Research Ideas and Outcomes 9: e116070
doi: 10.3897/rio.9.e116070

Grant Proposal

Water-Ecosystems-Food nexus security achievement in the context of climate change: the case study of an agricultural Mediterranean Basin, Greece

Dimitrios Malamataris[‡], Anastasia I. Tsavdaridou[‡], Dimitra Banti[‡], Athanasios Malliaras[§], Apostolos Karalis[§], Nikolaos Theocharis[|], Christodoulos Michos[¶], Antonios Mazaris[‡]

‡ Department of Ecology, School of Biology, Aristotle University of Thessaloniki, Thessaloniki, Greece
§ Malliaras A. – Karalis A. Company, Serres, Greece
| Theocharis Nikolaos Company, Serres, Greece
¶ Michos Christodoulos Company, Serres, Greece

Corresponding author: Dimitrios Malamataris (dimalamataris@gmail.com)

Reviewable v 1

Received: 21 Nov 2023 | Published: 29 Nov 2023

Citation: Malamataris D, Tsavdaridou AI, Banti D, Malliaras A, Karalis A, Theocharis N, Michos C, Mazaris A (2023) Water-Ecosystems-Food nexus security achievement in the context of climate change: the case study of an agricultural Mediterranean Basin, Greece. Research Ideas and Outcomes 9: e116070.
https://doi.org/10.3897/rio.9.e116070

Abstract

Natural resources conservation is considered indispensable for a sustainable future. A thorough managerial analysis of the current and future conservation and availability to meet future demands is both necessary and challenging. As water of adequate quantity and good quality is required for a favourable condition of natural ecosystems and for agricultural production, a comprehensive analysis which would consider hydrological, environmental and agricultural dimensions is needed to properly address their interactions and potential impacts. This study presents a Water-Ecosystems-Food (WEF) nexus methodological flamework aiming at identification and mitigation of critical challenges. The framework is tested in a highly productive water basin in north Greece, the Kokkinorema River Bain, which is also characterised by intense agriculture practices. The presented methodological approach was developed in the context of a natural resources sustainability scheme adapted by the national funded AgroClim project. The selection and prioritisation of the most efficient measures, including Nature-based Solutions, would be driven by a Decision Support System (DSS) tool which will feed upon ecological, social, economic and legislative information. The proposed DSS will also incorporate future climate scenarios to evaluate and address expected future water scarcity, ecosystems degradation and reduced agricultural productivity issues. The proposed methodology for addressing nexus challenges could be transferred to any other natural resources-stressed water basin with similar characteristics.

Keywords

nexus, sustainability, Mediterranean area, natural resources management

Introduction

The climate of our planet is rapidly changing with potentially severe and catastrophic implications for human life if immediate action to limit greenhouse emissions is not taken. While climate change is already reported to significantly alter water availability in many Mediterranean countries (Andrew and Sauquet 2017, Verkerk et al. 2017), surface and groundwater resources face significant degradation. From an economic perspective, decrease in agriculture production and increase in pumping costs result in a reduction in income from agriculture-related activities at a local and regional scale, mainly affecting smaller agriculture-related entities (i.e. local producers and farmers' cooperatives). Coupling climate change impacts on hydrological cycle components with the intensification and modernisation of cultivation practices has increased the need for enhancing sustainable agriculture (Munaweera et al. 2022).

Agriculture constitutes the major water user in the Mediterranean Region, accounting for about 80% of water withdrawals (Ferragina and Canitano 2015). Climate change is expected to affect agricultural productivity in a great extent. A mean temperature increase would likely result in an associated increase in mean evapotranspiration and, consequently, in crop water needs. Meanwhile, changes in the daily temperature range are expected to affect the productivity of certain crops in different geographical and climatic regions (Tanasijevic et al. 2014, Vargas-Amelin and Pindado 2014, Garrote et al. 2015). Furthermore, precipitation decrease is expected to intensify pressures on water resources, while increase in the frequency and intensity of precipitation extremes is likely to result in flooding and agricultural production loss (Varela-Ortega et al. 2016, Schmidt and Zinkernagel 2017, Masia et al. 2018). Following a chain effect, current and projected temperature and precipitation changes are expected to increase uncertainty on the spatial and temporal availability of water resources.

