ECWS-7 2023

water

MDPI

The 7th International Electronic Conference on Water Sciences

15–30 MARCH 2023 | ONLINE

Water and Nitrogen Use and Agricultural Production Efficiency under Climate Change in a Mediterranean Coastal Watershed

Aikaterini Lyra[1], Athanasios Loukas[2]

[1] Laboratory of Hydrology and Aquatic Systems Analysis, Department of Civil Engineering, School of Engineering, University of Thessaly

[2] Laboratory of Hydraulic Works and Environmental Management, School of Rural and Surveying Engineering, Aristotle University of Thessaloniki

Problem:

Coastal aquifer systems nowadays present an **ever-declining water quantity and quality degradation** as they are intensively used for irrigation purposes.

Problem:

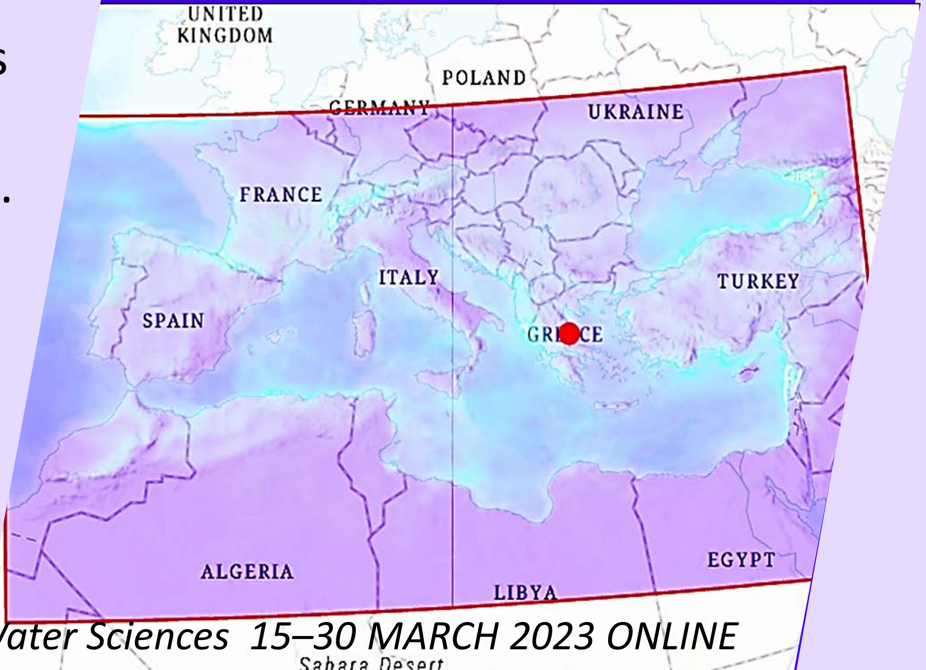
Coastal aquifer systems nowadays present an **ever-declining water quantity and quality degradation** as they are intensively used for irrigation purposes.

Where:

In **arid and semi-areas** like the **Mediterranean basin** where fertile soils and favorable climatic conditions host the **productivity** of the agricultural and food sectors.

Why:

Climate change will have a greater impact on the water resources of the Mediterranean areas, and it will alter the water cycle's temporal and geographical distribution.



