 2, the depiction of many Greek rivers is not visible on the EEA map because it is due to their rapid drainage and automatically makes them invisible in the satellite and geospatial imagery data. The intensification of agricultural production,

[13] Gatzouyannis A., Paraskevopoulou P. (2001), *Hydrographic network base of Greece: Project: Computerization of Hydrophological Data Bank (National Network) and using G.I.S. : Β΄ΚΠΣ E.P. Energy,* Hellenic Geological & Mineral Exploration Authority, Athens, 2001

urbanization and industrialization have drained the country's water areas, resulting in increasing pressure on the existing water system.

2.1.1 River Basins Districts of Greece

Initially, a river basin is defined as the area of land from which all forms of water, such as rainfall, snowfall or hail, are drained in a particular area through the hydrographic network created by successive streams, torrents, rivers or even lakes, which then discharge into the sea through the estuary (delta) of a river[14]. For example, for any Greek river basin there is a separate water compartment formed by each river. Greece has a total of 14 water districts in its geographical area, according to Law 1739/1987 (Greek Government Gazette 201/A/20-11-1987). As referred to in the institutional framework *''Management of water resources and other provisions''*, in Article 4. *''Water compartments are areas delimited between them by watersheds or island areas, comprising integrated hydrographic networks, with hydrological conditions as similar as possible.''* The Greek territory is divided into the following water catchment areas: Western Peloponnese (EL01), Eastern Peloponnese (EL02), Northern Peloponnese (EL03), Western Central Greece (EL04), Epirus (EL05), Attica (EL06), Eastern Central Greece and Evia (EL07), Thessaly (EL08), Western Macedonia (EL09), Central Macedonia (EL10), Eastern Macedonia (EL11), Thrace (EL12), Crete (EL13) and the Aegean Islands (EL14). In more detail:

The **River Basin District of Western Peloponnese (EL01)** extends geographically in the southwestern Peloponnese, but regionally belongs 1/3 to the region of Western Greece and 2/3 to the region of Peloponnese. The surface area of the district is 7.235 km^2. The precipitation in the area of Alfios is quite significant and reaches about 1.058 mm of water per year. That is, they can reach an estimated 8.1 hm^3 of water per year, which feeds the hydrological cycle of the basin.

The **River Basin District of Northern Peloponnese (EL02)** is geographically located in the northern Peloponnese. Some of the Ionian islands, such as Kefalonia, Ithaca, and Zakynthos, belong to the same river basin district. Its surface area is 7.397km^2. Administratively, 2/4 of it is part of the Western Greece Region, 1/4 includes islands is part of Region of the Ionian Islands

[14] As defined according to the European Environment Information and Observation Network (Eionet) - Archived content - water topic - Glossary definitions - River basin. Source: *https://www.eea.europa.eu/archived/archived-content-water-topic/wise-help-centre/glossary-definitions/river-basin*

and the remaining 1/4 to the Peloponnese Region. The highest average annual precipitation can be approximated to a volume of 4.3 hm^3 of water per year, which feeds the hydrological cycle of the basin. It should be noted that in the River Basin District of Northern Peloponnese there are technical lakes that play a key role in the need for irrigation and water use. The most important is the artificial lake of Pinios. But equally important are the Asopos and Asteriou artificial lakes.

The **River Basin District of Eastern Peloponnese (EL03)** extends geographically in the eastern and south-eastern Peloponnese. Administratively it belongs entirely to the Peloponnese Region, except for a very small part of the province of Troizinia which belongs to the Region of Attica. The main rivers of the Eastern Peloponnese Water District are the Eurotas and the Inachos, with the artificial lake Taka, located on the plateau of Tegea, in the south-western part of Tripoli, playing a decisive role in the needs for irrigation and water use.

In total, the Peloponnese Region contributes almost 15,6 hm3 of water annually through the river basins within its administrative boundaries. Rising temperatures, minimal rainfall, and intensive agriculture are putting increasing pressure on the region's water resources every day. As analyzed in the following chapter with the climatic data, the minimum and maximum temperatures in the Peloponnese region are presented, as well as the mm of rainfall recorded year by year.

Table 1. Freshwater resources of the Peloponnese Region as a whole.

RBD	The Peloponnese Region	
	Surface (km2)	Freshwater resources (hm3)
EL01	4.888	7.850
EL02	1.843	1.135
EL03	8.144	6.656
Total	**14.875**	**15.641**

Source: Own Processing - *Data by Management Plan for the Water* - *Ministry of Environment & Energy*

The **River Basin District of Western Central Greece (EL04)** includes three main basins: the Acheloos, the Evinos and the Mornos. In this river basin there are very important lakes, which contribute to meeting water needs. The artificial lakes of the Tavropou dams, Kremaston, Kastraki, Stratos, Evinus and Mornos. Administratively it is divided into the regions of Central Greece, Ionian Islands, Thessaly and a small part of the Region of Epirus. This river basin district includes one of the largest rivers in the country, which provides water and life to thousand of acres of land in the region. The Acheloos River has a total area of 7,531km^2 and annually carries nearly 28hm^3 of water volume through annual precipitation, karstic water and surface runoff. In fact, annual rainfall on average corresponds to an approximate volume of water of about 32 hm^3 per year. Except, of course, for the Acheloos river system, which is shared with the region of western Greece, as only 1/2 of the river belongs to Central Greece.

The **River Basin District of Eastern Central Greece (EL07)** includes the river basins of the Sperchios, Evia, Northeastern Coast Kallidromos, Bootikos-Kifissos, Amfissa, Asopos and Sporades islands. The river basin district of the Eastern Central Greece is estimated to have an approximate volume of 6,8 hm^3 of water per year.[15] In overview, the Region of Central Greece has a potential of almost 22,5 hm^3 of water volume per year, through the river basins within its administrative boundaries (see table 2).

Table 2. Freshwater resources of the Central Greece Region as a whole.

RBD	The Central Greece Region	
	Surface (km2)	Freshwater resources (hm3)
EL04	10.499	15.624
EL07	12.279	6.885
Total	**22.778**	**22.509**

Source: Own Processing - *Data by Management Plan for the Water* - *Ministry of Environment & Energy*

Overall, in the region of Central Greece, only the river basins of Acheloos and Sperchios contribute to the conservation of water resources. The 1/2 of the Acheloos basin plays a key role in Central Greece, which provides almost 14 hm^3 of water (see table 3). All other rivers are ephemeral, and seasonal are usually maintained in the winter months with high rainfall.

Table 3. River Basins of the Western Greece Region in annual freshwater resources.

The Western Greece Region		
RBD	**Surface (km2)**	**Freshwater resources (hm3)**
Alfios	1.905	4.050
Northwest Coast of Peloponnese	1.843	1.135
Peiros-Verga-Pinios	2.423	1.570
Acheloos	3.765	14.001
Evinus	1.344	2.177
Mornos	1.259	1.623
Total	**12.539**	**24.556**

The **River Basin District of Epirus (EL05)** has an area of 7.978 km^2, of which 121 km^2 belong to Corfu. It is one of the most mountainous departments in the country, since its mountainous areas account for 70% of the total area, while the lowland areas account for only 15%. In addition, the river basin of Epirus has 3 artificial lakes which ensure maximum efficiency of water resources for the needs of the region. The river basin district of Epirus Greece is estimated to have an approximate volume of 31 hm^3 of water per year.

[15]According to the data presented in the National Management Plan of River Basin District of Eastern Central Greece, through the Approved MP: GR07/26b – Summary of management plan, via link: http://wfdver.ypeka.gr/en/management-plans-en/approved-management-plans-en/gr07-approved-en/

Table 4. River Basins District of Epirus in annual freshwater resources.

River Basin District of Epirus (EL05)		
River Basins	**Surface (km2)**	**Freshwater resources (hm3)**
Aoos	2.322	5.966
Kalama	1.996	11.221
Acherontos	825	1.812
Arachthos	1.912	9.474
Corfu – Paxus	121	101
Lourus	802	2.318
Total	**7.978**	**30.892**

Source: Own Processing - Data by Management Plan for the Water - Ministry of Environment & Energy

The **River Basin District of Attica (EL06)** consists of the Region of Attica and the islands of Salamina, Aegina, Agistri, and Makronissos. The river basins of Attica have mostly been converted into motorways, roads, pavements, real estate plots, etc. There is no longer any existing river in its natural form, only groundwater. For this reason, Attica exploits water resources from other bordering geographical areas. It is estimated that almost 0,245 hm^3 of water can be recorded annually in the Attica river basin and the total area is 3,187 km. The only lake that constitutes the needs of the region is the artificial lake Marathon with an area of 2,98 km, which takes up the size of all the other water bodies that can be formed by the river basins of Attica as a whole.

Table 5. Freshwater resources of Attica in annual freshwater resources.

River Basin District of Attica (El06)		
River Basins	**Surface (km2)**	**Freshwater resources (hm3)**
Attica Area	3,187	0,245

Source: Own Processing - Data by Management Plan for the Water - Ministry of Environment & Energy[16]

The **River Basin District of Thessaly (EL08)** almost coincides with the corresponding geographical region. The overall area of the department is 13.377 km^2. The river basin district of Thessaly is divided into the Pinios and the Almyrus-Pelion basins with an area of 11.062 km^2 and 2.078 km^2 respectively. However, the estimated average annual runoff of the river basins in Thessaly is almost 34,3 hm^3 of water per year.[17] One of the largest rivers in Greece is in this district and it is the Pinios. It is estimated that in total from the annual precipitation and karstic waters, it provides a total of 34.1 hm^3 of water volume to the areas it runs through. All productive activities in Thessaly rely exclusively on the Pinios. Both agricultural and urban

[16] The collection, processing, analysis and tabulation was done by me. The data were taken from the National Water Management Plan for the Attica Region - *Ministry of Environment & Energy, Special Secretariat for Water, Athens, 2017.*

[17] The values are approximated through the revised water management plan for Thessaly. See more: *http://wfdver.ypeka.gr/el/management-plans-gr/1revision-approved-management-plans-gr/approved-1revision-el08-gr/*

activities. It is no coincidence that Thessaly has the most important and largest agricultural production in the country.

Table 6. River Basin District of Thessaly in annual freshwater resources.

River Basin District of Thessaly (EL08)		
River Basins	**Surface (km2)**	**Freshwater resources (hm3)**
Pinios	11.062	34.101
Almyrus-Pelion	2.078	213
Total	**13.140**	**34.314**

Source: Own Processing – Data by Management Plan for the Water - Ministry of Environment & Energy

The **River Basin District of Western Macedonia (EL09)** is in the northwestern part of the country. The average annual total water supply in the river basin district of Western Macedonia is 34,2 hm^3, the second largest river basin district of water resources in Greece. However, since a large part of this water compartment is divided and shared with the Region of Central Macedonia, the approximation of average annual runoff varies accordingly. From the total of the above quantity, the needs of the Central Macedonia Water Division and part of it are covered, as a quantity of water equal to approximately 0,500 hm^3 is transported through the Aliakmon-Axios Canal to cover the needs of the Central Macedonia Water Division irrigation needs of the Thessaloniki - Lagada Plain. Therefore, of the total amount of resources only almost 2/3 of the total amount of water resources belong to the Region of Western Macedonia (see table 7).

Table 7. Freshwater resources of the Western Macedonia Region.

RBD	**The Western Macedonia Region**	
	Surface (km2)	**Freshwater resources (hm3)**
Total	10.514	22.803

Source: Own Processing – Data by Management Plan for the Water - Ministry of Environment & Energy

The **River Basin District of Central Macedonia (EL10)** has an area of 10,163 km^2 and consists of four river basins. According to the National Water Management Plan of the Ministry of Environment (2017)[18], the total water supply in the Axios river basin amounts to 39,2 hm^3 of water volume, of which 1,43 hm^3 comes from the river's own resources and the remaining 37,76 hm^3 from the inflow of water from the neighboring country of FYROM through the river. Of course, the amount of water transferred from the Aliakmon River has not been counted. As far as the Gallikos River basin is concerned, the maximum annual runoff of the river system is about 0.820 hm^3 of water volume and its only lake water system is the natural lake Pikrolimni

[18] 1st commissioning, Approved Management Plans, WF10 - Central Macedonia, via link: http://wfdver.ypeka.gr/wp-content/uploads/2022/01/EL10_1REV_P22b_Perilipsi_EN.pdf

with an area of 4.27 km^2. The most important lakes in Central Macedonia that supply the urban and agricultural areas are Lake Koronia and Volvi, of which only Volvi is a natural lake.

The **River Basin District of Eastern Macedonia (EL11)** consists of only one river basin, that of the river Strymon. The total area of the department is 7.319 km^2. The Strymon is a transboundary river, whose waters are shared by Greece and Bulgaria. The Strymon is one of the largest rivers of the Balkan peninsula, with a total length of 315 km to its mouth at Lake Kerkini. Lake Kerkini has developed into an important and internationally important wetland, protected by international conventions, although it is known that it is often affected by irrigation activities.

Administratively, however, half of this area essentially belongs to the Region of Central Macedonia and the other half to Thrace. For example, Table 8 shows the estimated water management area for the whole of the Central Macedonia Region. The administrative water management which is included in the Region of Central Macedonia accounts for almost 58 hm^3 of water volume, which makes the Region the first in the category of water resources in the country. Of course, the vulnerability of the resources is increased due to the intensive agriculture practiced in a total of 60-70% of land use in this Region. Increasing pressure for irrigation has made the water bodies at times dry areas with imminent risk of water scarcity.

Table 8. Freshwater resources in the Region of Central Macedonia.

RBD	The Central Macedonia Region	
	Surface (km2)	Freshwater resources (hm3)
EL09	3.101	8.325
EL10	10.163	40.744
EL11	3.660	8.965
Total	**16.924**	**58.034**

Source: Own Processing - *Data by Management Plan for the Water* - *Ministry of Environment & Energy*

The **River Basin District of Thrace (EL12)** consists of five river basins, those of Nestos, Xanthi - Xiroremma, Komotini, Evros and the islands of Thassos and Samothrace. The river Evros is partly the national border between Greece and Bulgaria and Greece and Turkey. The river basin is divided between the three countries it crosses as follows: 35.085 km^2 belongs to Bulgaria, 14.575 km^2 to Turkey and 4.080 km^2 to Greece. In total for the administrative region of Eastern Macedonia and Thrace, almost 27 hm3 of water volume per year within the total area of almost 15 km2 is allocated to manage its river systems. The above volumes are always to a point estimated and theoretical according to the data presented in the National Water Resources Management Plans (2017).

Table 9. Freshwater resources of the Eastern Macedonia & Thrace Region.

RBD	The Eastern Macedonia & Thrace Region	
	Surface (km2)	Freshwater resources (hm3)
EL11	3660	8965
EL12	11240	17990
Total	**14.900**	**26.955**

Source: Own Processing - Data by Management Plan for the Water - Ministry of Environment & Energy

The **River Basin District of Crete (EL13)** is the 13th of the 14 water management areas of the country and consists of three river basins. It covers an area of 8,327 km^2. The river water bodies of Crete are presented by river basin in the following table. Crete does not have very large and famous rivers. They are usually ephemeral, seasonal, and transient (see table 19).

Table 10. River Basin District of Crete in annual freshwater resources.

River Basin District of Crete (EL13)		
River Basins	**Surface (km2)**	**Freshwater resources (hm3)**
North Chania - Rethymnon - Heraklion	3.644	807
South Chania - Rethymnon - Heraklion	2.798	471
East Crete	1.885	81
Total	**8.327**	**1.359**

Source: Own Processing - Data by Management Plan for the Water - Ministry of Environment & Energy

It is also the only water compartment of river systems that fully coincides with the administrative boundaries of the Regions. Therefore, in aggregate, the Region of Crete must manage its water potential of only almost 1.3 hm^3 of water volume per year for its total area of 8 km^2. Most of the geomorphologically formed rivers in the Region of Crete are seasonal and ephemeral, resulting in an increased level of vulnerability in case of water scarcity due to Climate Change.

The last **River Basin District is the Aegean Islands (EL14)**, specifically the Cyclades, the Dodecanese and Ikaria, Lesvos, Lemnos, Samos, and Chios. Its total area is approximately 17,958 km^2, of which 9,105 km^2 is on land and 8,852 km^2 is in coastal areas. Its coastline is mainly estimated at 7.090 km excluding the rocky islets. Administratively this river basin district is divided between the North and South Aegean Region. The rivers present in the basins are mainly ephemeral, seasonal, and ephemeral. They are fully dependent on precipitation rates and climatic data. The table below gives a detailed breakdown of water resources by river basins for the Aegean islands. As can be seen in Table 11, the Aegean islands have an increased risk of water scarcity given their low water resources. The vulnerability of their system is high and makes them extremely fragile if annual temperatures increase further and rainfall rates decrease.