As a result of a growing global population, improved living conditions and changes in dietary habits, crop water demands are likely to increase, raising the issues of food security as a high political priority (Godfray and Garnett 2014, Ferragina and Canitano 2015). Under the same context, projected global patterns are expected to lead to an overexploitation of water resources (Mancosu et al. 2015) and an intense competition for water in agricultural areas (Intergovernmental Panel on Climate Change (IPCC) 2014). In addition, water abstractions from aquifers are expected to increase compared to those from surface water systems (Kundzewicz and Döll 2009, Taylor et al. 2013).

Therefore, there is now mounting evidence that climate change greatly affects crops and food production at local, regional and global scales (Ray et al. 2019). Food access and price stability are expected to be affected by climate change (Intergovernmental Panel on Climate Change (IPCC) 2014). Yet, food insecurity, which is expected to be intensified in the next decades, is likely to be inflamed by an increase in nutritional needs mainly due to population growth and dietary habits alteration (Intergovernmental Panel on Climate Change (IPCC) 2014).

Agriculture constitutes the dominant form of land management in the Mediterranean Region, including Greece. Agroecosystems can be considered as both providers and users of ecosystem services (Schipanski et al. 2014), including surface water storage, climate conditions moderation, food and fibre provision, nutrient concentration reduction, water quality improvement and biological diversity and productivity maintenance and, thus, are essential to human well-being (De Vrees et al. 2021). Ecosystem services are affected by human activities developed in both the study and surrounding areas.

To overcome current issues and move a step forward towards devising solutions, we need advanced integrated approaches that could address shortcomings derived from the different dimensions that are related to the resilience and functionality of agriculture systems and the services they provide. To contribute to this societal and scientific challenge, a system-informed decision-making process needs to be developed which will offer tailored decisions by acknowledging and accounting for the complex socio-environmental systems.

Materials and Methods

Study Area

The Kokkinorema River Basin (KRB), Regional Unit of Serres in northern Greece (Fig. 1), covers an area of 558.19 km^2 and it constitutes one of the most agriculturally developed basins in northern Greece. The elevation of Kokkinorema Basin was found to vary between 6.15 and 1,963.29 m a.s.l. The hydrological basin is mainly drained by the Kokkinorema River, which has a length of 28.94 km and discharges into the transboundary Strymonas River, the sixth longest river in Greece. Forest and semi-natural areas comprise 55.68% of the total area in Kokkinorema Basin, followed by agricultural areas (41.82%) and artificial surfaces (2.50%).

The significant development of the agricultural sector in the Regional Unit of Serres in northern Greece must be conserved against significant challenges, such as the reduced availability of irrigation water, changes in humidity and other soil characteristics and the application of unsustainable agricultural practices. In parallel, promotion of ecosystem services through preservation and improvement of natural protected areas faces significant challenges mainly due to reduced water availability that adversely affects habitats of various species. All the above challenges affect both agricultural production and biodiversity, while impacting the economic status of the wider area. The above challenges are expressed as high intensity in most of the Region's area. The project entitled "Ensuring Agricultural Production and Ecosystem Services within the context of Climate Change" is expected to contribute to the maintenance and strengthening of rural incomes via the conservation or even improvement of agricultural production and ecosystem quality. The proposed methodology and the Decision Support System that will be developed in the agricultural study area can be easily applied in the entire Region of central Macedonia or any other rural area in Mediterranean area with similar characteristics.