ac

S

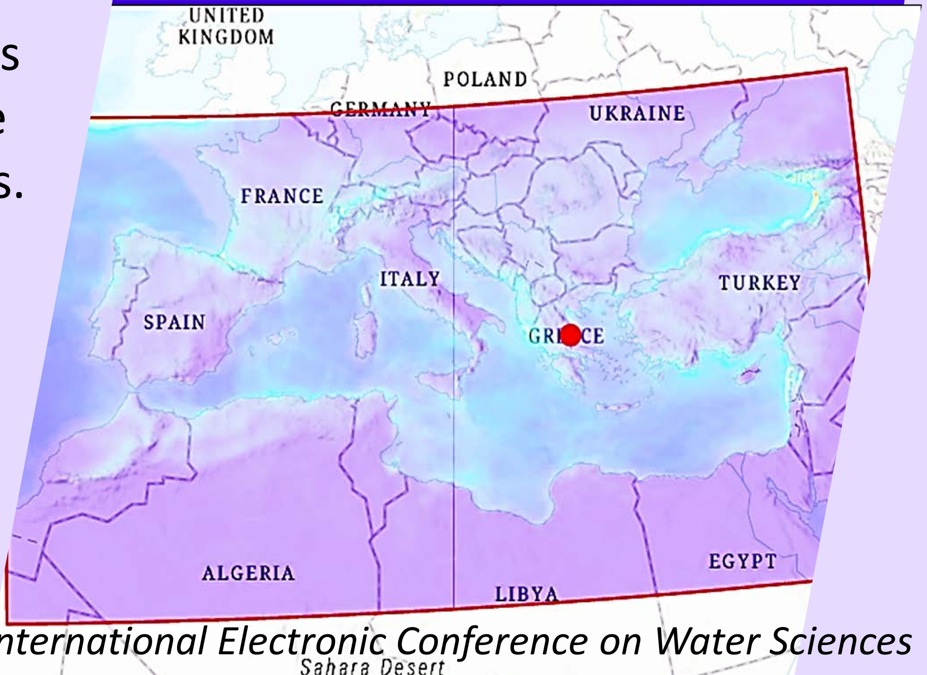
ar

Where:

In **arid and semi-areas** like the **Mediterranean basin** where fertile soils and favorable climatic conditions host the **productivity** of the agricultural and food sectors.

Why:

Climate change will have a greater impact on the water resources of the Mediterranean areas, and it will alter the water cycle's temporal and geographical distribution.

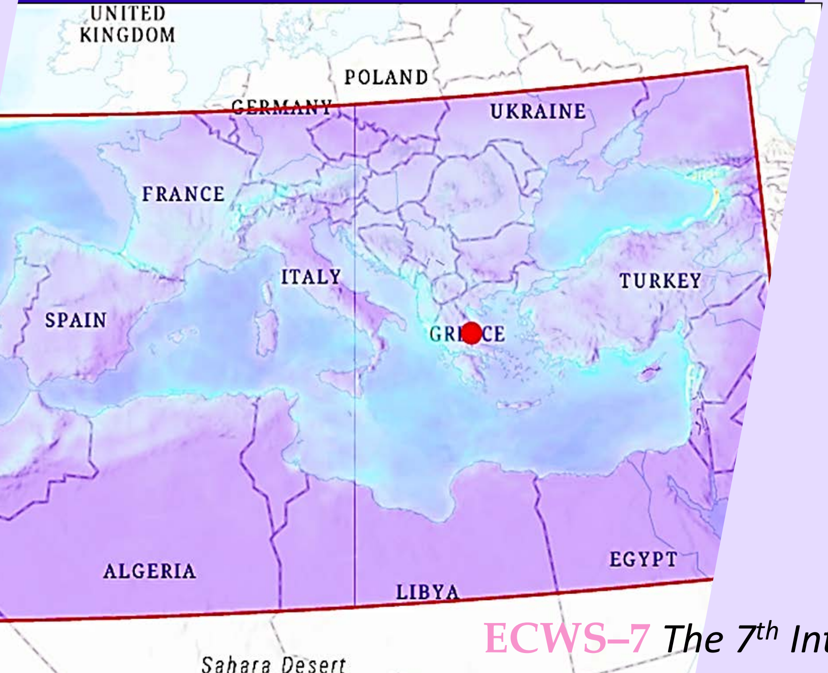


Hazards:

Water scarcity will be advanced in intensity and magnitude while crop yields are expected to decline.
Seawater intrusion is an area of concern for water resources in irrigated agriculture.

Why:

Climate change will have a greater impact on the water resources of the Mediterranean areas, and it will alter the water cycle's temporal and geographical distribution.



Hazards:

Water scarcity will be advanced in intensity and magnitude while crop yields are expected to decline.
Seawater intrusion is an area of concern for water resources in irrigated agriculture.