Table 11. Freshwater resources of the North & South Aegean Regions separately.

RBD	The Region of North Aegean	
	Surface (km2)	Freshwater resources (hm3)
Eastern Aegean	3.830	514
RBD	**The Region of South Aegean**	
	Surface (km2)	**Freshwater resources (hm3)**
Cyclades Islands	2573	40
Dodecanese Islands	2.702	193
Total	**5.275**	**234**

Source: Own Processing - Data by Management Plan for the Water - Ministry of Environment & Energy

Overall, of all the river basins district of the country, the Region that is called upon to deal directly with the effects of water scarcity, and the need for water management as shown in the tables with estimated available water resources, is the South Aegean Region. Certainly, the geomorphology of the islands, their coastal environment, the lack of mountains and slopes create the natural capacity of the system for few freshwater resources, but at the same time, the intensive agriculture and the multiple needs for freshwater make the system all at the limit.

Table 12. Annual Freshwater Resources in Greece per Region.

Administrative Regions	Annual Freshwater Resources in Greece per Region	
	Surface (km2)	Freshwater Resources (hm3)
Peloponnese	14.875	15.641
Central Greece	22.778	22.509
Western Greece	12.539	24.556
Epirus	7.978	30.892
Attica	3.187	245
Thessaly	13.140	34.314
Western Macedonia	10.514	22.803
Central Macedonia	16.924	58.034
Eastern Macedonia &Thrace	14.906	24.955
Crete	8.327	1.359
South Aegean	5.275	234
North Aegean	3.830	514
Ionian Islands	1.425	592
Total	**131.957**	**236.648**

Source: Own Processing - Data by Management Plan for the Water - Ministry of Environment & Energy

In conclusion, for the whole country, the administrative districts for the most part have considerable volumes of cubic water volume per year. The river systems in many areas have large quantities of fresh water, which are used to supply regions that are in greatest need of water. Looking at Table 12, aggregated for all regions of Greece, the most vulnerable are the Aegean islands, Attica, the Ionian islands, and then Crete. While the Regions of Macedonia, Thrace, and Thessaly come first in terms of fresh surface water abstraction per year. But there is a paradox in all this, these districts may receive millions of volumes of water annually, but the demand is far greater than the water supply. Climate change is driving agricultural activity to put increasing pressure on water systems, causing many of these regions to already face problems in managing their water. The following chapters will analyze the needs of agricultural production for irrigation, the available groundwater in the regions, and how climate affects the availability of these existing surface waters.

2.1.2 Groundwater by region

As far as groundwater is concerned, Greece has enough potential in many of its lowland areas to ensure that agricultural production can withstand dry periods. However, even in this case, there is an uneven distribution of groundwater (see Map 3). Most of the Aegean islands have no groundwater reserves at all, as is the case in western Crete, which means that their vulnerability to water scarcity is increased. Furthermore, agricultural production on these islands is entirely dependent on rainfall and surface water generated through precipitation.

Map 3. *Groundwater mapping of Greece through the geodata.gov.gr application.*
Source: Geoadata.gov.gr serving as an INSPIRE conformant Spatial Data Infrastructure[19] *via link* http://geodata.gov.gr/maps/

[19] Geodata.gov.gr is powered exclusively by open-source software developed in the context of the EU-funded project, as well as the international Open-Source community. *http://geodata.gov.gr/content/about-en/*

According to the Max Planck Institute of Meteorology[20], groundwater is defined as water stored in the ground, in the form of soil moisture or in aquifers known as porous rocks. Besides the sufficiency of groundwater, Greece has to deal with the influx of seawater into its groundwater. More specifically, it is due to the hydrogeological character of the geological formations that make up the groundwater system and the development of groundwater resources. It occurs between karstic, granular, fractured and mixed groundwater systems. Due to its geomorphology, coastal areas have suffered from erosion in many aquifers, thus endangering groundwater quality if not detected in time. In addition, another factor that can affect groundwater is nitrate pollution caused by intensive agricultural activities, as well as heavy metal contamination from industrial installations (Dokou Z., Kourgialas N. & Karatzas G., 2015)[21].

Looking at map 3 most of the groundwater areas are in coastal regions, some of which are being eroded daily and groundwater systems are under pressure. In addition to the pressure of coastal erosion, there are mainly in the north of the country agricultural pressures of water pumping, which make the groundwater of the northern part of the country vulnerable and under increasing pressure. Comparing the following map 4 with the previous groundwater maps, we see that most agricultural areas are geographically identical to groundwater points.

In fact, a characteristic of agricultural production is that during the summer months the need for water is high, therefore groundwater irrigation is obvious for agricultural areas. Apart from the summer months, when the water needs of agricultural production are increasing due to climate change, low rainfall and the long summer period with high temperatures until October, many rural areas are now under severe pressure on water systems. Mainly in central Macedonia, Thessaly, the Aegean islands and Crete, water scarcity is almost inevitable. Evidence in this context is provided by Table 13 with the estimated annual groundwater levels for each administrative region of the country.

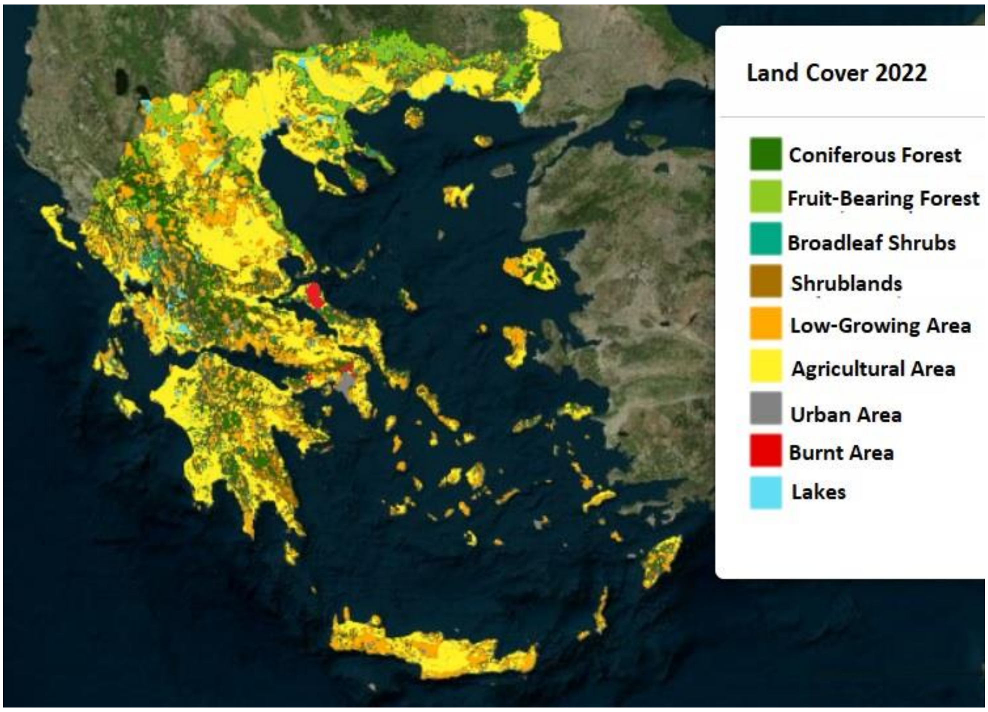
[20] The Max Planck Institute for Meteorology Earth System Model, AQA (2012): AS & A2 Geographical Terminology.

[21] Dokou Z., Kourgialas N. & Karatzas G., (2015), *Assessing groundwater quality in Greece based on spatial and temporal analysis*, doi:10.1007/s10661-015-4998-0 Springer International Publishing Switzerland 2015

Table 13. Estimated Annual Groundwater resources per Administrative Region of Greece.

Estimated Annual Groundwater Resources		
Regions	Surface (km2)	Groundwater Resources (hm3)
Peloponnese	14.875	4.272
Central Greece	22.778	3.495
Western Greece	12.539	2.972
Epirus	7.978	4.024
Attica	3.187	246
Thessaly	13.140	3.225
Western Macedonia	10.514	619
Central Macedonia	16.924	2.214
Eastern Macedonia &Thrace	14.906	820
Crete	8.327	1.608
South Aegean	5.275	380
North Aegean	3.830	147
Ionian Islands	1.425	746
Total	**131.957**	**24.149**

Source: Own Processing - Data by "Management Plan for the Country's Water Resources" (2008), NTUA



Map 4. Land cover 2022 by categories, according to the data of CORINE[22].

As can be seen in the above table, the Region which has the least groundwater reserve is the North Aegean islands. Specifically, only in Lesvos in the area of Kalloni there is about 0.070hm^3 of water volume, while the rest of the islands due to their geomorphological characteristics have high percentages of brackish water in their groundwater reserves.

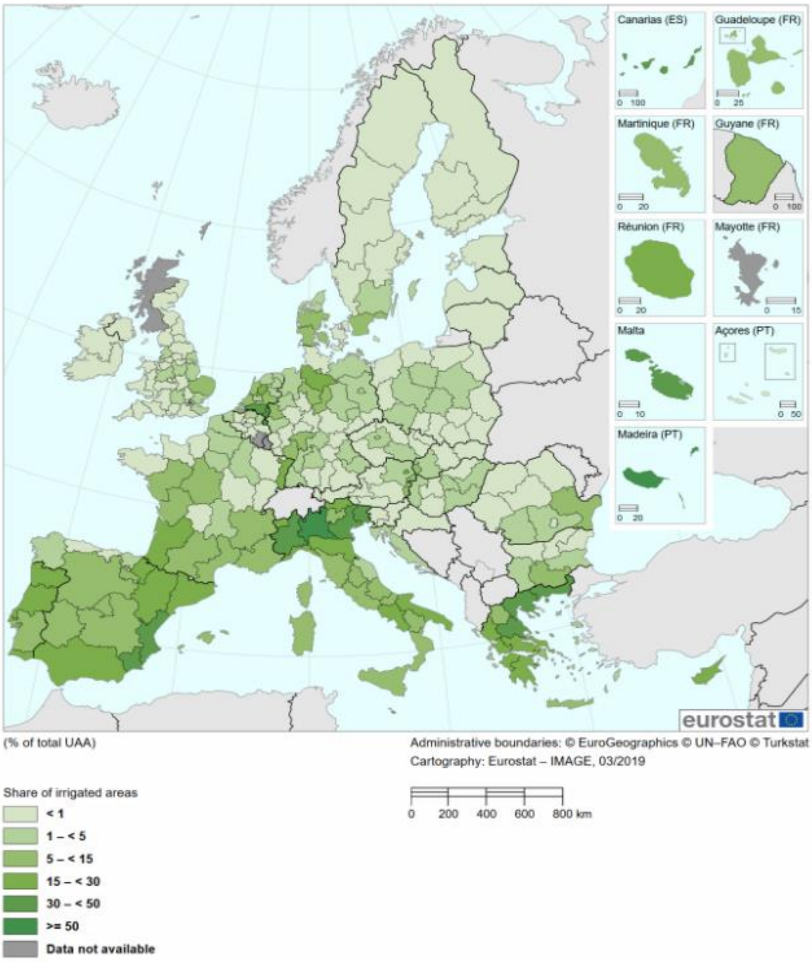
[22] CORINE is the system of land cover for Greece, according to the deliverables of the eponymous project of the European Union and the Copernicus website https://land.copernicus.eu/pan-european/corine-land-cover

Following the data of the NTUA report *''Management Plan for the Country's Water Resources''* (2008)[23], the Region of Attica faces a serious issue with the availability of its groundwater. As mentioned in the previous chapter (see Table 5), the only water resources it has and utilizes are groundwater, together with the technical ponds it has created for this purpose. The risk of water scarcity is high, as urbanized geography prevents the absorption of precipitation into its soil and river basin district, with the result that percentages of water per year resulting from precipitation end up in the stormwater runoff of the region's drainage systems. The great paradox regarding water resources in river basin systems and groundwater is Macedonia and Thrace. For the regions of these districts, while they have the largest rivers in the country, and the most surface water resources in terms of annual water volume, their groundwater reserves are dangerously low (see Tables 7, 8 & 9). The region of Central Macedonia is estimated to be able to accept 58.034hm^3 of surface water volume in its water resources annually, while its underground water reserves are estimated to be approximately 2.214hm^3. This is due to the over-supply of groundwater and its unsuitability as nitrogenous, nitrate compounds due to intensive agriculture.

At a similar level is the Region of Eastern Macedonia and Thrace, whose surface water of its river systems is estimated at 26.955hm^3 annually but its underground water reserves are only 0.820hm^3. The case of Thrace has another vulnerability besides intensive agriculture and over-exploitation of water resources. Its geomorphology does not allow it to retain large quantities of water because its soil is nitrified and prone to all forms of pollution. Therefore, according to map 6 above, which maps land use in each region of Greece, the regions with agriculture as the main land use characteristic have the lowest groundwater resources and will face a serious water management problem in the future.

[23] Central Water Agency of the Ministry of Environment and Natural Resources, ''*Management Plan for the Country's Water Resources''*, by NTUA in cooperation with the Ministry of Development, Directorate of Water Resources and Natural Resources and the Institute of Geological and Mineral Research (IGME), Athens, 2008

2.1.3 Water abstraction by river basin district



Map.5 Percentage of irrigated area in total utilized agricultural area by NUTS 2 regions, for 2016.

Source: Eurostat-Database, https://ec.europa.eu/eurostat/web/main/data/database

According to the above Eurostat (see Map. 5) for 2016, the regions with the highest water irrigation rates are Central, Eastern Macedonia, Thrace and Thessaly for the whole year. Looking at all the regions of Europe, the Greek regions of Macedonia, Thrace and Thessaly have high irrigation rates compared to the European regions. Of course, most Southern European Regions have high irrigation rates compared to the Northern Regions and this is mainly due to climate, agricultural water needs and certainly geomorphology. However, due to climate change in recent decades, intensive agriculture has increased, waterlogging is becoming more and more intense, and rainfall is decreasing. In detail, the tables below show the irrigation data of surface and groundwater reserves for the whole of Greece and in comparison, with Europe, specifically for agricultural production.

Table 14. Water Abstraction by Agriculture – Freshwater Irrigation in 2011 & 2019.

Water Abstraction by Agriculture - Fresh Surface Water Irrigation (hm3)		
Administrative Regions	**2011**	**2019**
Peloponnese	473,9	129,3
Central Greece	396,5	377,2
Western Greece	473,4	408,9
Epirus	214,2	275,0
Attica	0	0
Thessaly	89,0	298,29
Western Macedonia	333,8	138,8
Central Macedonia	882,8	491,6
Eastern Macedonia &Thrace	645,8	599,2
Crete	27,0	34,6
South Aegean	7,4	4,2
North Aegean	3,7	2,1
Ionian Islands	117,05	95,13
Total Area	**3.664,70**	**2.854,40**

Source: Own Processing – Data by Eurostat-Database,
https://ec.europa.eu/eurostat/databrowser/view/env_watabs_rb/default/table?lang=en

Table 15. Water Abstraction by Agriculture – Groundwater Irrigation in 2011 & 2019.

Water Abstraction by Agriculture - Groundwater Irrigation (hm3)		
Administrative Regions	**2011**	**2019**
Peloponnese	428,23	562,68
Central Greece	591,05	669,10
Western Greece	269,22	357,25
Epirus	102,90	95,80
Attica	68,46	66,68
Thessaly	1.035,60	842,82
Western Macedonia	369,63	713,19
Central Macedonia	848,23	633,44
Eastern Macedonia &Thrace	575,41	649,72
Crete	290,00	443,81
South Aegean	24,2	70,0
North Aegean	12,1	35,0
Ionian Islands	100,44	143,1
Total Area	**4.715,50**	**5.282,60**

Source: Own Processing – Data by Eurostat-Database,
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_watabs_rb&lang=en

It is easy to see from the above tables that there is strong pressure from the agricultural sector to secure more water resources. While surface water irrigation activity may have decreased in the overall total of the regions in Greece, groundwater irrigation activity is gradually increasing. This signals the need for the agricultural sector to seek water resources, as with climate change surface water has been reduced due to limited precipitation. A considerable pressure on water resource needs is observed in the Region of Crete, where agricultural activity from 2011 to 2019 almost doubled groundwater irrigation (see table 15). As well as almost all the islands of the country where agricultural activity relies mainly on groundwater reserves. While, in Thessaly and Central Macedonia, there is a decrease in the irrigation capacity of agricultural production, with the possibility of a gradual shortage of resources.