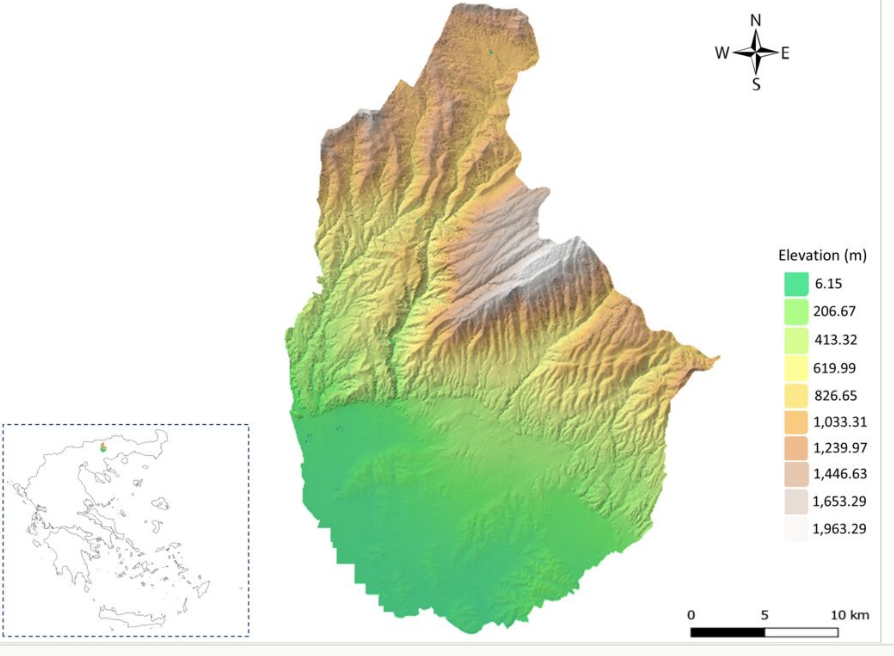

Figure 1. doi

Kokkinorema River Basin pilot area.

KRB Water Sector

KRB belongs to the water district of eastern Macedonia (EL11) and covers almost the 7.63% of this district. In the framework of the 1st Update of River Basin Management Plans of the Eastern Macedonia Water District implemented in accordance with the 2000/60/EC Water Framework Directive, seven rivers and three groundwater bodies have been delineated in KRB (Fig. 2). The quantitative and chemical status of all water-bodies is characterised as "good", apart from the quantitative status of one river body that is "moderate".

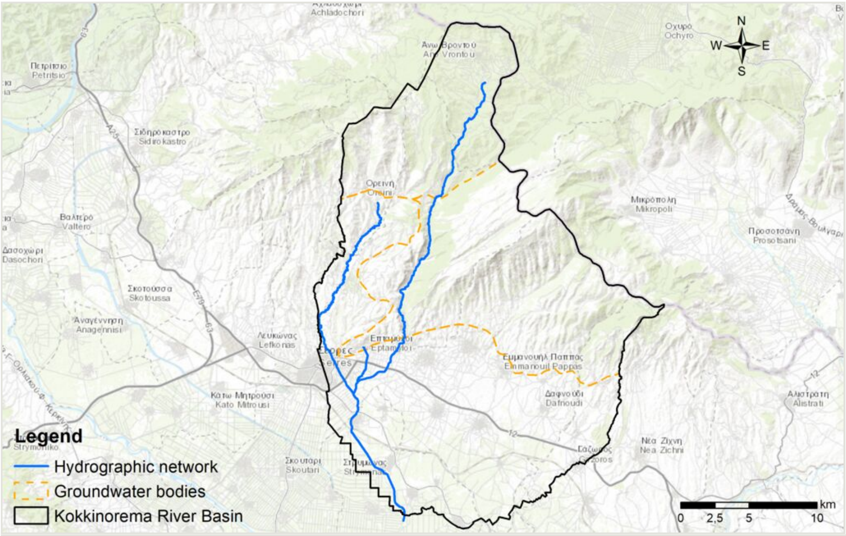

Figure 2. doi

Water sector in Kokkinorema River Basin.