Approach:

Examine the potential effects of climatic change in coastal arable watersheds.

In coastal watersheds where agriculture is the main economic activity

In coastal watersheds where agriculture is the main economic activity

Water Resources' Hazards Stem From

- Absence of water storage works
- Large amounts of fertilizers to maximize Yields
- Large amounts of groundwater abstractions
- Seawater Intrusion
- Irrigation with salinized water
- Physiological drought to crops

Impacts on crop productivity

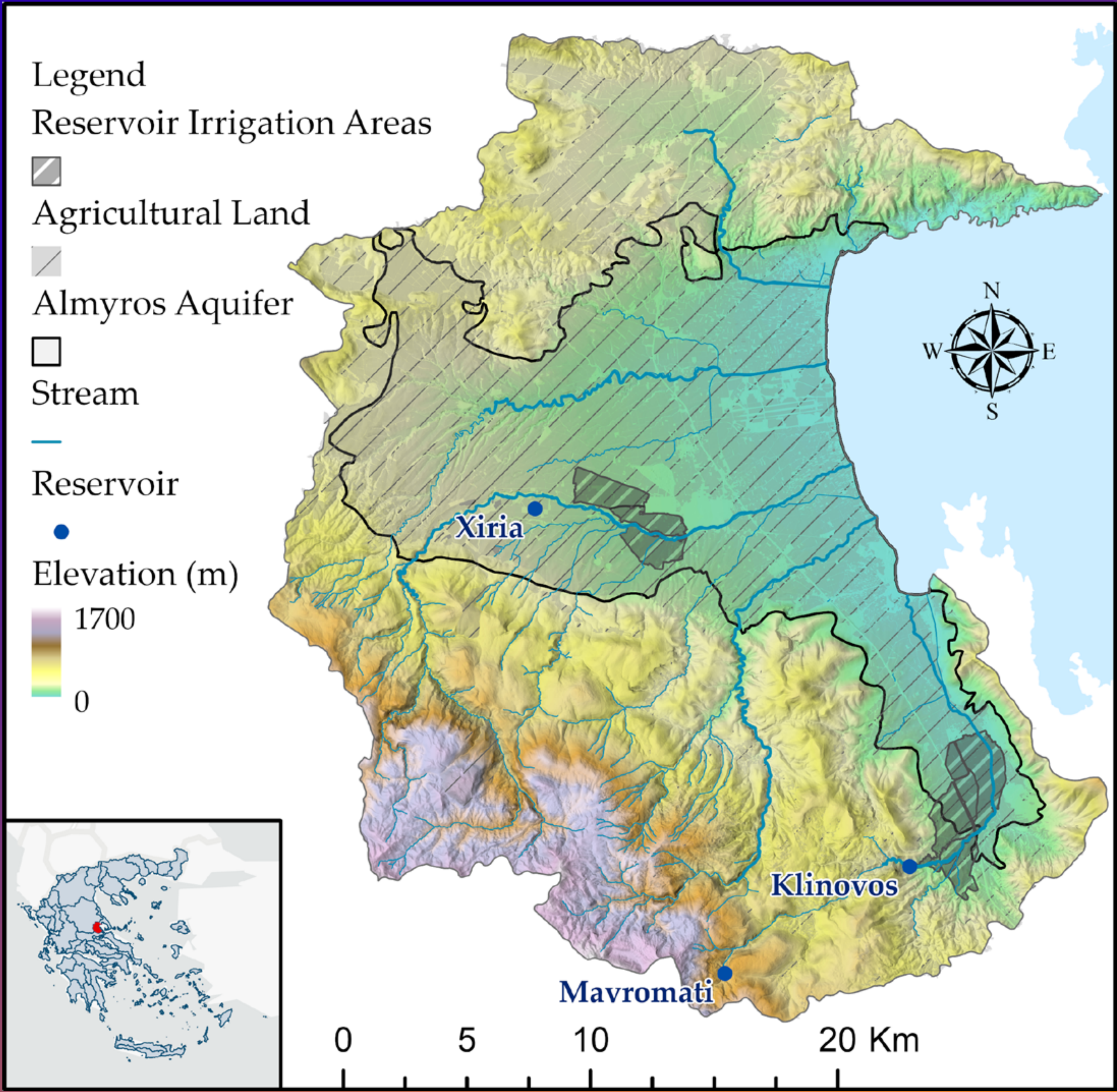
Impacts on water productivity

Materials and Methods
STUDY AREA:
ALMYROS BASIN, CENTRAL GREECE.