2.2 Climate Data

2.2.1 Soil Moisture

Soil moisture is an important parameter controlling plant growth and influences the way heat is exchanged between the soil and water in the atmosphere. It regulates soil structure and contributes to prevent soil erosion. Observing soil moisture scarcity is a prerequisite for managing drought adaptation and ecosystem resilience, as provided for in the EU Nature Recovery Plan for the EU Biodiversity Strategy 2030[24]. The climate data have been taken from the European Environment Information and Observation Network (Eionet) through the Copernicus Emergency service, which compiles soil moisture in standard anomalies[25], with values deviating from normal conditions.

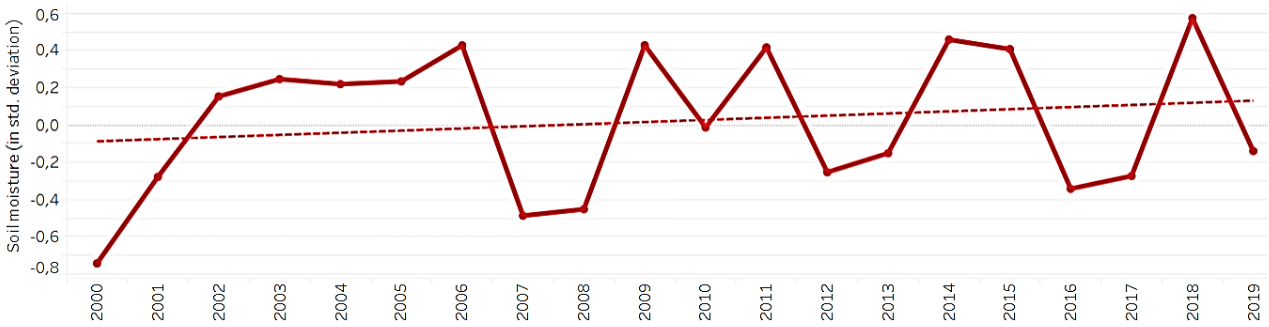
The time period to be studied for Greece is 2000-2019, because only for this time period soil moisture data are available. Below are derived in detail the values, where negative values equate to a deficit in soil moisture content, while positive values indicate a high content compared to the average soil moisture value. Soil moisture is calculated in standard anomalies, the following diagram shows the values in deviations in the period 1995-2019.

Negative values denote a shortage in soil moisture capacity, while positive values denote a higher-than-average soil moisture capacity. The soil moisture data set is obtained through the Copernicus Emergency Service supported by the European Commission's Joint Research Centre.

[24] The European Commission aims to put Europe's biodiversity on the road to recovery by 2030 with benefits for people, climate and the planet. It aims to strengthen the vulnerability of our societies to future threats such as the impacts of climate change, forest fires, food insecurity, etc. For more information see European Commission website - Biodiversity strategy for 2030, via link https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

[25] ‘’Anomalies are estimated based on the Soil Moisture Index (SMI) of the European Drought Observatory (EDO) of the European Commission's Joint Research Centre in the baseline period 1995-2019. The annual start and end of the GS periods are potential and calculated according to the EDO phenology indices. A positive anomaly indicates that the observed SM was wetter than the long-term average SM for the baseline period, while a negative abnormality indicates that the observed SM was drier than the mean reference value. However, SM anomalies are measured in standard deviation units from the long-term average SMI, they can be used to compare annual SM shortfalls/surpluses between geographic regions.’’ As defined in Biodiversity Information System for Europe, Copernicus land monitoring of European Environment Information and Observation Network (Eionet) via link https://www.eea.europa.eu/data-and-maps/data/soil-moisture-deficit-during-the

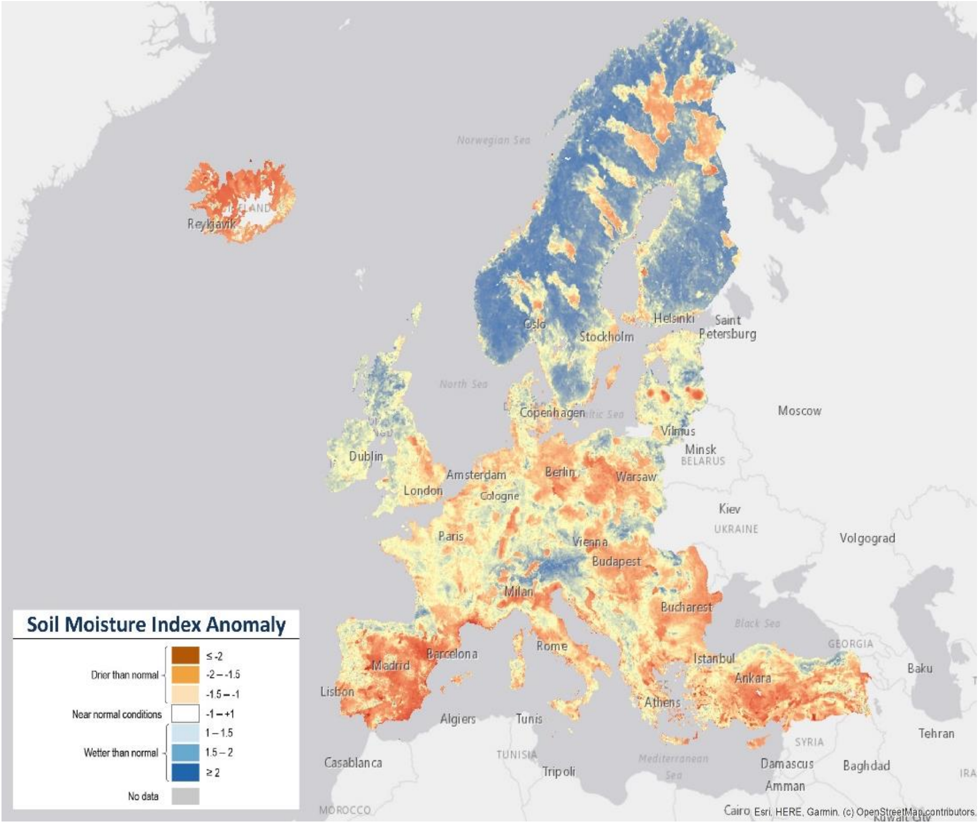
Figure 4. Annual Average Soil Moisture Values and its Rate of Increase.



Source: European Environment Information and Observation Network, [*https://www.eea.europa.eu/data-and-maps/data/data-viewers/soil-moisture*](https://www.eea.europa.eu/data-and-maps/data/data-viewers/soil-moisture)

As shown in Figure 4, Greece may be gradually increasing its average soil moisture levels, but there are intense periods of time which indicate severe drought and directly affect every activity and every river basin. A feature of these fluctuations is based solely on Climate Change. The strong fluctuations in the diagram indicate the intense climatic phenomena that affect the country every year. Climate Change is characterized by sudden weather changes, atmospheric variations and its effects on the human environment. The amounts of average soil moisture in each case are close to the average annual rainfall percentages we will see below for Greece. Also, the map below summarizes soil moisture levels for the whole of Europe, according to normal and abnormal conditions.

The Map 6 clearly shows the anomaly of Europe's geography based on its soil moisture levels. The north-eastern part of Europe has a surplus of soil moisture than the southern part. However, one would expect Ireland to have high levels of soil moisture due to its characteristics, but it is among the areas at high risk of drought, because of its geomorphology and very old water catchment systems, Ireland has a major freshwater drinking water problem. Also, the percentage of arable land is almost 1% as the country is surrounded by mountain ranges and low-lying coastal areas. All southern European countries have a high risk of soil moisture deficit. Mainly Spain, southern France, followed by Italy and Greece. In particular, Greece as given in Diagram 1, its values range from -0.1 to 0.1 characterizing it as marginal. In the following subsection, correlations between annual precipitation amounts and the soil moisture index for Greece and its administrative regions are presented.



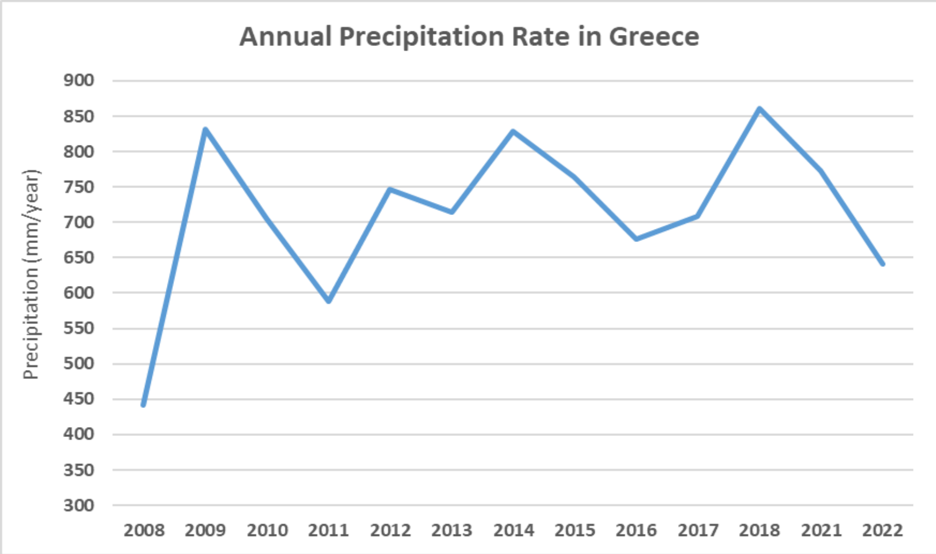
Map 6. Soil Moisture Index Anomaly for Europe, by normal and abnormal levels. (Source: European Environment Information and Observation Network, https://www.eea.europa.eu/data-and-maps/data/data-viewers/soil-moisture)

2.2.2 Precipitation

According to the table below, based on the climate data of the National Observatory of Athens for the period 2008-2018[26], the average annual precipitation in Greece is estimated to reach 713 mm per year. This annual amount corresponds to almost 1.95 mm per day which is highly controversial as there are many days without rainfall and others where it rains more than 4.3 mm per day and of course depending always on the region and month in the country. As the data is given in Table 26, the mountainous areas have the highest levels of rainfall while the lowland and especially the coastal areas have very low levels of rainfall.

[26] The data were taken exclusively from the METEO.GR website which was launched in June 2000. It is the Greek and simplified version of the already existing page of the National Observatory of Athens. Via link *https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fmeteosearch.meteo.gr%2FRaw%2520Materials%2FRECORDS_Temp_STATIONS_METEO_2006-2018.xlsx&wdOrigin=BROWSELINK*

Figure 5. Annual Precipitation Rate in Greece



Source: Own Processing – Data by Meteo.gr of the National Observatory of Athens, *https://meteosearch.meteo.gr/*

Also, during this ten-year period there are reasonable fluctuations in the total annual precipitation amounts (see figure 2.) like the soil moisture index analyzed above (see figure 4). If we isolate the soil moisture values from 2008 to 2018, the same rate of change as the annual rate of change in precipitation is observed. Which means that each millimeter of precipitation determines an important role in soil formation. As shown in the diagram, Greece experiences frequent periods of very low rainfall and other periods of heavy rainfall. These conditions of fluctuations are clearly due to the effects of Climate Change and the intense sudden weather events that it causes from time to time. In general, however, Greece's climate is characterized by hot, dry summers and cold, wet winters. In which the mountainous areas concentrate the highest rainfall rates, while the coastal areas with the islands have the very low rates. According to the World Bank Report, through the Climate Change Knowledge Portal[27] project, Greece is experiencing a decrease in its rainfall mainly in the winter months of December, January, February for the Attica region for the period 1991-2020. In Tables 27 and 28 below, all the regions are studied according to the seasonal rainfall they record annually.

[27] The World Bank created the Climate Change Knowledge Portal (CCKP), which provides an online platform for access to global, regional, and country data related to climate change and development.

Table 16. Annual Precipitation (mm/year) by Administrative Regions.

Annual Precipitation (mm/year) by Region													
Administrative Regions	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2021**	***2022****
Peloponnese	584,6	1060,4	684,6	563,5	632	939,6	917,2	774,4	1133,8	709,6	1013	664,4	*659,8*
Central Greece	491,6	790,7	812,6	963,8	1201,8	968,7	938,9	1236,7	841,2	1082,6	1485,8	945,1	*675,6*
Western Greece	350,4	1181,7	779,4	583,6	785,4	1212,4	1190,4	951,6	988,8	879	959	557,5	*654,6*
Epirus	1011,8	1766,5	1859,6	1026,3	1637,9	1411,9	1400,9	1124	1061	1146,6	1921,6	1803,4	*1896*
Attica	357	567,5	337,6	464	485,5	467,6	602,5	509,4	406,6	471	689,2	512	*355,6*
Thessaly	505,8	654,3	398,4	455,8	768,1	401,2	427	703,6	650	932	761,2	493,8	*688,4*
Western Macedonia	372,8	527	492,4	394,8	596,4	508,2	781,8	807,8	636,2	591,6	548,2	557,5	*631,4*
Central Macedonia	458	634,4	616,9	521,6	519,4	456,8	906	818,4	612	560	503,4	416,4	*475*
Eastern Macedonia &Thrace	327,8	555,5	738,1	462,9	520,7	759,2	789,9	526	459	692,4	533,2	793,6	*418,5*
Crete	268,6	586,1	490,8	456,6	510,8	357,4	533	614	407,8	440,6	453,8	494,4	*524,8*
South Aegean	151,8	384	334	599	353,6	317	320,6	386	220,8	308,4	391,6	259,4	*290*
North Aegean	305,6	956,2	732,8	302,2	849,4	535,9	759,8	694,1	476,2	553	728,2	952,8	*402,2*
Ionian Islands	560,6	1151,1	887	853,1	835,8	950,2	1200,7	789,3	894,4	834,6	1212	1590,2	*664,6*
Total Average	**442,03**	**831,95**	**704,93**	**588,24**	**745,9**	**714,31**	**828,36**	**764,25**	**675,98**	**707,8**	**861,55**	**772,34**	***641,26****

Note: Data for 2019 and 2020 could not be found. So, data for 2021 is given with accuracy and 2022 up to the fall of this paper. (Source: Own Processing – Data by Meteo.gr of the National Observatory of Athens, https://meteosearch.meteo.gr/ [28])

In table 16, all annual rainfall values are recorded by Administrative Region. In red are the values that are much lower than the permissible rainfall levels and in green are all values that exceed the average annual rainfall for the country as a whole. In the reddened Regions the rainfall amounts are extremely low. The Aegean islands, Crete, Macedonia, Thessaly and Attica are highly vulnerable to water resource issues. They have extremely small groundwater reserves, surface water. In addition, agricultural production is fully dependent on climatic disturbances and rainfall. Thessaly, Macedonia, Thrace and Crete have the highest agricultural production in the country, the lack of rainfall makes agriculture vulnerable and unproductive. The paradox in this is that the regions in red, where rainfall is below the national average, are home to the largest rivers as discussed in the previous subsection 2.1. Regarding the Regions in green are mainly all mountainous areas, with a high precipitation network due to altitude, geomorphology and geography. Perhaps the regions indirectly and to a lesser extent affected by climate change are the Peloponnese and Central Greece, especially the lowland and coastal areas, which have lower rainfall than their mountainous counterparts. The rainfall tables by seasonality in the geographical study areas are presented below. The division into only two seasons - winter and summer - was made on the basis that now, due to climate change and increasing temperatures, many months have lost their seasonal character and have been incorporated into the others. That is, winter in Greece now refers to the period from November to April and summer from May to early October.

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[28] The data were processed according to the existing meteorological stations throughout the country and the data were estimated at approximately the level of the Administrative Region. Certainly, there are outliers in the values, but the average of the above values is similar. As for the 2022 data, they are given as an estimate and with a deviation in the month of December, in which this paper is written.