KRB Ecosystems Sector

KRB is considered as one of the most important hydro-ecosystems in northern Greece, with the 44% of its total area, i.e. 247.98 km^2, being enclosed within the EU Natura 2000 protected area network. In particular, in KRB, there are three Sites of Community Importance (SCI) with a total area of 126.22 km^2 and one Special Protection Area (SPA) extending within an area of 189.10 km^2, which partially overlap. About one third of the Basin is also characterised as an Important Bird Area (IBA) covering an area of 171.57 km^2 (Fig. 3).

KRB Food/Agriculture Sector

KRB constitutes one of the most intensively cultivated and productive agricultural basins in northern Greece. The dominant crop in KRB is wheat (24.05%), followed by other cereals (24.04%), energy crops (12.20%), cotton (10.10%), forage (6.45%), fallow (5.78%), corn (4.47%), olives (3.14%), tobacco (1.79%), potatoes (1.77%), vegetables (1.73%), legumes (0.80%), pome fruits (0.72%), vineyards (0.66%) and other crops (2.30%) regarding the year 2015, according to the recordings of the Payment and Control Agency for Guidance and Guarantee Community Aid (Fig. 4).

Methodological framework

Motivated by the need for a thorough analysis of the WEF nexus in KRB, this study comprises of eight different phases (Fig. 5), aiming at ensuring the nexus security in the study area through the development of a flexible and comprehensive DSS. The presented analysis is formulated to optimise and manage the available water, ecosystems and food nexus resources in an integrated way. The implementation of the project is based on nine Work Packages and nineteen relevant Deliverables as follows to ensure the successful achievement of its objectives.

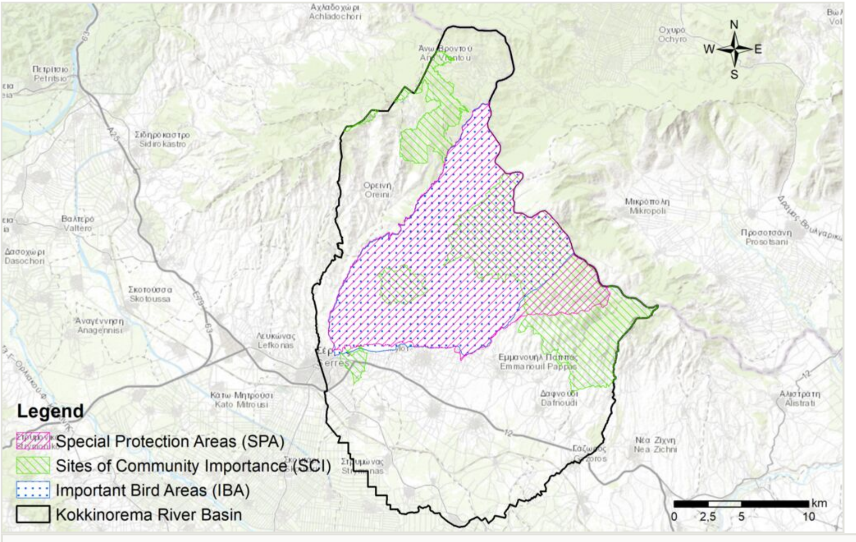

Figure 3. doi

Ecosystems sector in Kokkinorema River Basin.