- Almyros basin is an agricultural coastal basin located in Central Greece

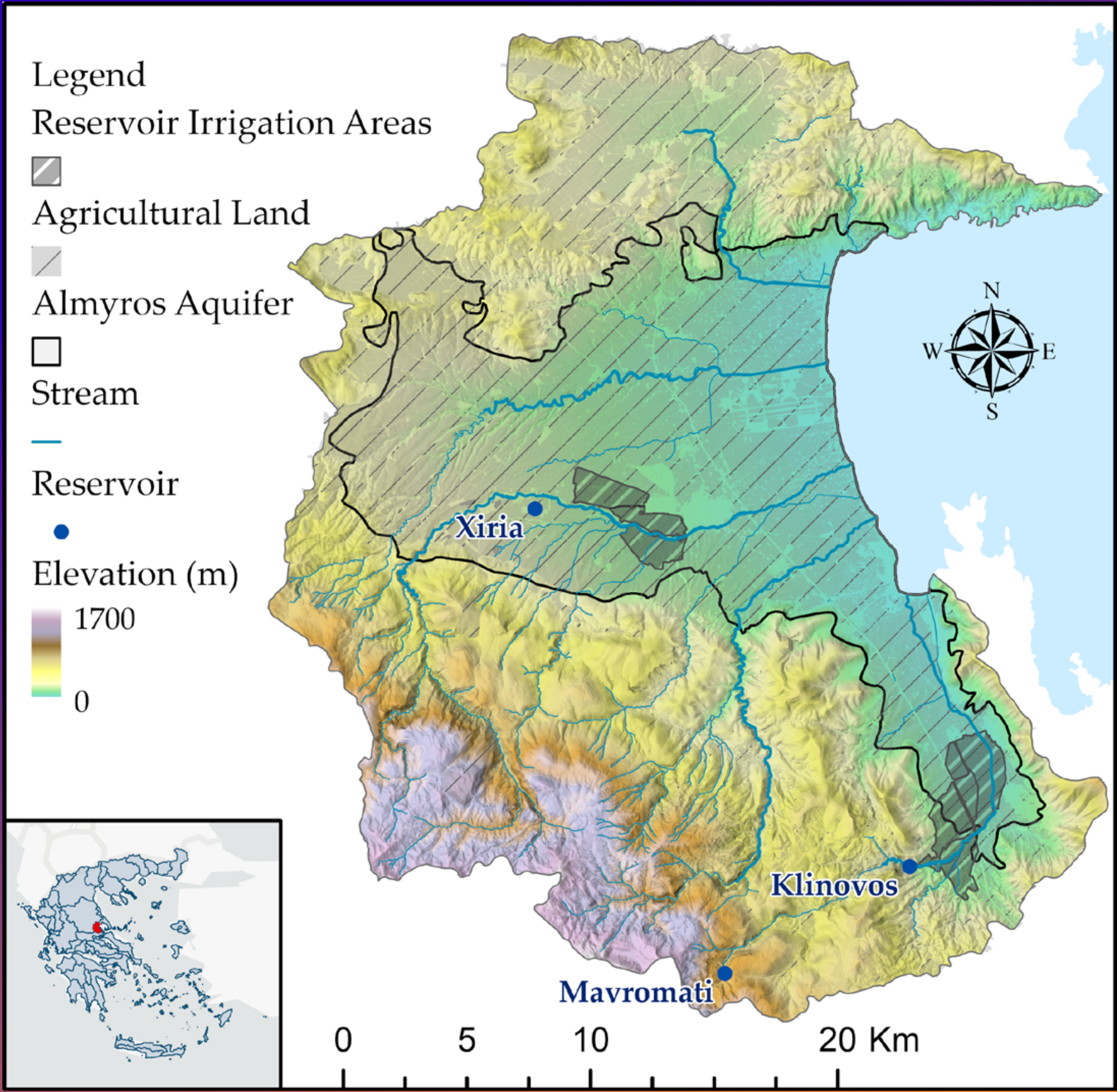
STUDY AREA: ALMYROS BASIN, CENTRAL GREECE.