Table 17. Winter precipitation by region and year (2008-2021)

Administrative Regions	Winter Precipitation (mm/year)											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2021
Peloponnese	75,7	134,7	82,7	73,5	79,9	127,1	112,3	88,3	115,5	89,4	106,3	83,5
Central Greece	54,4	94,1	91,7	119,1	139,8	117,4	104,4	141,5	76,5	99,3	133,3	111,0
Western Greece	62,7	158,7	98,5	70,0	85,5	145,7	154,3	102,6	117,1	117,0	104,7	65,4
Epirus	119,8	230,2	218,2	117,4	200,1	174,9	162,4	121,7	98,8	136,9	201,3	243,7
Attica	61,7	69,8	36,7	54,8	64,9	64,5	68,1	55,9	47,1	45,7	40,7	66,7
Thessaly	43,7	78,4	35,7	47,2	84,7	40,3	44,9	57,9	58,0	93,1	88,1	55,7
Western Macedonia	29,2	46,8	50,5	28,8	62,7	55,7	78,3	69,1	31,0	51,4	37,6	65,4
Central Macedonia	44,5	60,6	61,1	48,6	53,2	46,2	87,7	75,9	45,7	45,8	35,5	50,7
Eastern Macedonia &Thrace	28,8	65,0	75,5	47,8	57,3	91,4	79,5	54,7	53,8	78,6	54,3	95,7
Crete	33,4	75,4	68,8	58,0	72,2	48,6	67,8	80,2	52,7	53,0	55,0	69,1
South Aegean	45,9	109,7	47,4	84,2	49,3	42,6	43,6	49,1	29,9	42,8	48,4	35,8
North Aegean	93,9	129,9	103,4	42,3	113,5	68,6	93,1	90,2	66,2	71,2	89,0	135,5
Ionian Islands	168,1	149,9	95,8	110,8	107,7	132,6	151,0	97,5	90,7	107,0	157,3	223,3
Greece	**861,8**	**1403,1**	**1066,1**	**902,5**	**1170,7**	**1155,5**	**1247,5**	**1084,4**	**883,0**	**1031,2**	**1151,6**	**1301,3**

Note: Data for 2019 and 2020 could not be found. However, data for 2021 is given with accuracy and 2022 up to the fall of this paper. Source: Own Processing – Data by Meteo.gr of the National Observatory of Athens, https://meteosearch.meteo.gr/

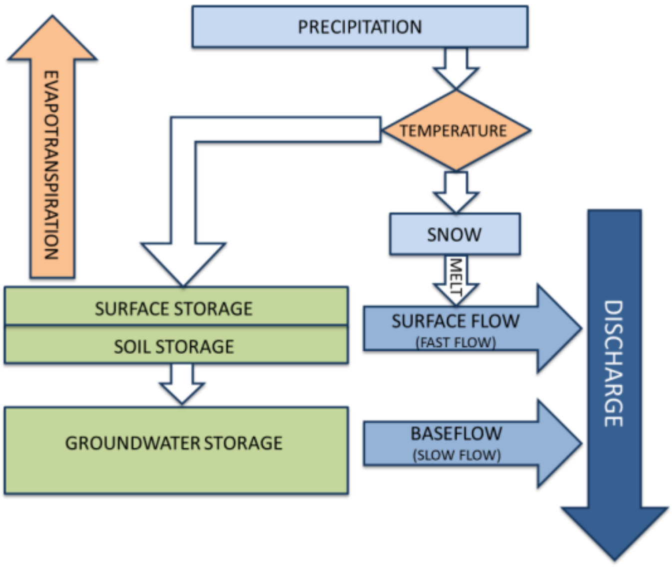
Table 18. Summer precipitation by region and year (2008-2022)

Administrative Regions	Summer Precipitation (mm/year)												
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2021	2022
Peloponnese	10,9	23,5	21,1	9,8	14,5	10,0	26,2	31,3	65,1	16,7	53,7	16	19,4
Central Greece	22,2	26,4	34,1	26,0	44,6	29,4	41,6	49,2	61,1	77,5	110,6	33,64	61,84
Western Greece	9,3	14,2	18,0	18,7	37,3	38,6	22,1	46,6	33,8	12,0	45,3	19,96	31,96
Epirus	34,7	31,1	66,4	40,8	47,4	37,6	52,8	54,5	73,9	37,7	102,4	19,48	74,78
Attica	9,7	15,8	16,1	16,0	6,2	3,2	25,2	23,7	15,4	30,2	80,9	9,04	19,8
Thessaly	39,9	21,1	29,7	25,1	35,0	23,8	22,5	59,7	48,8	56,1	28,9	20,72	51,52
Western Macedonia	33,7	39,8	27,8	38,7	31,6	23,7	46,8	64,8	83,8	46,3	57,0	19,96	71,34
Central Macedonia	29,3	42,0	37,8	36,3	29,4	26,7	58,4	57,5	58,4	47,8	50,9	12,32	57,32
Eastern Macedonia &Thrace	25,2	20,1	41,9	25,6	24,0	23,9	46,7	28,6	16,4	28,4	30,6	24,76	39,82
Crete	7,0	11,7	1,8	10,1	1,1	3,4	11,6	10,6	7,8	14,0	13,8	2,08	3,24
South Aegean	4,7	18,3	0,4	1,9	1,8	3,7	3,0	8,5	2,3	1,8	10,5	1,8	6,36
North Aegean	23,8	9,3	1,8	1,3	11,0	11,2	21,6	12,6	2,6	11,0	21,0	0,88	3,24
Ionian Islands	28,1	20,4	43,3	15,5	16,4	4,4	28,7	21,4	51,9	17,2	22,2	5,48	14,72
Greece	**278,3**	**293,8**	**340,3**	**265,9**	**300,3**	**239,5**	**407,3**	**468,9**	**521,4**	**396,6**	**627,8**	**186,12**	**455,34**

Note: Data for 2019 and 2020 could not be found. So, data for 2021 is given with accuracy and 2022 up to the summer of this paper. Source: Own Processing – Data by Meteo.gr of the National Observatory of Athens, https://meteosearch.meteo.gr/

As can be observed in the above tables, Epirus, due to its geographical location, is the only Region that records significant precipitation rates in winter and summer. The exact opposite example due to its geography is Crete and the South Aegean islands. In particular, in the summer of 2010, the Cyclades and the Dodecanese recorded months without a single millimeter of rainfall. But also, in the North Aegean in 2018 from May to September only 0.88 mm of rain were recorded. These data within the decade are extremely low. Furthermore, the Region of Attica between 2008 and 2013 recorded a severe lack of rainfall in the summer months, in contrast to the summer of 2018 when almost 81 mm of precipitation was recorded, as much as it has not recorded all winter months until 2022. Of course, it should be noted that the summer of 2018 was extremely rainy for the entire country. This is in contrast to 2021 which was an extremely dry summer for all regions in Greece. Below is a figure illustrating the importance of precipitation on soil and groundwater resources.

Figure 6. The key role of precipitation in shaping groundwater and surface water.



Source: The World Bank, Climate Variability and Change: A Basin Scale Indicator Approach to Understanding the Risk to Water Resources Development and Management [29]

According to the diagram, precipitation is at the highest stage of the stage that creates the so-called water cycle. Areas that have high precipitation rates and subsequently high soil and atmospheric moisture rates have more water resources. Of course, an important factor in the correct modulation of this cycle is the temperature of the surrounding area. Temperature directly affects the relationship between soil and precipitation. In the next subsection, the temperatures for the study regions and for the country as a whole are given in detail for the last few years.

2.2.3 Temperature

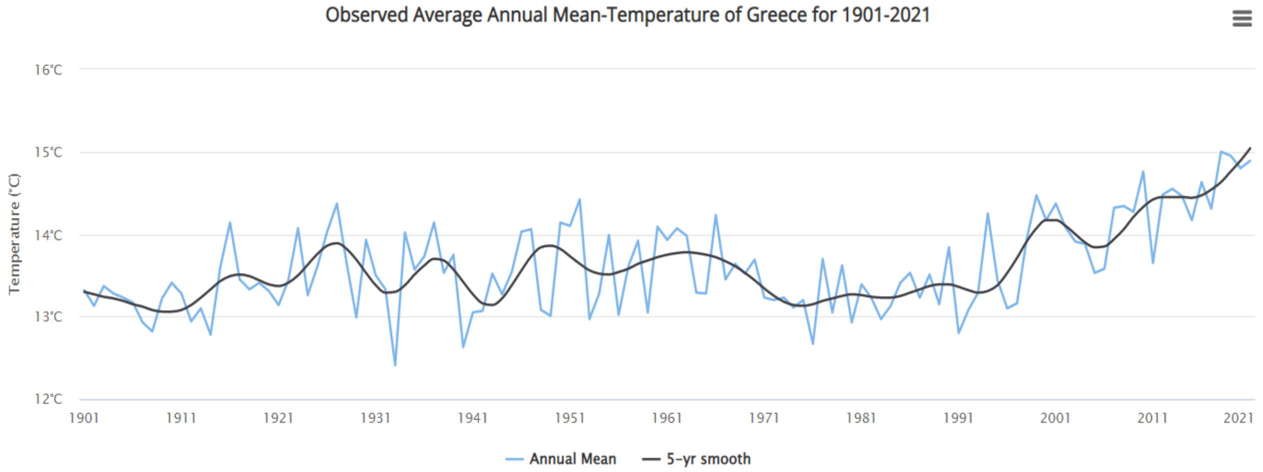
The climate of Greece is defined as Mediterranean. It has very dry-warm summers and mild winters with rainfall usually in the mainland. The coastal areas and the islands have cooler summers than the inland areas because of the sea breeze. Spring, climatically, is considered an unstable transitional period, with summer characteristics. Autumn is usually of short duration and with a somewhat abrupt onset of winter, mainly in Macedonia, Thrace and central Greece.

[29] K. Strzepek, A. McCluskey, B. Boehlert, M. Jacobsen, The Word Bank Report for Water and Climate, September 2011, for more information: *https://www.worldbank.org/en/topic/water and https://www.un.org/waterforlifedecade/pdf/2011_world_bank_climate_variability_change_eng.pdf*

According to the National Meteorological Service[30], summer daily maximum air temperature values have in recent years increasingly reached 42°C or 45°C degrees, in contrast to the winter days of the continental regions, which can be as low as -20°C degrees. Abrupt changes in the temperature environment directly affect agricultural production. Frost often destroys citrus trees in areas with a Mediterranean climate. Similar temperature changes can also destroy olive trees in northern regions, which are exposed to the winds, due to the strong invasion of cold air masses over these regions. As well as maximum summer temperatures, increased air temperatures combined with low rainfall rates are an economic disaster for the agricultural sector.

As a result of climate change, extreme temperatures are becoming more and more frequent, increasing the average monthly temperature in each individual region and thus increasing the production activity index. The diagram illustrating the rate of change of the average annual temperature in Greece from 1901-2021 is shown, according to the World Bank's Climate Change Knowledge Portal[31]. Based on this diagram, one can see the strong upward trend of the average annual temperature in the country, specifically in the period 1981-2021. Given the industrialization of the planet and the increase of carbon dioxide in the atmosphere, Greece's climate was bound to be affected by this. The country's temperate Mediterranean climate is now characterized for all its regions, as now, due to climate change, many areas of the country have been converted to a subtropical climate with dry winters and extremely hot summers.

Figure 7. Evolution of the Annual Average Temperature in Greece for 1901-2021.



Source: The World Bank, Climate Variability and Change, Greece - Current Climate, https://climateknowledgeportal.worldbank.org/country/greece/climate-data-historical

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[30] National Meteorological Service, Climate data per city, for selected stations in Greece, via link: http://emy.gr/emy/el/climatology/climatology_city?perifereia=Central%20Macedonia&poli=Thessaloniki_Mikra

[31] The World Bank Group, *Climate Change Knowledge Portal* , Greece Climate Data Historical, via link: https://climateknowledgeportal.worldbank.org/country/greece/climate-data-historical

In terms of detailed temperatures for each of the country's regions, the maximum and minimum temperatures recorded in the last 30 years are presented. These data were obtained from the European Centre for Medium-range Weather Forecasts (ECMWF)[32] because temporal and spatial gaps between the data of the National Meteorological Service of Greece were addressed.

One could say that starting from the Peloponnese, due to its geomorphology, it has relatively mild values of variation. The mountainous areas help it to balance the increased temperatures in the summer months, while the coastal areas help it to balance the temperate climate in winter. The highest temperature recorded in its interior was in 2017 at 41°C degrees, while the lowest in 2006 at -13°C degrees. With its average monthly temperature is within the Mediterranean climate, between 12°C to 5°C in winter and 28°C to 18°C degrees in summer.

Table 19. Temperature Anomaly and Mean Temperatures per month of the Peloponnese

Temperature Anomaly	**The Region of Peloponnese**											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	18 *(2021)*	18 *(2010)*	21 *(2020)*	28 *(2021)*	36 *(2020)*	**41 *(2017)***	38 *(2017)*	**39 *(2021)***	36 *(2017)*	29 *(2020)*	15 *(2018)*	16 *(2009)*
Min Temp (C°)	-10*(2022)*	**-13*(2006)***	-8 *(2005)*	4 *(2000)*	8 *(2004)*	13 *(2015)*	9 *(1993)*	12 *(2017)*	8 *(2018)*	2 *(2005)*	8 *(2006)*	-8 *(2016)*
Mean Temp (C°)	9°C/3°C	10°C/2°C	12°C/4°C	16°C/7°C	21°C/11°C	26°C/15°C	28°C/18°C	28°C/18°C	24°C/15°C	19°C/11°C	14°C/8°C	12°C/5°C

Source: *Own Processing – Data by* European Centre for Medium-Range Weather Forecasts, *https://www.ecmwf.int/*

As far as the Region of Central Greece is concerned, summer extends from May to October, with temperatures exceeding 35 degrees. However, extreme low temperatures in winter, especially in the early 2000s with -13 degrees in December, and in 2017 with -11 in January, are noted, so that these temperature variations have a huge economic impact on the agricultural sector and crops.

Table 20. Temperature Anomaly and Mean Temperatures per month of Central Greece

Temperature Anomaly	**The Region of Central Greece**											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	21 *(2002)*	23 *(2016)*	32 *(2001)*	31 *(2016)*	37 *(2020)*	**42 *(2017)***	**45 *(2007)***	**44 *(2012)***	**40 *(2015)***	32 *(2003)*	19 *(2021)*	24 *(1996)*
Min Temp (C°)	**-11*(2017)***	**-12*(2006)***	-7 *(2005)*	-2 *(2003)*	5 *(2000)*	10 *(1994)*	15 *(1996)*	14 *(1993)*	9 *(2004)*	3 *(2005)*	6 *(2017)*	**-13 *(2001)***
Mean Temp (C°)	11°C/3°C	13°C/4°C	16°C/6°C	21°C/9°C.	26°C/14°C	31°C/18°C	34°C/20°C	33°C/20°C	29°C/17°C	23°C/13°C	17°C/8°C	13°C/5°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

The paradox for the regions of Greece turns out to be Epirus. As shown in Table 21, it has recorded temperatures that contradict the geomorphology of the continental region. Most of its regions are located at high altitude and one could say that its monthly averages are quite high

[32] ECMWF is the European Centre for Medium-Range Weather Forecasts. It relies purely on Copernicus satellite data as the Earth observation component of the European Union, providing quality-assured data on climate change, atmospheric composition, floods and fire risk. More information: *https://cds.climate.copernicus.eu/cdsapp#!/toolbox* and *https://www.ecmwf.int/en/forecasts/datasets*

in the summer months, as of course are the records of 2008, 2007 and 1998, 1999. Of course, it should be mentioned that the heatwave that hit Greece in the summer of 2007 is one of the ten worst heatwaves to have hit Europe since 1950, according to research by scientists at the European Union's Joint Research Centre (JRC). Although one would expect these temperatures to be recorded in areas of Thessaly or Central Greece, but because there have not been such high temperatures since then in Epirus, it is something 'fortunately' reassuring.

Table 21. Temperature Anomaly and Mean Temperatures per month of Epirus

Temperature Anomaly	The Region of Epirus											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	20 *(2007)*	23 (2016)	28 *(2001)*	32 *(2013)*	40 *(2008)*	**43 *(1998)***	**48 *(2007)***	**45 *(1999)***	**40 *(2008)***	35 *(1993)*	20 *(2021)*	21 *(2010)*
Min Temp (C°)	**-13*(2000)***	**-13*(2006)***	-11*(2005)*	-3 *(2003)*	6 *(2000)*	10 *(1994)*	14 *(1993)*	13 *(2012)*	9 *(1995)*	2 *(2005)*	8 *(2018)*	-7 *(2000)*
Mean Temp (C°)	12°C/4°C	13°C/5°C	16°C/7°C	21°C/10°C	27°C/15°C	32°C/19°C	35°C/21°C	35°C/22°C	29°C/18°C	24°C/14°C	18°C/10°C	14°C/7°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

As far as the Attica region is concerned, in recent years the average monthly temperature has been gradually increasing. The last record for the highest temperature was set in 2021 for the month of August with 42 degrees, but also for the winter months of November and January. Also, the increase in temperature for the month of May is crucial for many crops that thrive but also dry out immediately because dry months follow.