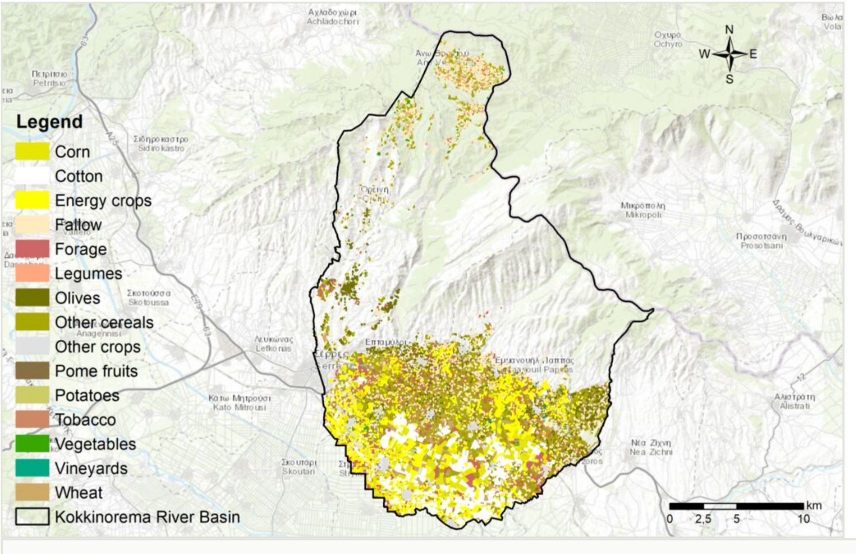

Figure 4. doi

Food/Agriculture sector in Kokkinorema River Basin.

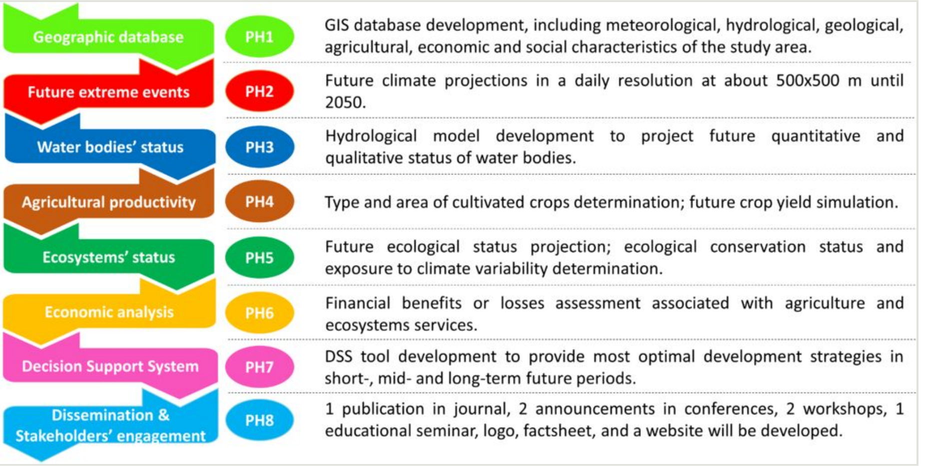

Figure 5. doi

Methodological approach of the project.

Phase #1: Development of a Geographic Database. An extensive investigation will be conducted to collect all the relevant data, including meteorological, hydrological, geological, agricultural, economic and social characteristics of the study area. The collected information will be imported into a Geographic Information Systems (GIS) database to spatially visualise the information.

Phase #2: Projection of Future Extreme Events. Future climate of the study area will be projected in a daily resolution for the most critical meteorological parameters in terms of agricultural production, such as precipitation, temperature, air humidity, sunshine and wind speed and the frequency and intensity of extreme weather events, such as droughts and floods will be determined. The climate change analysis will be carried out at a very high temporal (daily) and spatial (approximately 500 m) resolution until 2050. Several climate scenarios and models will be utilised to reduce future climate uncertainty. The output information will be conveyed to farmers, decision-makers and other stakeholders though dissemination and stakeholders' engagement process described in the 8th phase.

Phase #3: Determination and Projection of Quantitative and Qualitative Status of Water Bodies. Agriculture is strongly interrelated with water systems in terms of abstracting water for irrigation and deteriorating their quality through pollutants' transportation resulting from leaching of used nitrate and phosphate fertilisers. Investigation of the quantitative and qualitative status of the water resources in the study area will be based on detailed satellite data of the "Copernicus" European Earth Observation and Monitoring Programme. In parallel, a hydrological model will be developed to simulate surface water balance and project future quantitative and qualitative status of water resources utilising climate data produced in the previous phase.