- Almyros basin is an agricultural coastal basin located in Central Greece
- The hydrology of the region is described by streams with intermittent flows and semiarid climatic conditions
- Wheat, alfalfa, cereals are the main cultivars while cotton, olives trees, maize, vegetables, orchards, vineyards are also cultivated
- The groundwater in the study basin has been seriously affected and polluted by contaminants from nitrogen leachates and chloride ions from saltwater intrusion



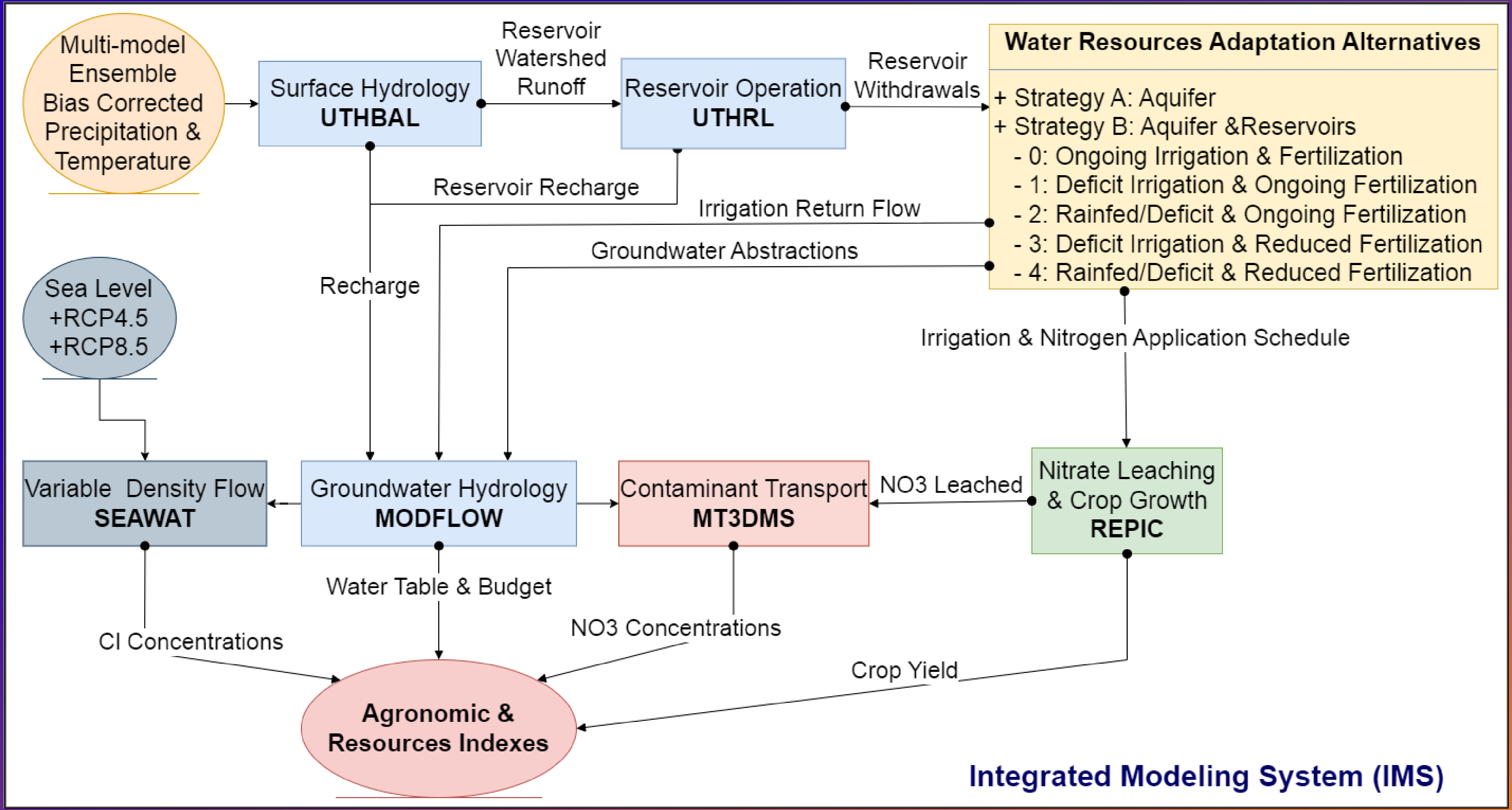
STUDY AREA: ALMYROS BASIN, CENTRAL GREECE.