Table 22. Temperature Anomaly and Mean Temperatures per month of the Attica

Temperature Anomaly	The Region of Attica											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	21 *(2021)*	23 *(2016)*	26 *(2001)*	30 *(2018)*	36 *(2017)*	**42 *(2017)***	**42 *(2017)***	**42 *(2021)***	38 *(2017)*	32 *(2020)*	20 *(2021)*	21 *(2010)*
Min Temp (C°)	-3 *(2007)*	**-4 *(2008)***	-1 *(2022)*	0 *(2003)*	8 *(1995)*	13 *(2006)*	16 *(1993)*	18 *(2009)*	13 *(2004)*	6 *(2011)*	10 *(2017)*	-2 *(2001)*
Mean Temp (C°)	14°C/6°C	15°C/6°C	17°C/8°C	22°C/9°C	26°C/14°C	31°C/18°C	33°C/23°C	33°C/23°C	30°C/20°C	26°C/16°C	18°C/12°C	16°C/9°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

Table 23. Temperature Anomaly and Mean Temperatures per month of the Thessaly

Temperature Anomaly	The Region of Thessaly											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	20 *(2021)*	23 *(2016)*	27 *(2001)*	32 *(2021)*	38 *(2008)*	**44 *(2017)***	**44 *(2009)***	**42 *(2021)***	**40 *(2015)***	34 *(1993)*	20 *(2021)*	22 *(2010)*
Min Temp (C°)	**-12*(2017)***	**-11*(2006)***	-8 *(2005)*	-4 *(2003)*	5 *(2000)*	10 *(1994)*	14 *(1998)*	13 *(2012)*	9 *(2003)*	2 *(2005)*	7 *(2018)*	**-10 *(2008)***
Mean Temp (C°)	12°C/2°C	15°C/3°C	18°C/5°C	21°C/10°C	27°C/15°C	34°C/16°C	36°C/20°C	36°C/19°C	32°C/15°C	27°C/10°C	17°C/9°C	13°C/6°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

As for Thessaly, it has equally high temperatures in the summer months and very low temperatures below zero in the winter months. The glaciers that occurred in recent years, 2006, 2008 and 2017, have had a devastating effect on agriculture. Combining the temperature data with Tables 17 and 18 rainfall data will answer many questions about agricultural productivity. The low rainfall, high temperatures, and glaciers in winter create unpleasant consequences for crops and large financial costs for producers.

Table 24. Temperature Anomaly per month of the Western Macedonia

Temperature Anomaly	The Region of Western Macedonia											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	13 *(2022)*	18 *(2022)*	22 *(2017)*	32 *(2018)*	32 *(2020)*	35 *(2021)*	**36 *(2021)***	**36 *(2022)***	33 *(2008)*	28 *(2020)*	13 *(2021)*	13 *(2021)*
Min Temp (C°)	**-20*(2012)***	**-20*(2006)***	**-19*(2005)***	**-9 *(2015)***	0 *(2012)*	2 *(2005)*	6 *(1993)*	8 *(2012)*	0 (1995)	-5 *(2005)*	-4 *(2016)*	**-19(2000)**
Mean Temp (C°)	5°C/-5°C	8°C/-5°C	11°C/-2°C	14°C/4°C	19°C/9°C	26°C/10°C	28°C/14°C	28°C/13°C	24°C/9°C	20°C/4°C	10°C/3°C	13°C/-5°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

As far as Western Macedonia is concerned, it is one of the regions in Greece where temperatures are often below -5, with many days of frost and intense cold. However, in recent years with Climate Change there has been an increase in temperatures in the summer months, especially in 2021 and 2022 were record years of temperature increase for this Region.

Table 25. Temperature Anomaly per month of the Central Macedonia

Temperature Anomaly	The Region of Central Macedonia											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	19 *(2007)*	23 *(2016)*	29 *(2001)*	33 *(2016)*	**41 *(1994)***	**44 *(2017)***	**45 *(2007)***	**44 *(2012)***	**39 *(2015)***	36 *(1993)*	23 *(2022)*	20 *(2021)*
Min Temp (C°)	**-18*(2012)***	**-17(2006)**	**-10*(2011)***	**-6 *(2003)***	5 *(2012)*	7 *(1997)*	12 *(1998)*	11 *(2000)*	2 *(1995)*	-2 *(1997)*	-4 *(2011)*	**-18*(2001)***
Mean Temp (C°)	10°C/0°C	11°C/2°C	17°C/3°C	23°C/6°C	28°C/12°C	33°C/16°C	34°C/20°C	35°C/20°C	31°C/14°C	25°C/9°C	16°C/7°C	15°C/-0°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

Central Macedonia in the case of temperatures shows a strong divergence between high and low temperatures. Its summers are intensely hot at around 40 degrees, while its winters are below zero with intense glaciers. Rainfall, as shown in tables 17 and 18, is minimal. Agricultural production encounters problems annually and the economic costs are high. In the spring months when production needs water and sedimentation, temperatures now rise, and greater amounts of water resources are required. The same for cheap spring crops which are directly dependent on weather conditions.

Table 26. Temperature Anomaly per month of the Eastern Macedonia & Thrace

Temperature Anomaly	The Region of Eastern Macedonia & Thrace											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	20 *(2010)*	24 *(2016)*	29 *(2001)*	34 *(2016)*	**40 *(1994)***	**44 *(2010)***	**46 *(2000)***	**44 *(1994)***	**42 *(2015)***	35 *(2012)*	21 *(2021)*	17 *(2011)*
Min Temp (C°)	**-17*(2015)***	**-17*(2005)***	**- 9*(2000)***	**-5 *(1997)***	5 *(1995)*	9 *(2000)*	12 *(1998)*	9 *(1995)*	8 *(1997)*	1 *(2009)*	-2 *(2003)*	**-14*(2001)***
Mean Temp (C°)	11°C/0°C	14°C/1°C	18°C/4°C	21°C/10°C	28°C/13°C	31°C/19°C	35°C/20°C	33°C/21°C	31°C/14°C	26°C/9°C	19°C/5°C	11°C/4°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

Eastern Macedonia and Thrace is almost identical in weather characteristics to Central Macedonia. The years in which record temperatures were recorded are almost the same, as their geographical location is understood to be a characteristic factor. It has equally warm summers and sharp cold winters, with average monthly temperatures differing by almost 15 degrees. The increase in warm days is a fact that puts pressure on the agricultural production system for more water needs, coupled with minimal rainfall.

Table 27. Temperature Anomaly per month of the Crete

Temperature Anomaly	The Region of Crete											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	24 *(2021)*	26 *(2016)*	32 *(2001)*	32 *(2021)*	36 *(2017)*	**40 *(2017)***	**41 *(1998)***	**41 *(2021)***	36 *(2017)*	34 *(2003)*	24 *(2021)*	27 *(2009)*
Min Temp (C°)	0 *(2022)*	0 *(2004)*	4 *(2022)*	5 *(1997)*	10 *(1995)*	14 *(2021)*	17 *(1993)*	18 *(1995)*	13 *(2003)*	13 *(2011)*	11 *(2003)*	3 *(2016)*
Mean Temp (C°)	16°C/11°C	16°C/11°C	18°C/12°C	20°C/13°C	24°C/17°C	26°C/22°C	28°C/24°C	29°C/24°C	27°C/23°C	24°C/20°C	20°C/17°C	16°C/11°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

Regarding Crete as the southernmost part of the country, it has the hottest temperatures throughout the year. Very few times it has recorded zero temperatures in winter, and in summer the average temperature does not exceed 38 degrees, with the exception of course of the years 1998, 2017 and 2021 when it recorded 41 degrees. The climate in general of Crete is favorable for large crops to grow and agricultural production to have economic benefits. Of course, the minimal rainfall damages farmers, requiring large amounts of water for irrigation.

Table 28. Temperature Anomaly per month of the South Aegean

Temperature Anomaly	The Region of South Aegean											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	21 *(2021)*	24 *(1995)*	23 *(1995)*	33 *(1994)*	35 *(2022)*	34 *(2021)*	**39 *(1997)***	35 *(2021)*	**37 *(1996)***	31 *(2020)*	24 *(2021)*	21 *(2010)*
Min Temp (C°)	2 *(2022)*	2 *(2004)*	2 *(2022)*	8 *(2005)*	13 *(2022)*	16 *(2020)*	14 *(1993)*	22 *(2022)*	17 *(2022)*	12 *(2011)*	11 *(2009)*	5 *(2016)*
Mean Temp (C°)	15°C/12°C	16°C/11°C	17°C/10°C	21°C/12°C	24°C/16°C	29°C/19°C	31°C/23°C	31°C/24°C	27°C/22°C	25°C/15°C	19°C/14°C	21°C/10°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

Table 29. Temperature Anomaly per month of the North Aegean

Temperature Anomaly	The Region of North Aegean											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	20 *(2021)*	22 *(2021)*	22 *(2018)*	29 *(2018)*	35 *(2022)*	**38 *(2017)***	**40 *(2007)***	**39 *(2010)***	36 *(1999)*	32 *(2020)*	25 *(2021)*	21 *(2021)*
Min Temp (C°)	-2*(2017)*	-4 *(2004)*	1 *(2022)*	3 *(1997)*	10 *(1995)*	14 *(1997)*	18 (1993)	18 *(1995)*	14 *(2022)*	9 *(2011)*	10 *(2009)*	1 *(2010)*
Mean Temp (C°)	14°C/7°C	15°C/8°C	18°C/9°C	22°C/11°C	26°C/15°C	31°C/19°C	33°C/23°C	32°C/24°C	28°C/21°C	26°C/15°C	21°C/11°C	20°C/9°C

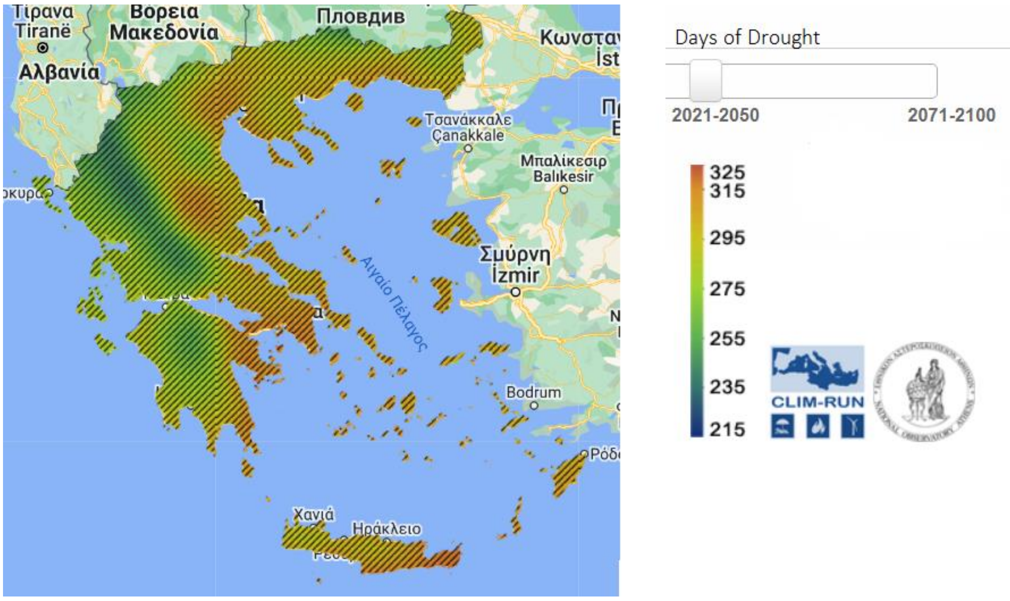
Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

The North Aegean islands do not experience as warm temperatures as the rest of mainland Greece. Their geography allows them to maintain a temperate climate throughout the months. On the other hand, the South Aegean islands are particularly vulnerable to high temperatures, as there are long periods of drought and in winter there is a lot of cold and humidity. The agricultural sector in the Aegean islands is more affected than in any other region, due to the long duration of drought and the fact that the groundwater is semi-marine. Finally, the Ionian Sea islands have normal temperate average monthly temperatures, with summer intensifying into autumn and August being the hottest month. The winter months are mainly rainy, as can even be seen in Table, which is due to the intense vegetation of the Ionian islands in contrast to the Aegean islands.

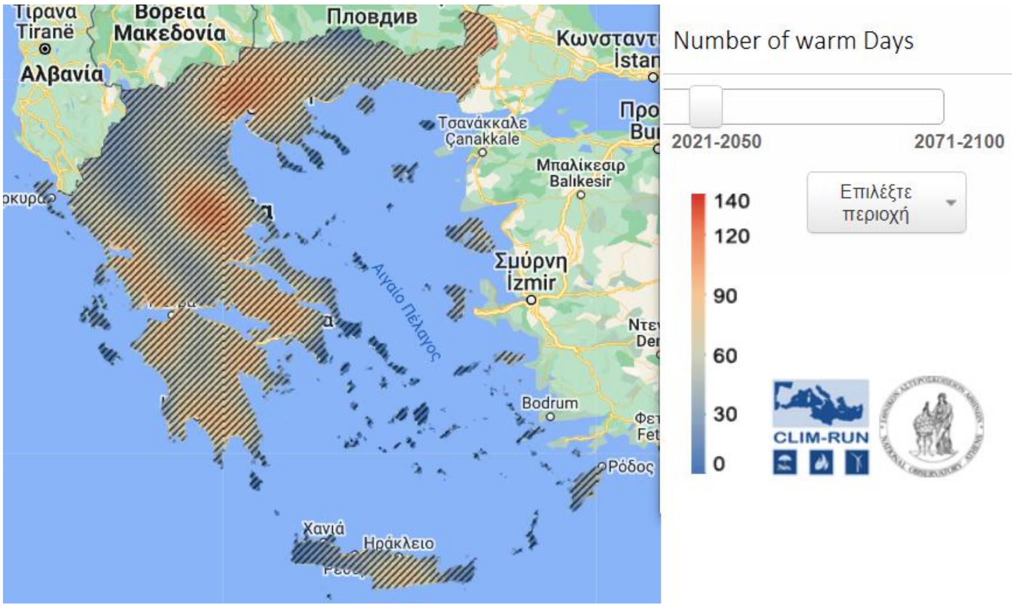
Table 30. Temperature Anomaly per month of the Ionian Islands

Temperature Anomaly	The Region of Ionian Islands											
	January	February	March	April	May	June	July	August	September	October	November	December
Max Temp (C°)	21 *(2021)*	22 *(2016)*	24 *(2004)*	28 *(2018)*	32 *(2020)*	36 *(2021)*	**39 *(2015)***	**37 *(2021)***	35 *(2015)*	30 *(2020)*	26 *(2021)*	21 *(2010)*
Min Temp (C°)	-2 *(2015)*	-1 *(2006)*	2 *(2022)*	5 *(2003)*	10 *(1995)*	14 *(2015)*	10 (1993)	17 *(2014)*	12 *(2014)*	10 *(2014)*	10 *(2018)*	2 *(2001)*
Mean Temp (C°)	15°C/8°C	14°C/9°C	16°C/11°C	19°C/13°C	24°C/17°C	30°C/19°C	32°C/22°C	32°C/23°C	30°C/19°C	26°C/15°C	21°C/12°C	14°C/9°C

Source: Own Processing – Data by European Centre for Medium-Range Weather Forecasts, https://www.ecmwf.int/

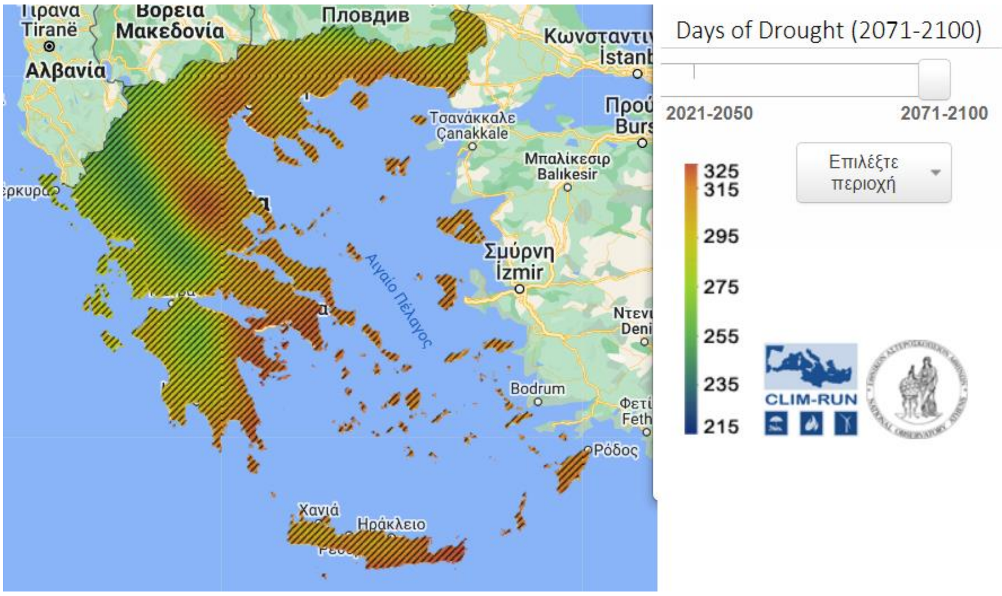


Map 7. Number of drought days in Greece in the period 2021-2050
Source: www.oikoskopio.gr by Clim-Run of National Observatory of Athens