Phase #4: Determination and Projection of Agricultural Productivity. Satellite data will be utilised and analysed regarding the type and extent of cultivated crops, while indicators will be developed to determine the functional and morphological crops diversity, such as the Leaf Area Index (LAI), Normalised Difference Vegetation Index (NDVI) and soil moisture content. Then, projections of climate and water availability as produced in the previous two phases will be imported into an agricultural simulation model to simulate future crop yields.

Phase #5: Determination of Ecosystems Conservation Status. An ecological model will be developed to project future ecological status utilising the outcomes of the 2^{nd} and 3^{rd} phases. In parallel, the critical ecosystem characteristics, such as the ecosystems conservation status and their exposure to climate variability will be identified and measured using relevant indicators.

Phase #6: Economic Analysis of Agricultural Activities and Ecosystem Services. A thorough economic analysis will be conducted to assess economic benefits or losses associated with both agricultural activities and ecosystem services. Changes in farmers and other stakeholders' income will be estimated until 2050 in the context of future climate, water and ecosystem conditions as produced in the previous phases.

Phase #7: Development of a Decision Support System for the Economic, Environmental and Social Sustainability of the Rural Area. A Decision Support System (DSS) tool will be developed to facilitate the sustainable development of the study area. The DSS would aim at providing the most optimal development strategies in the short-term (2020-2025), mid-term (2025-2035) and long-term (2035-2050) future periods. The proposed development strategies would be based on the promotion of crops which are both economically profitable for producers, as well as water and climate resilient. The proposed strategies are expected to maintain the high agricultural productivity in the context of the sustainable development of the wider area, in compliance with national and European policies. In particular, the DSS tool will combine the produced results of all the previous phases and produce stakeholders-specific results.

The innovative Decision Support System (DSS) which will be developed within the framework of the project will be composed by six individual tools:

- Database of geographic information.
- Extreme weather events projection database.
- Hydrological model and satellite observations to monitor and project future quantitative and qualitative water status.
- Agricultural model and satellite observations to monitor and project future agricultural production.
- Ecological model to project future ecosystems conservation status.
- Economic model to project future economic assets related to agricultural productivity and ecosystem services provision.

The developed DSS is expected to propose sustainable agricultural practices, based on the promotion of crops which are expected to have a high resistance to future climate and water availability, while being economically profitable for farmers. The DSS will be made available to agriculture-related companies, farmers' groups, Local and General Land

Reclamation Organisations, competent decision- and policy-makers and any other interest groups. The DSS will significantly contribute to highly agricultural productivity maintenance, farmers' income increase and environmental protection, in compliance with national and European policies.

Phase #8: Dissemination of Project' Results and Stakeholders' Engagement. Dissemination activities will be carefully and appropriately considered in a dissemination plan including publication in a journal, announcements in conferences and organisation of workshops and seminars. Stakeholders covering all the different WEF sectors and administrative levels will be engaged to all the phases of the project.

Expected outputs

The main goal of the proposed framework is to deliver, science-based, tailored, comprehensive suggestions for local uses and policy-makers to support and achieve sustainable agricultural practices, protect ecosystems, improve local livelihoods and contribute to economic growth, under changing environmental conditions. Under this context, the following overarching objectives are expected to be fulfilled. Firstly, we target to maintain or even improve agricultural production by promoting resilient farming practices that can withstand future climate and water conditions through the identification of economically profitable crops that are well-suited to changing environmental conditions. Secondly, this work seeks to preserve and even enhance the ecosystem services provided in the agro-tourism areas, taking into account the impacts of climate change. This would involve the protection of the integrity of ecosystems, particularly with regard to the decline in water resources' quantity and quality. Furthermore, we strive to offer solutions that would maintain and even improve the income of local farmers by ensuring the stability of agricultural production and the continued provision of ecosystem services. Additionally, the proposed framework would offer solutions to alleviate the prevailing sense of job insecurity amongst the local population, often linked to the various obstacles encountered in the agricultural sector. By addressing these challenges and implementing resilient farming practices, we could offer a basis for decision-makers and local farmers to benefit from stable and secure employment opportunities under changing conditions.