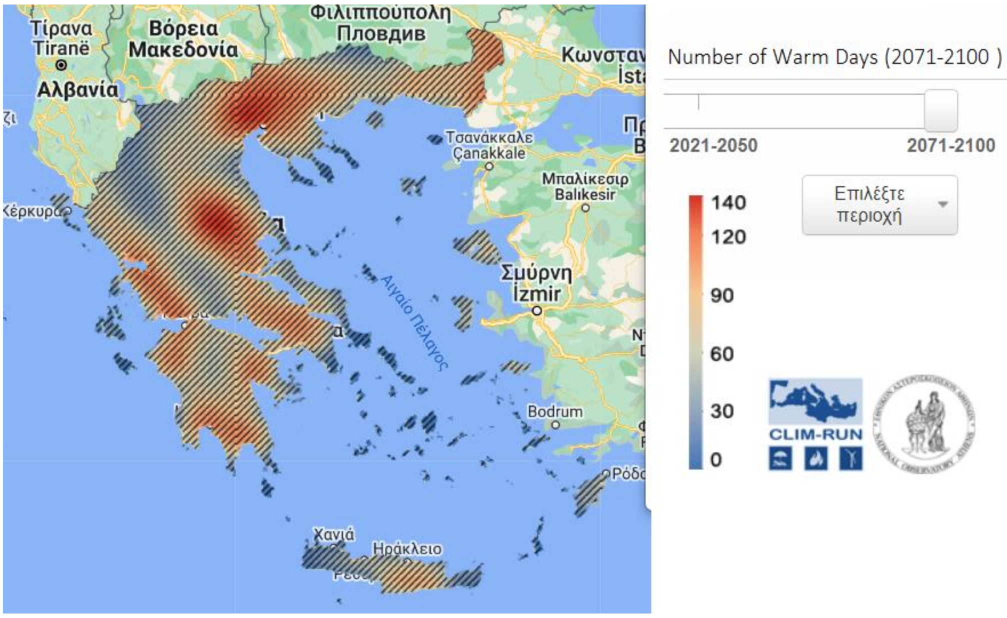


Map 8. Number of Hot Days in the period 2021-2050 for Greece.
Source: www.oikoskopio.gr by Clim-Run of National Observatory of Athens

For the period 2021-2050 it is predicted for Central Macedonia and Thessaly more than 300 days per year to be dry, with a minimum rainfall of 0.5 mm per day and around 120 to 140 days which will be too hot, i.e., will exceed 30 degrees, according to CLIM-RUN of the National Observatory of Athens. Also, Crete, the islands of the southern Aegean as mentioned earlier and Attica along with the eastern Peloponnese will have a severe drought problem. Almost all coastal areas are already starting to experience problems in managing their surface water due to the drought. However, the most vulnerable areas due to the increase in temperature will be mainly Thessaly and Central Macedonia, which are the largest agricultural production areas in the whole country, as they will have to face an increased risk of water scarcity and the economic costs will be high.



Map 9. Number of drought days in Greece in the period 2071-2100
Source: www.oikoskopio.gr by Clim-Run of National Observatory of Athens



Map 10. Number of Hot Days in the period 2071-2100 for Greece.
Source: www.oikoskopio.gr by Clim-Run of National Observatory of Athens

But the worst-case scenario is in 2071-2100, under Ceteris Paribus conditions, if everything stays constant and the temperature increases at the rate it has been increasing in recent years, the agricultural sector will be in terrible trouble. As shown in maps 9 and 10, all coastal areas will face a drought problem almost all year round, but also temperatures exceeding 35 degrees more than 140 days per year, i.e., almost 5 months with temperatures above the normal limit. Under these conditions few crops can thrive and the pressure for irrigation will increase by at least 60% more.

CHAPTER III

Study Area Assessment and Management Policies

3.1 Economic Impact of Climate Change on Greek Agriculture

Following the latest National Agricultural Census[33] 2020 in Greece, a very important decline in the agricultural sector was found throughout the country. This decrease is as high as 18.8% from the 2009 data. In total Greece has almost 28 million hectares of used agricultural land, which in 2009 was 35 million hectares. The agricultural holdings have also decreased, from 723,006 in 2009 to 530,679 in 2020. As well as the total irrigated land from 10,386,004 to 9,606,841 in 2020, this decrease may seem small at 7.6% but in terms of farms with irrigated land, there was a decrease of 27.7%. In recent years, the reduction in annual precipitation and the increase in annual temperatures have created problems for already stressed water systems.

Table 31. Number of irrigated holdings and total irrigated area in Greece, between 2009 and 2020.

Administrative Regions	Irrigated Areas (Acres)		Variation (%)	Holdings with Irrigated Land		Variation (%)
	2009	*2020*		*2009*	*2020*	
Peloponnese	926.004	798.288	**-13,8**	54.766	38.975	**-28,8**
Central Greece	941.002	903.179	**-4**	34.842	24.760	**-28,9**
Western Greece	976.022	876.485	**-10,2**	53.987	41.642	**-22,9**
Epirus	330.768	244.133	**-26,2**	24.303	15.850	**-34,8**
Attica	101.083	102.319	**1,2**	10.366	7.703	**-25,7**
Thessaly	1.680.646	1.693.850	**0,8**	45.384	31.867	**-29,8**
Western Macedonia	359.580	287.625	**-20**	13.529	8.366	**-38,2**
Central Macedonia	2.574.444	2.485.583	**-3,5**	71.704	49.101	**-31,5**
Eastern Macedonia &Thrace	1.479.633	1.296.887	**-12,4**	40.589	26.950	**-33,6**
Crete	868.378	765.099	**-11,9**	63.808	52.065	**-18,4**
South Aegean	63.247	56.349	**-10,9**	11.451	8.582	**-25,1**
North Aegean	57.878	71.009	**22,7**	11.090	10.400	**-6,2**
Ionian Islands	27.315	26.031	**-4,7**	15.439	9.995	**-35,3**
Greece	***10.386.004***	***9.606.837***	***-7,2***	***451.258***	***326.256***	***-27,7***

Source: Own Processing – Data by the Greek Statistical Authority,
https://elstat-outsourcers.statistics.gr/apografi_georgias_21_FINAL_web.pdf

As can be seen in the table above, the reduction in irrigated areas is significant. Except for Attica, the North Aegean islands and Thessaly, where there is an increase in irrigated area per hectare. All other regions show a decrease of more than -10%. A great irrigation project helped the Thessaly region with the rebuilding of Lake Karla[34], which was completed in 2018. It provides large quantities of water to the rural areas of the Thessaly plain, quantities that in the years 1990 and 2000 had an increased level of water stress. However, as far as the number of

[33] Agriculture-Livestock Census 2021 results from the Greek Statistical Authority, through the official report: https://elstat-outsourcers.statistics.gr/apografi_georgias_21_FINAL_web.pdf

[34] For more information: https://en.wikipedia.org/wiki/Lake_Karla

agricultural irrigation farms is concerned, the number of farms has decreased dramatically throughout the whole territory. Combined with Tables 24 and 25 in the previous chapter, many explanations for this data are provided. The decrease in groundwater pumping is noted in Thessaly, Attica, Central Macedonia which also leads to fewer irrigation farms.

This dramatic decline in irrigation activities suggests multiple causes. First, a major factor is Greece's overall decline in agricultural activities. Nowadays, agricultural products have to compete with cheap imported products. Agricultural production in the country is quite costly, especially when unpredictable variables such as frost, drought, hail, etc. damage hundreds of acres of production. Every agricultural product depends on environmental conditions and requires a large number of water resources. It is noteworthy, of course, that the regions with the largest river basins have the largest reductions in irrigation systems and farms, and greater needs for water resources as their agricultural sector declines more and more each year. According to the Hellenic Statistical Authority[35], for 2020, agricultural crops decreased by 22.4%, livestock activities decreased by 20%, and mixed crops and production by 45.7% since 2009.

The dependence of producers on water resources is highly significant and is attributed differently depending on the type of product and its water needs. For example, the following table of the evolution of the water deficit of the maize crop during the growing season, from the European Environment Information and Observation Network (2016)[36], is given to illustrate the water needs of this crop. Essentially, the crop water deficit is the difference between the water requirement for the crop and the water available through rainfall. In the map below, the red colors show an increase in the gap between the crop's water requirement and the available water. Also, areas, where the seasonal crop water requirements exceed the available water, have been marked with dashed lines. One of these areas where the available water exceeds the available water is Greece. Most of its crops, especially cereals, have an increased need for water resources than the country can now afford. As indicated in the 2016 agricultural census[37] for

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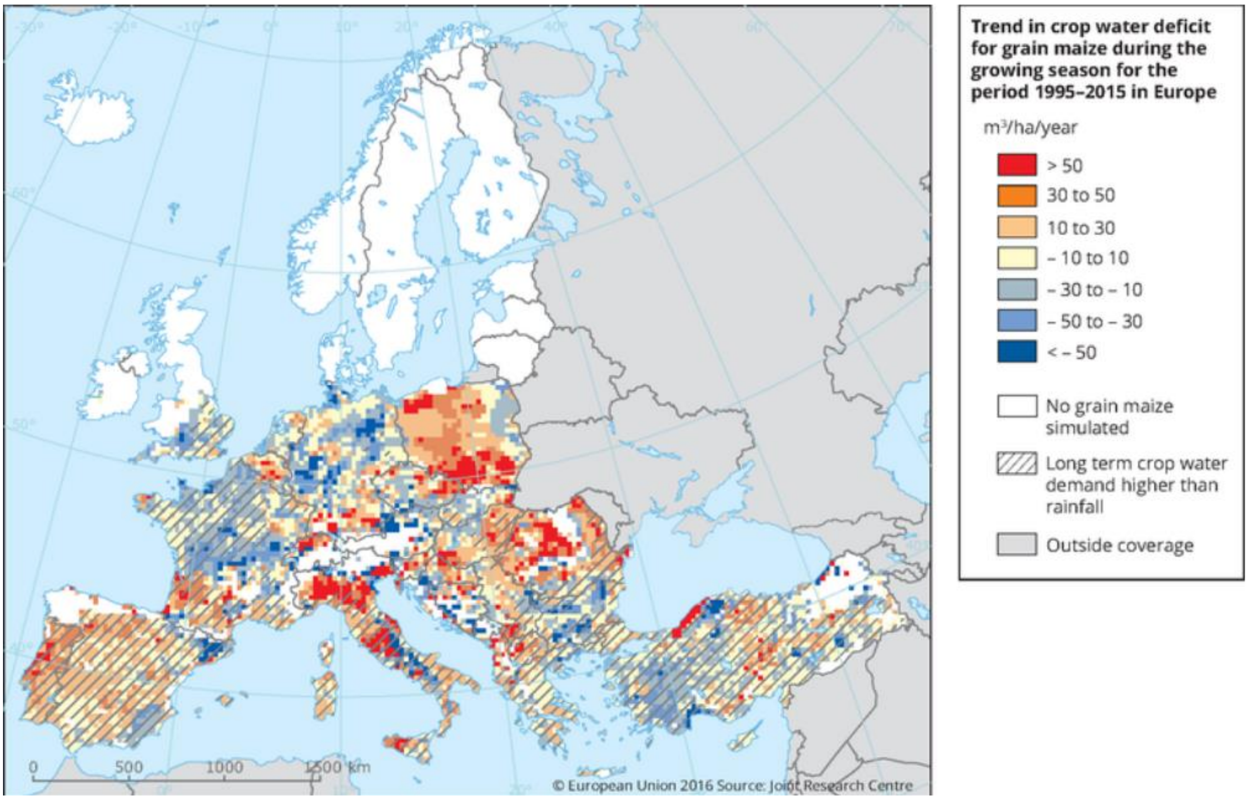
[35] Census of Agricultural and Livestock Holdings, *Annual Agricultural Statistical Survey*, Hellenic Statistical Authority, Athens 2021, for more information: https://www.statistics.gr/en/statistics/agr

[36] European Environment Information and Observation Network, (2016), *Trend in crop water deficit of grain maize during the growing season*, The EEA is an agency of the European Union, via link: https://www.eea.europa.eu/data-and-maps/figures/trend-in-crop-water-deficit

[37] Hellenic Statistical Authority, *Annual Agricultural Statistical Survey (Final Results), Areas and production*, 2016 https://www.statistics.gr/el/statistics?p_p_id=documents_WAR_publicationsportlet_INSTANCE_qDQ8fBKKo4lN&p_p_lifecycle=2&p_p_state=normal&p_p_mode=view&p_p_cacheability=cacheLevelPage&p_p_col_id=column-2&p_p_col_count=4&p_p_col_pos=1&_documents_WAR_publicationsportlet_INSTANCE_qDQ8fBKKo4lN_javax.faces.resource=document&_documents_WAR_publicationsportlet_INSTANCE_qDQ8fBKKo4lN_ln=downloadResources&_documents_WAR_publicationsportlet_INSTANCE_qDQ8fBKKo4lN_documentID=337942&_documents_WAR_publicationsportlet_INSTANCE_qDQ8fBKKo4lN_locale=el

Greece, the maize crop has declined 18.7% since 2014 and continues to decline. In fact, 2020 recorded a -27.5% change in all cereal crops.

Map 13. Crop water deficit of grain maize during the growing season in Europe, 1995-2015.



Source: European Union 2016, Joint Research Centre Published 20 Dec 2016

Table 32. Crop yields per year by type of production in Greece.

Thousand tonnes per year	Crop yields throughout Greece				
	2014	**2016**	**2018**	**2019**	***Variation (%)***
Cereals	4.084	3.725	3.146	3.011	***-26,3***
Cotton	861	777	860	901	***4,6***
Livestock plants	2.390	3.034	3.614	3.772	***57,8***
Peppinoids	560	493	366	356	***-36,4***
Potatoes	616	496	463	472	***-23,4***
Horticultural lands	1.174	1.114	1.071	1.038	***-11,6***
Vineyards	1.099	1.136	1.115	1.098	***-0,1***
Citrus trees	972	1.034	921	915	***-5,9***
Fruit plants	805	908	1.218	1.216	***51,1***
Almond groves	62	67	89	97	***56,5***
Olive groves	2.844	3.207	3.093	3.530	***24,1***

Source: Hellenic Statistical Authority, Agricultural Statistical Survey
https://www.statistics.gr/en/statistics/agr

Wheat, maize and cereals in Greece, as we can see on the map, need more water than is available annually due to precipitation. According to Table 40, the yields of cereals and grains have decreased by 26.3% in recent years. Certainly, their yield is based on the ever-decreasing rainfall and reduced soil moisture. As mentioned in the previous chapters, temperature, precipitation and soil moisture are essential factors in crop yields. When these factors change negatively, large economic costs are incurred in agricultural production. As can be seen in Table 41, with the economic accounts of the cereal crop in the regions with the highest production, the fall is extremely high. Eastern Macedonia and Thrace Region has lost 57.3% of its economic benefit from cereal cultivation in recent years. Central Macedonia, the largest grain producer, has lost 40% of its economic gains in a decade. According to Eurostat, Greece's downward trend in grain yields has been very much influenced by climatic parameters. The severe glaciations and the minimal but intense rainfall have had a devastating effect on this production.

Table 33. Economic Accounts (in million €) for the major Cereal Producers (Regions) for the period 2007-2018

Administrative Regions	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Variation (%)
Eastern Macedonia & Thrace	248,95	205,44	159,72	188,11	209,32	217,17	172,74	151,87	130,78	131,75	118,86	106,36	*-57,3*
Central Macedonia	362,22	334,73	265,78	270,22	305,25	307,42	279,96	262,00	274,67	250,09	230,22	216,20	*-40,3*
Western Macedonia	128,08	108,63	81,96	102,22	113,23	104,66	96,33	82,24	79,33	73,02	58,43	57,12	*-55,4*
Thessalia	170,68	190,17	167,62	166,92	193,76	200,22	198,58	191,10	205,62	180,09	174,07	150,07	*-12,1*
Western Greece	116,55	74,09	66,56	104,29	105,82	116,91	86,68	75,15	71,19	60,06	54,61	51,88	*-55,5*
Central Greece	87,30	89,32	82,80	74,15	86,78	89,29	75,92	78,23	68,70	59,69	62,24	57,38	*-34,3*
Greece	**1.181,43**	**1.049,82**	**865,44**	**959,49**	**1.070,39**	**1.093,83**	**956,06**	**874,06**	**865,02**	**785,56**	**724,96**	**668,01**	***-43,5***

Source: Own Processing – Official Data by Eurostat Database, Economic accounts for agriculture by NUTS 2 regions, *https://ec.europa.eu/eurostat/databrowser/view/agr_r_accts/default/table?lang=en*

The largest increase was in crops related to livestock plants because the present increase is based on the growing livestock breeding due to the overconsumption of meat and dairy products. As shown in Table 34 with the annual regional economic accounts for the crops of forage plants, there has been a rapid increase of almost more than 300% in the economic income of the Region of Thessaly from livestock products. A factor that automatically raises the whole percentage annual economic share of agricultural production throughout the country.

Table 34. Economic Accounts (in million €) for the major Livestock Plants Producers (Regions) for the 2007-2018

Administrative Regions	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Variation (%)
South Aegean	69,1	70,6	72,8	58,1	61,9	55,7	64,6	47,7	39,0	35,2	33,6	30,6	*-55,7*
Crete	47,5	52,6	60,0	49,7	47,3	42,4	53,0	39,0	39,5	40,9	39,1	41,5	*-12,6*
Eastern Macedonia & Thrace	14,6	16,9	17,6	19,1	16,8	16,5	21,9	25,4	27,6	27,1	28,1	27,1	*85,9*
Central Macedonia	40,7	41,1	45,1	67,3	59,3	58,9	76,5	93,2	83,1	104,2	91,6	84,2	*107,1*
Thessalia	29,41	47,03	62,76	52,16	59,51	52,82	65,07	79,39	78,86	98,6	99,37	126,93	*331,6*
Western Greece	82,37	85,39	95,24	80,16	77,08	68,12	82,96	91,9	103,09	111,05	109,87	121,09	*47,0*
Central Greece	48,17	65,16	77,84	61,67	59,74	60,56	74,46	45,69	51,05	54,95	51,71	66,56	*38,2*
Peloponnese	68,73	78,15	82,95	64,95	61,69	52,23	65,17	43,4	45,29	42,36	37,82	37,19	*-45,9*
Greece	**448,0**	**505,9**	**577,1**	**502,3**	**493,0**	**446,9**	**549,9**	**547,5**	**566,9**	**591,1**	**562,5**	**621,4**	***38,7***

Source: Own Processing – Official Data by Eurostat Database, Economic accounts for agriculture by NUTS 2 regions, https://ec.europa.eu/eurostat/databrowser/view/agr_r_accts/default/table?lang=en

Also, there has also been a decrease horticultural crops as indicated by the data in Table 40 and as shown through the economic figures in Table 35. The regions with the largest decrease in the economic returns of horticultural crops are Attica, Northern Greece and Central Greece, excluding of course Thessaly which due to its good irrigation systems keeps its agricultural production stable. Horticultural crops need moderate, stable water resources and a temperate climate, without frost and high rainfall. In recent years, northern Greece has been facing critical situations of severe frost in the winter months and heavy rainfall of high millimeters, resulting in the destruction of many hectares of crops every year due to climate change.

Table 35. Economic Accounts (in million €) for the major Horticultural Producers (Regions) for the 2007-2018

Administrative Regions	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Variation (%)
Attica	108,4	102,5	88,5	67,7	58,8	62,1	49,9	60,8	55,3	34,7	62,0	60,9	*-43,8*
Crete	209,1	232,2	187,6	188,6	168,2	154,9	173,8	204,1	222,3	204,8	219,7	260,7	*24,7*
Eastern Macedonia & Thrace	119,9	82,6	85,5	78,4	59,5	56,3	50,4	64,0	44,9	33,0	48,5	45,0	*-62,4*
Central Macedonia	289,7	282,3	222,9	188,9	173,1	163,8	134,4	129,8	141,0	121,7	141,3	125,5	*-56,7*
Thessalia	368,6	509,6	453,2	434,0	316,4	370,0	326,4	370,4	445,3	364,9	369,5	421,3	*14,3*
Western Greece	273,7	295,0	257,6	258,9	238,8	249,0	243,6	255,6	293,6	331,1	259,5	285,9	*4,4*
Central Greece	326,7	291,2	306,3	312,0	251,2	269,1	237,1	273,8	267,6	228,3	226,3	180,1	*-44,9*
Peloponnese	123,7	73,0	116,9	112,9	112,5	125,0	116,3	134,5	151,8	159,8	157,5	182,0	*47,2*
Greece	**1931,5**	**1921,9**	**1812,7**	**1737,7**	**1467,9**	**1548,2**	**1422,2**	**1591,8**	**1730,3**	**1570,7**	**1576,2**	**1661,3**	***-14,0***

Source: Own Processing – Official Data by Eurostat Database, Economic accounts for agriculture by NUTS 2 regions, *https://ec.europa.eu/eurostat/databrowser/view/agr_r_accts/default/table?lang=en*

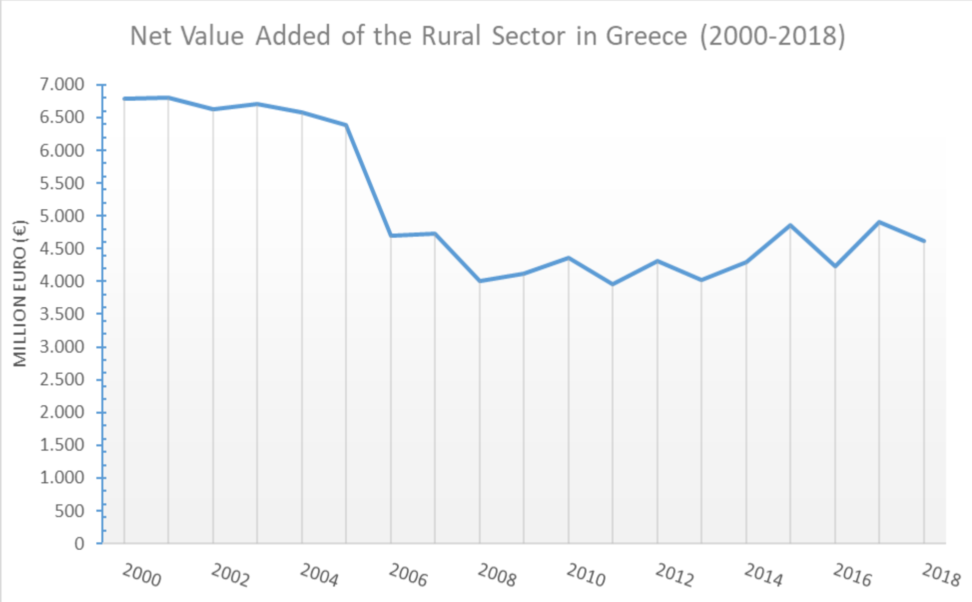
In recent years, almond and walnut crops have been gaining ground because they can adapt to dry summers without the need for water resources and are resistant to glaciers. Furthermore, these crops do not require any particular need for soil moisture and can be grown on dry and arid calcareous soils, even stony ones. It seems to be an excellent crop production for farmers coming exposed to climate change. On the contrary, the yields of oil producers in the country as a whole fell by 11.4%. Greece lost almost €100 million in 2018 from olive tree production compared to 2007 (see table 44). Crete suffered the biggest financial drop, i.e., it lost almost €200 million in 2018 from olive crop yields. These costs are purely due to climatic changes. The olive is a fragile agricultural product, which thrives in warm climates, but extremely hot temperatures weaken it.

Table 36. Economic Accounts (in million €) for the major Olive Producers (Regions) for the period 2007-2018

Administrative Regions	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Variation (%)
Crete	417,4	336,8	300,7	304,5	289,4	295,5	183,9	187,0	325,4	232,7	313,1	240,6	*-42,4*
Central Macedonia	17,7	17,5	15,4	18,0	12,4	48,0	13,6	25,8	32,0	23,3	31,6	21,3	*20,3*
Thessalia	54,0	38,2	32,9	35,5	28,6	33,1	22,0	32,3	58,0	54,6	72,6	47,5	*-11,9*
Western Greece	86,0	68,9	80,0	93,5	66,7	94,7	62,4	145,5	202,7	131,9	266,0	67,4	*-21,6*
Central Greece	55,0	64,9	40,9	44,5	38,1	63,4	39,7	66,5	58,7	41,8	89,2	72,5	*31,9*
Peloponnese	250,1	213,1	166,5	226,6	205,4	283,2	175,1	242,8	346,4	283,4	361,3	312,9	*25,1*
Ionian Islands	54,0	38,2	32,9	35,5	28,6	33,1	22,0	32,3	58,0	54,6	72,6	47,5	*-11,9*
South Aegean	15,7	22,1	23,5	23,0	26,8	23,3	36,4	18,8	35,8	33,7	43,5	34,5	*120,5*
North Aegean	13,2	12,4	8,4	10,7	8,2	11,0	6,5	10,8	14,6	8,8	15,0	5,7	*-56,8*
Greece	961,4	823,6	707,3	803,5	714,2	908,4	577,9	780,2	1142,2	868,4	1268,3	852,1	*-11,4*

Source: Own Processing – Official Data by Eurostat Database, Economic accounts for agriculture by NUTS 2 regions, *https://ec.europa.eu/eurostat/databrowser/view/agr_r_accts/default/table?lang=en*

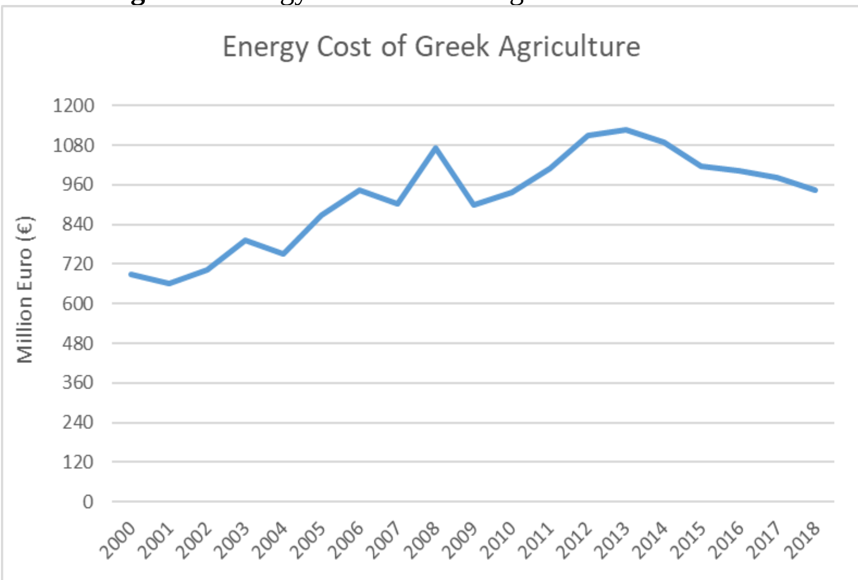
Figure 8. Net Value Added of the Rural Sector in Greece for the period 2000-2018



Source: Own Processing – Official Data by Eurostat Database, Economic accounts for agriculture by NUTS 2 regions, [*https://ec.europa.eu/eurostat/databrowser/view/agr_r_accts/default/table?lang=en*](https://ec.europa.eu/eurostat/databrowser/view/agr_r_accts/default/table?lang=en)

According to Figure 8, the net value added of Greece's agricultural sector for the 18-year period decreased significantly by 32%. From almost €7 billion per year, the agricultural sector now contributes only €4.5 billion to the country's total real GDP. The biggest drop was due to the economic crisis, it is clear that a huge similar drop in the index in a two-year period could only be marked by a financial crisis. Of course, small fluctuations between years can equate to the effects of climate phenomena, as every type of production is now vulnerable to the sudden weather extremes of climate change and has an impact on the country's economy. As given above in Table 40 with crop yields between 2014-2018, the country has been experiencing fluctuations in its crop yields by species, just as reflected in Figure 8 with an almost average increase recorded from 2014 to 2018 is at 7%. Climate changes do not leave much room for profitability and in fact are increasingly damaging production. Water management, proper irrigation and adequate irrigation runoff systems can ensure greater positive productivity results. The example of the reuse of Lake Karla in the Thessalian Campos is a salutary example of the enormous water needs of the agricultural area and even a positive factor in securing many hectares of crops.

Figure 9. Energy Cost of Greek Agriculture 2000-2018



Source: Own Processing – Official Data by Eurostat Database, Economic accounts for agriculture by NUTS 2 regions, *https://ec.europa.eu/eurostat/databrowser/view/agr_r_accts/default/table?lang=en*

Another factor affected by climate change is the energy costs that each agricultural production unit needs to cope with barren soil, water scarcity, bad weather and whatever else happens. The energy agricultural cost according to Eurostat is any external material factor that helps the yield of the crop. That is fertilizers, irrigation water costs, drilling, fuel, agricultural machinery, etc. As many attempts are made to share energy costs, the agricultural sector is increasingly under pressure over time. The soil is eroding more and more, putting more pressure on the system for farmers. In Greece from 2000 to 2013, there has been increasing pressure for more energy and costs are rising more and more. Of course, from 2014 onwards there is a decreasing trend in energy costs, which may be the same as the decrease in agricultural production year by year. But, on the contrary, the increase in organic farming in recent years may contribute positively. According to the National Agricultural Census 2021[38], Greece has seen an increase of almost 300% in organic livestock production overall. Although over the years energy costs have increased by 36.7% for the country's agricultural sector, it is certain that the future costs that climate change will create in the coming years will be much higher than in the past.

[38] Census of Agricultural and Livestock Holdings, Annual Agricultural Statistical Survey, Hellenic Statistical Authority, Athens 2021, for more information: *https://www.statistics.gr/en/statistics/agr*

3.2 Assessment of Agriculture Production by CGE Framework

As mentioned in chapters 1.2 and 1.3, general equilibrium economic models can be applied to yield policy applications and solutions for various issues, and in particular, they can be applied to the management of water resources in agricultural production. The parameters that a CGE model can accept for the agricultural sector are the types of production such as cereals, grains, fruits, vegetables, olives, and industrial crops. These are then assigned the water needs of each crop per species and per hectare. According to Ponce R., Parrado R., et al. (2016), the endowment land should be divided when applying CGE into Rainfed Land and Irrigated Land, as each type of water access to the soil depends on the way it enters. Also, a separation should be made between Irrigated Capital and Other Available Agricultural Capital so that the applications can be properly allocated.

In the case of Greece, the area designated as Rainfed Land is the surface waters of the river basins. And Irrigated Land is all areas where water can be irrigated, either from groundwater or from artificial runoff systems of lakes, reservoirs, etc., (Siebert, et al. 2010). As far as Irrigation Capital for the agricultural sector is concerned, it depends on each Region of Greece, and what amount of water resources it has for utilization for its agricultural sector. That is all the quantities of groundwater, technical ponds, and reservoirs that it has for irrigation in the agricultural sector.

As presented in the previous chapters Greece has 132 km^2 of Rainfed Land with an estimated water volume capacity of 237 hm^3 cubic meters (see table 22), while the available Irrigated Land in 2020 was 9.606 km^2 according to table 39. For the agricultural sector specifically, the available Irrigation Capital in 2020 was 2,854 hm^3 of surface freshwater irrigation and 5,282 hm^3 of groundwater irrigation.

Table 45. Split the land endowment and capital for the rural sector of Greece in 2020.

Land Endowment		Capital Endowment for Rural Sector	
Land (km2)		Irrigation Capital (hm3)	
Rainfed	Irrigated	Groundwater	Freshwater
131.957	9.606	5.282	2.854

Source: Own Processing – Data were collected from the previous chapters of this paper.