Discussion and Conclusions

The framework designed under the project "Ensuring Agricultural Production and Ecosystem Services within the context of Climate Change" is in compliance with the main guidelines of Water Directive - Framework 2000/60/EC, Common Agricultural Policy and United Nations Sustainable Development Goals, aiming at agricultural productivity increase, ecosystems preservation and adaptation capacity increase to adapt to the climate crisis. Indeed, the vulnerability of agriculture sector and concerns on food security due to the adverse effects of climate change, highlight the urgent need for measures to mitigate these risks.

In addition, the framework also aligns with the European rural development guidelines and policies, supporting the objectives of Common Agricultural Policy and “Green Deal” in terms of agricultural production enhancement and social cohesion improvement under climate change. Considering the decline trends in the primary and secondary sectors in the study area which may be further exacerbated by the impacts of climate change on water resources, the design and application of the necessary actions to adapt to changing climate conditions and safeguarding water resources, could offer a solid basis for supporting the sustainability of agricultural activity at a local and regional level. As a final note, the proposed framework under the project "Ensuring Agricultural Production and Ecosystem Services within the context of Climate Change" seeks to also support the Habitats and Birds Directives (92/43/EEC & 2009/147/EC), the new EU Biodiversity Strategy (COM/2020/380) and the Green Infrastructure Strategy [COM(2013)249]. This will be achieved by highlighting ecological and environmental assets and integrating them into the DDS process, with expected outcomes on social and economic benefits paying full respect to biodiversity conservation policies, targets and principles.

Funding program

This research was carried out as part of the project «Supporting Agricultural Production and Ecosystems Services under the prism of Climate Change» (Project code: KMP6-0219951) under the framework of the Action «Investment Plans of Innovation» of the Operational Programme «Central Macedonia 2014-2020», that is co-funded by the European Regional Development Fund and Greece.

Hosting institution

Department of Ecology, School of Biology, Aristotle University of Thessaloniki, 54636 Thessaloniki, Greece; Malliaras A. – Karalis A. Company, Polytechneiou Kefallinias St., 62125 Serres, Greece; Theocharis Nikolaos Company, Georgiou Papandreou St. No. 7, 62125 Serres, Greece; Michos Christodoulos Company, Kilkis St. No. 24, 62100 Serres, Greece.

Conflicts of interest

The authors have declared that no competing interests exist.

References

- Andrew J, Sauquet E (2017) Climate Change Impacts and Water Management Adaptation in Two Mediterranean-Climate Watersheds: Learning from the Durance and Sacramento Rivers. Water 9 (2): 126. https://doi.org/10.3390/w9020126

- De Vrees R, Dumitru A, Eiter S, Jones L, Wendling L, Zandersen M, Pilla F (2021) Evaluating the Impact of Nature-based Solutions: Appendix of Methods. European Commission https://doi.org/10.13140/rg.2.2.30051.27684
- Ferragina E, Canitano G (2015) Geopolitical Implications of Water and Food Security in Southern and Eastern Mediterranean Countries. In: Paciello MC (Ed.) Building Sustainable Agriculture for Food Security in the Euro Mediterranean Area: Challenges and Policy Options. Edizioni Nuova Cultura for Istituto Affari Internazionali (IAI), Rome, Italy, 33-56 pp.
- Garrote L, Iglesias A, Granados A, Mediero L, Martin-Carrasco F (2015) Quantitative Assessment of Climate Change Vulnerability of Irrigation Demands in Mediterranean Europe. Water Resources Management 29 (2): 325-338. https://doi.org/10.1007/s11269-014-0736-6
- Godfray HCJ, Garnett T (2014) Food security and sustainable intensification. Philosophical Transactions of the Royal Society B: Biological Sciences 369 (1639). https://doi.org/10.1098/rstb.2012.0273
- Intergovernmental Panel on Climate Change (IPCC) (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of IPCC. Cambridge University Press, Cambridge, U.K., 1132 pp.
- Kundzewicz ZW, Döll P (2009) Will groundwater ease freshwater stress under climate change? Hydrological Sciences Journal 54 (4): 665-675. https://doi.org/10.1623/hysj.54.4.665
- Mancosu N, Snyder R, Kyriakakis G, Spano D (2015) Water Scarcity and Future Challenges for Food Production. Water 7 (3): 975-992. https://doi.org/10.3390/w7030975
- Masia S, Sušnik J, Marras S, Mereu S, Spano D, Trabucco A (2018) Assessment of Irrigated Agriculture Vulnerability under Climate Change in Southern Italy. Water 10 (2): 209. https://doi.org/10.3390/w10020209
- Munaweera TIK, Jayawardana NU, Rajaratnam R, Dissanayake N (2022) Modern plant biotechnology as a strategy in addressing climate change and attaining food security. Agriculture & Food Security 11 (1): 1-28. https://doi.org/10.1186/s40066-022-00369-2
- Ray D, West P, Clark M, Gerber J, Prishchepov A, Chatterjee S (2019) Climate change has likely already affected global food production. PloS one 14 (5). https://doi.org/10.1371/journal.pone.0217148
- Schipanski M, Barbercheck M, Douglas M, Finney D, Haider K, Kaye J, Kemanian A, Mortensen D, Ryan M, Tooker J, White C (2014) A framework for evaluating ecosystem services provided by cover crops in agroecosystems. Agricultural Systems 125: 12-22. https://doi.org/10.1016/j.agsy.2013.11.004
- Schmidt N, Zinkernagel J (2017) Model and Growth Stage Based Variability of the Irrigation Demand of Onion Crops with Predicted Climate Change. Water 9 (9): 693. https://doi.org/10.3390/w9090693
- Tanasijevic L, Todorovic M, Pereira L, Pizzigalli C, Lionello P (2014) Impacts of climate change on olive crop evapotranspiration and irrigation requirements in the Mediterranean region. Agricultural Water Management 144: 54-68. https://doi.org/10.1016/j.agwat.2014.05.019
- Taylor R, Scanlon B, Döll P, Rodell M, van Beek R, Wada Y, Longuevergne L, Leblanc M, Famiglietti J, Edmunds M, Konikow L, Green T, Chen J, Taniguchi M, Bierkens MP,

MacDonald A, Fan Y, Maxwell R, Yechieli Y, Gurdak J, Allen D, Shamsudduha M, Hiscock K, Yeh P-, Holman I, Treidel H (2013) Ground water and climate change. Nature Climate Change 3 (4): 322-329. https://doi.org/10.1038/nclimate1744

- Varela-Ortega C, Blanco-Gutiérrez I, Esteve P, Bharwani S, Fronzek S, Downing T (2016) How can irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain. Regional Environmental Change 16 (1): 59-70. https://doi.org/10.1007/s10113-014-0720-y
- Vargas-Amelin E, Pindado P (2014) The challenge of climate change in Spain: Water resources, agriculture and land. Journal of Hydrology 518: 243-249. https://doi.org/10.1016/j.jhydrol.2013.11.035
- Verkerk P, Sánchez A, Libbrecht S, Broekman A, Bruggeman A, Daly-Hassen H, Giannakis E, Jebari S, Kok K, Krivograd Klemenčič A, Magjar M, Martinez de Arano I, Robert N, Smolar-Žvanut N, Varela E, Zoumides C (2017) A Participatory Approach for Adapting River Basins to Climate Change. Water 9 (12): 958. https://doi.org/10.3390/w9120958