Following the example given by Ponce R., Parrado R., et al. (2016), for the external model relating irrigation system conduct to water adequacy in each region, it is possible to link all the data in this paper to a set of functions that structure the CGE models. As they point out, the model they have built differentiates the expected impacts of climate change on water allocation. Essentially, they point out that for rainfed land, a reduction in rainfall will have an impact on agricultural productivity yields. This is in contrast to irrigated land, where the lack of precipitation does not directly affect this relationship, as they can consider the available irrigation capital to mitigate the effects of climate change. Of course, the impact of climate change with the gradual reduction of precipitation and surface water resources has led to changes in irrigated areas due to changes in surface water availability. The data for Greece in the agricultural sector shows a shortage of irrigated land, both per hectare area, and in the number of farms (see table 39). The factors that affect irrigation for the agricultural sector are precipitation, river flow, soil moisture, temperature and all available water resources in reservoirs or technical ponds. When all climate indicators change, the need for irrigation increases and irrigation capital decreases. What must be respected in order not to further disturb Greece's water resources is to apply the water balance, which links input and output flow. This in turn can be applied to a complex equation to lead us to equilibrium models. The water balance, according to Ponce R. et al. (2016) is:

$$Q_{EA} + P_A = Q_{SA} + E_A$$

- Q_{EA} is the actual input flow, P_A is the actual precipitation rate
- Q_{SA} is the actual output flow, E_A is the actual soil moisture

However, to analyze the impacts of climate change on the agricultural sector in terms of water availability, the future equation, which includes changes in both river flows and precipitation, needs to be applied. The future scenario according to them is:

$$Q_{EF} = (1+x)*Q_{EA}$$
$$P_F = (1+\gamma)*P_A$$

- Q_{EF} is the future input flow, P_F is the future precipitation rate
- x and γ are the anticipated variations

$$\Delta V = R*V_{MAX} = Q_{EF} + P_F - Q_{SA} - E_A$$

- ΔV is the result of the difference of future inputs and actual outputs
- R is the percentage at which the volume of water in the basin will be changed.

The higher the R-value, the higher the impact of climate change on the volume of water. Areas with small water resources will experience large increases in their water supply.

For Greece, as already shown in the table below that analyzes the change in irrigated areas in each Region, from 2009 to 2020 the need for water resources increased in areas where their groundwater is few. Due to climate change and according to the above equation of climate change, every time the amounts of precipitation are reduced, the irrigation needs increase, thus minimizing the existing resources each time.

Table 37. Irrigation Capital and Holdings with Irrigated Land by Region between 2009 & 2020.

Administrative Regions	Irrigation Capital		Holdings with Irrigated Land (number of farms)		Variation (%)
	Freshwater Resources (hm3)	Groundwater Resources (hm3)	*2009*	*2020*	
Peloponnese	15.641	4272	54.766	38.975	**-28,8**
Central Greece	22.509	3495	34.842	24.760	**-28,9**
Western Greece	24.556	2972	53.987	41.642	**-22,9**
Epirus	30.892	4024	24.303	15.850	**-34,8**
Attica	245	246,1	10.366	7.703	**-25,7**
Thessaly	34.314	3225	45.384	31.867	**-29,8**
Western Macedonia	22.803	619	13.529	8.366	**-38,2**
Central Macedonia	58.034	2214	71.704	49.101	**-31,5**
Eastern Macedonia &Thrace	24.955	820	40.589	26.950	**-33,6**
Crete	1.359	1608	63.808	52.065	**-18,4**
South Aegean	234	379,64	11.451	8.582	**-25,1**
North Aegean	514	146,94	11.090	10.400	**-6,2**
Ionian Islands	592	746	15.439	9.995	**-35,3**
Greece	**236.648**	**24.149**	***451.258***	***326.256***	***-27,7***

Source: Own Processing – Data were collected from the previous chapters of this paper.

The table 37 can provide data for equations based on future parameters, especially for regions that have small water supplies and whose agricultural sector is fully dependent on irrigation capital. The future irrigation demand can be shown through the following equation:

$$ID_{F} = {}^{N}{}_{i=1} C_i * A_{iF} = {}^{N}{}_{i=1} C_i \,(1-z) * A_{iA}$$

- C_i is the demand for water resources for crop i, A_{iA} is the actual land of the crop i with irrigation,
- A_{if} is the future irrigated area of crop, z is the variation rate in the irrigated area.

According to this equation and the data analysis from previous chapters, the immediate necessary solution is the shift of producers to dryland farming activities, in order to reduce the cost of damage in the case of extreme phenomena in crops, as well as to reduce the need for water. Therefore, the agricultural production continues its growth rate, but this time towards the rise and not the decline. Of course, the change in production has some economical risks and costs. In order to better analyze these, we rely on a cost-effectiveness scenario[39]. The choice of this analysis is made because we know the risk of water scarcity and we refer to agricultural production, which is highly dependent on water resources and weather conditions, so we must always think about the potential costs that each production may have per unit of output. This

[39] Thrikawala, S., Batzlen, C., Korale-Gedara, P. (2022*). Cost-Benefit Analysis of Irrigation Projects*. In: Weerahewa, J., Jacque, A. (eds) Agricultural Policy Analysis. Springer, Singapore. *https://doi.org/10.1007/978-981-16-3284-6_12*

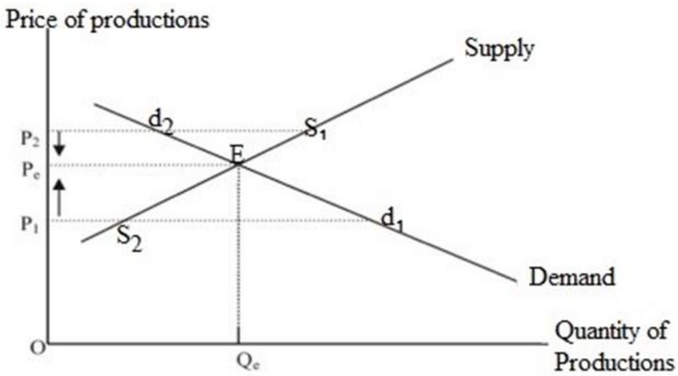
comes in contrast to the cost-benefit analysis that proves the disadvantages and advantages of a scenario. In this case, the meaning is for agricultural production to be efficient, so cost-effectiveness analysis is considered the most appropriate.

In essence, the equation $y = \frac{(C1+C2)}{E}$, is used, where y defines the cost per unit of efficiency, C_1 the direct cost, and C_2 the indirect cost. Then we replace C_1 with the change of production process, i.e., the costs from the new anhydrous plants, new durable seeds, seedlings with minimal need for water resources, etc., C_2 with the cost of waiting for a new harvest and E with the results of the new production, i.e., more sustainable production, economic growth of the agricultural sector and securing and conserving water resources. Therefore :

- If this equation $y = \frac{(C1+C2)}{E} < 1$, it will achieve an imaginary short-term political solution,
- If $y = \frac{(C1+C2)}{E} > 1$, then crop yield and irrigation systems should be better studied, with possible causes of non-compliance with dry farming crops or proper management irrigation systems.

Moreover, the above policy solution can be combined with a computable general equilibrium model (CGE), in order to manage the water shortage phenomenon in an excellent way. This model comes as a type of economic balance in economies that have suffered a possible ΄΄shock΄΄. In this case, the water shortage in the agricultural sector as analyzed suffered great financial costs in production.

Figure 10. Computable General Equilibrium (CGE) Model of Agricultural Productions.



Source: Own Processing inspired by the general theory of CGE models

The simulation of this model will start with a general equilibrium condition in the price of agricultural products (see Figure 10), which will be changed by the effects of water scarcity due to the reduced supply of farmers (d_1) resulting in an increase in their price (P_1), therefore the model will be called upon to restore the system to a new equilibrium. The data that will be incorporated in this model will be the new anhydrous agricultural products, as the supply of anhydrous products (due to the resistance to water shortage conditions) will increase (d_2), resulting in their price falling (P_2). Therefore, the CGE model will restore the economy of agricultural production to a point of equilibrium (E).

3.3 Rural Resilience as a New Security and Sustainability Policy

In coming years, agriculture will be confronted more and more directly with the effects of climate change, all over the planet. Southern European countries are already experiencing the first signs of its effects and the consequences are economically unbearable for the agricultural sector. To cope with the next challenges ahead, agriculture must become more resilient, robust, sustainable, and flexible to the new climate changes. In some parts of the Mediterranean, the agricultural sector has already started to adapt to the new climatic changes and is experiencing crop rotation, such as many summer crops being planted from winter and spring due to water stress in the summer months, some summer crops now perform better in the winter months, as long as there are no extreme temperature drops or glaciers[40]. This of course cannot happen in all regions of the Mediterranean, for example, Central and Western Macedonia in Greece cannot shift crop production to winter due to reduced temperatures and frost. But in areas of the coastal Peloponnese or Central Greece, this example could be real.

The Regions of Greece in which part of their economic losses are based on negative crop yields can be compensated with high-tech agricultural applications, in which producers can monitor their soil moisture, water resource rates, adaptation of sowing dates to patterns of temperature and future rainfall and the use of varieties of aid applications for resistant crops adapted to the new conditions.

As EEA Report No 4/2019 states[41], the food-water-energy nexus, which includes the synergies and trade-offs between water, and energy use for food production, will be strongly affected by the 2°C warming scenario. Future increases in water demand from the agricultural

[40] European Environment Information and Observation Network (Eionet), *Agriculture and climate change,* Published 30 Jun 2015 - Last modified 11 May 2021, https://www.eea.europa.eu/signals/signals-2015/articles/agriculture-and-climate-change

[41] European Environment Agency, *Climate change adaptation in the agriculture sector in Europe,* Created 14 May 2019 Published 04 Sep 2019, https://www.eea.europa.eu/publications/cc-adaptation-agriculture

sectors will be dramatic, with water demand likely to exceed supply by 2050. Therefore Greece, as a Mediterranean country already affected by warming, will have to take emergency measures for its regions under severe water stress. Alternative water management strategies should be implemented, such as the re-creation of drained former lakes, and the creation of more dams and technical reservoirs, so that any amount of water that is precipitated is not wasted.

A notable example is the re-hydration of Lake Karla in Thessaly. This lake had been drained since the beginning of the 20th century, due to flooding conditions that prevented farmers' crops from yielding, combined with the abundance of insects and mosquitoes that bothered the surrounding residential areas. In 1962 in particular, the lake was completely drained, with the creation of a tunnel that diverted the estuary into the Pagasitikos Gulf. This drainage brought about major catastrophic changes. Entire agricultural villages were forced to shift their habits and activities to fishing. Huge irrigation problems were noted in all rural areas, greater than the costs of the floods of 1940-1950[42]. The decision to re-water was as important as it was necessary. The first works began in 1990 and were completed in 2018, with the lake now back to its natural character. It has an area of almost 37.372 km² and a depth of 6 meters. This project essentially contributed to the restoration of water resources, the improvement of agricultural production, to the increase of economic returns through positive crop yields. This case in the years of climate change is a positive example of securing water resources[43]. In particular, for the rural regions of Greece, such as Thessaly, Macedonia, Crete, Thrace and Central Greece, an increase in the number of technical ponds is necessary. With increasing temperatures, agricultural production will have more and more water needs, as water stress will increase accordingly. Without appropriate hydrological infrastructure, the agricultural sector will slowly die out.

Another case of the Greek agricultural sector adapting to the new climate conditions is to follow the example of Montpellier, France. This city in southern France has initiated sustainable practices and resilient adaptation measures for its agricultural sector through the implementation of agroforestry[44]. This practice can be followed in regions of Greece whose

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[42] Pampoukis G., Vouvaloudis I., (2020), *Investigation of water level change in Lake Karla, due to overdraft, using GIS observations,* National Technical University of Athens, School of Agricultural and Surveying Engineering
https://dspace.lib.ntua.gr/xmlui/bitstream/handle/123456789/51777/PampoukisvouvaloudisGeorgiosIason_DiplomaThesis.pdf?sequence=1

[43] Tzambyras I., (2022), *Development of a water resources management system for agricultural basins under climate change and variability conditions,* University of Thessaly. Faculty of Engineering. Department of Civil Engineering, https://www.didaktorika.gr/eadd/handle/10442/51337

[44] Vatikiotis S., (2017), *Investigation of Approaches and Best Practices for Adaptation to Climate Change,* National Technical University of Athens,

geographical characteristics allow the maintenance of forest land use and crops. These areas can be in Western Macedonia and Eastern Macedonia and Thrace, i.e., areas where the agricultural sector will operate at a moderate altitude. In the case of Montpellier, the plan adopted involved a combination of walnut and wheat cultivation. As mentioned in the previous chapters, Macedonia is facing a terrible decline in grain production. In this sustainable way, it can use the complementarity between trees and crops so that the available resources can be used more efficiently. It is a practice that respects the environment and has an obvious benefit for the landscape. Researchers at INRAE[45] have shown that the production of one hectare of walnut/wheat mix is the same as that of 1.4 hectares of separated trees and crops. This is an increase of productivity by 40%, as agroforestry is less vulnerable to climate change.

Conclusions

Climate change is a subject that is being intensively researched by scientists at the moment and the connection with the agricultural sector made in this study gives very interesting future prospects to study this issue further. In particular, the exposure of agricultural sector producers to the risks of climate change is important, as they are already experiencing a range of adverse impacts on the productivity, diversity, and resilience of their crops, the fertility of their soils, the availability, sufficiency and quality of irrigation water, etc., impacts which in turn affect their income and largely determine the viability of their farms, their standard of living and, in general, their life and their stay in the Greek countryside.

As climate conditions escalate, the planet's natural resources are threatened. The water resources in Greece are showing increased vulnerability, as presented through the data of the thesis, the water resources available in the country year by year are diminishing. The

https://dspace.lib.ntua.gr/xmlui/bitstream/handle/123456789/46410/Diploma_Thesis_Vatikiotis_Stavros.pdf?sequence=1

[45] INRAE is France's National Research Institute for Agriculture, Food, and Environment. It was formed by the merger of INRA (National Institute for Agricultural Research) and the IRSTEA (National Research Institute of Science and Technology for the Environment and Agriculture). INRAE is playing a major role in research related to the UN's Sustainable Development Goals (SDGs). It has focused on various issues of the agricultural sector and its adaptation to climate change. One of these is Agroforestry: trees provide a way forward for sustainable farming https://www.inrae.fr/en/news/agroforestry-trees-provide-way-forward-sustainable-farming

agricultural sector puts pressure on the water system accordingly as the average temperature of the country increases and rainfall decreases. As has been seen, Greece is divided climatically into areas with a strong tendency towards water scarcity and areas where there is an abundance of resources. The agricultural sector will certainly not be the same in any of the country's regions. Each region must be studied separately and must implement sustainable policies that are appropriate to its own needs. For example, the region of Western Greece and Epirus has enough water resources so that the pressure from the agricultural sector is low. While the Region of Central Macedonia, Crete and Thessaly have increased vulnerability to water scarcity and already the needs of producers exceed the supply of resources.

These rural regions with the largest contribution to Greek GDP will certainly decline by 15% even more in the coming years if no significant measures are taken. Economic costs increase as water resources decrease. Agricultural production is decreasing and becoming more and more expensive. In order to avoid the worst-case scenario, new farming practices must be developed that are resistant to the new climate scenario of +2°C.

This challenge consists of a scenario of adopting an adaptive management strategy through cost effectiveness analysis in combination with CGE models, in which the change of traditional crops and intensive irrigation to arid crops, adapted to extreme weather conditions, will greatly achieve economic growth of primary sector. This increase can even become competitive to other regions of Greece, through the economic growth of the sector in the total Gross Domestic Product of the Region.

Implementation and measures which may include actions to restructure crops by selecting varieties that show greater adaptability and resilience to the new conditions, encouraging the implementation of public and private investments on the one hand, for more efficient use of natural resources, in particular water irrigation, on the one hand, and to protect production from natural disasters, on the other, pests and diseases, and the extension of the application of organic production methods, the preservation of pasture land and its low-intensity use, the good management of pasture land and the animal welfare, the protection of sensitive ecosystems through the use of low-impact agricultural practices, the protection and improvement of genetic diversity and the promoting agroforestry and agroecological systems that will contribute to further contribute to the conservation of biodiversity and landscape in the Greek countryside.

Changing agricultural production and cropping patterns is the only solution to avoid water scarcity in this sector. Traditional crops require hundreds of tons of water per month for the whole country. Shifting crop applications to dwarf or even agroforestry crops is a worthy sustainable and resilient application. Of course, nothing is easily implemented without the support of appropriate funds, state and/or European funding.

In conclusion, therefore, water scarcity in the coming years may be a phenomenon that will concern several coastal and lowland areas of Greece, with the main emphasis on agricultural production. However, with the right efficiency tools, computational equilibrium models and economic evidence, much of the damage can be avoided. Proper management of water resources through technological and computational tools can provide sustainable applications in the agricultural sector in Regions in need.

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