- Recently, an urban water supply reservoir, the **Mavromati** reservoir, has been built
- an irrigation water supply reservoir, the **Xirias** reservoir is under construction
- a greater irrigation water reservoir has been studied, the **Klinovos** reservoir



Climate change and Integrated Modelling System

Climate change and Integrated Modelling System


Multi-model Ensemble Bias Corrected Precipitation & Temperature
Surface Hydrology
UTHBAL
Reservoir Watershed Runoff
Reservoir Operation
UTHRL
Reservoir Withdrawals
Water Resources Adaptation Alternatives
+ Strategy A: Aquifer
+ Strategy B: Aquifer &Reservoirs
- 0: Ongoing Irrigation & Fertilization
- 1: Deficit Irrigation & Ongoing Fertilization
- 2: Rainfed/Deficit & Ongoing Fertilization
- 3: Deficit Irrigation & Reduced Fertilization
- 4: Rainfed/Deficit & Reduced Fertilization
Reservoir Recharge
Irrigation Return Flow
Groundwater Abstractions
Sea Level
+RCP4.5
+RCP8.5
Recharge
Irrigation & Nitrogen Application Schedule
Variable Density Flow
SEAWAT
Groundwater Hydrology
MODFLOW
Contaminant Transport
MT3DMS
NO3 Leached
Nitrate Leaching & Crop Growth
REPIC
Water Table & Budget
Cl Concentrations
NO3 Concentrations
Crop Yield
Agronomic & Resources Indexes
Integrated Modeling System (IMS)

Water resources and agronomic/crop scenarios and strategies

Water resources and agronomic/crop scenarios and strategies

Strategy A0

BASELINE HISTORICAL STRATEGY

- only groundwater is used for irrigation/urban water supply
- historical irrigation and nutrient practices

Strategy B0

WATER RESERVOIRS STRATEGY

- surface water reservoirs developed and used along with groundwater abstractions for irrigation/urban water supply
- historical irrigation and nutrient practices

Strategy A1

- only groundwater is used for irrigation/urban water supply
- **deficit irrigation and historical nutrient practices**

Strategy B1

- surface water reservoirs have been developed and used along with groundwater abstractions for irrigation/urban water supply
- **deficit irrigation and historical nutrient practices**

Strategy A2

- only groundwater is used for irrigation/urban water supply
- **rainfed agriculture and historical nutrient practices**

Strategy B2

- surface water reservoirs have been developed and used along with groundwater abstractions for irrigation/urban water supply
- **rainfed agriculture and historical nutrient practices**

Strategy A3

- only groundwater is used for irrigation/urban water supply
- **deficit irrigation and reduced nutrient practices**

Strategy B3

- surface water reservoirs have been developed and used along with groundwater abstractions for irrigation/urban water supply
- **deficit irrigation and reduced nutrient practices**

Strategy A4

- only groundwater is used for irrigation/urban water supply
- **deficit irrigation and rainfed agriculture and reduced fertilization**

Strategy B4

- surface water reservoirs have been developed and used along with groundwater abstractions for irrigation/urban water supply
- **deficit irrigation and rainfed agriculture and reduced fertilization**

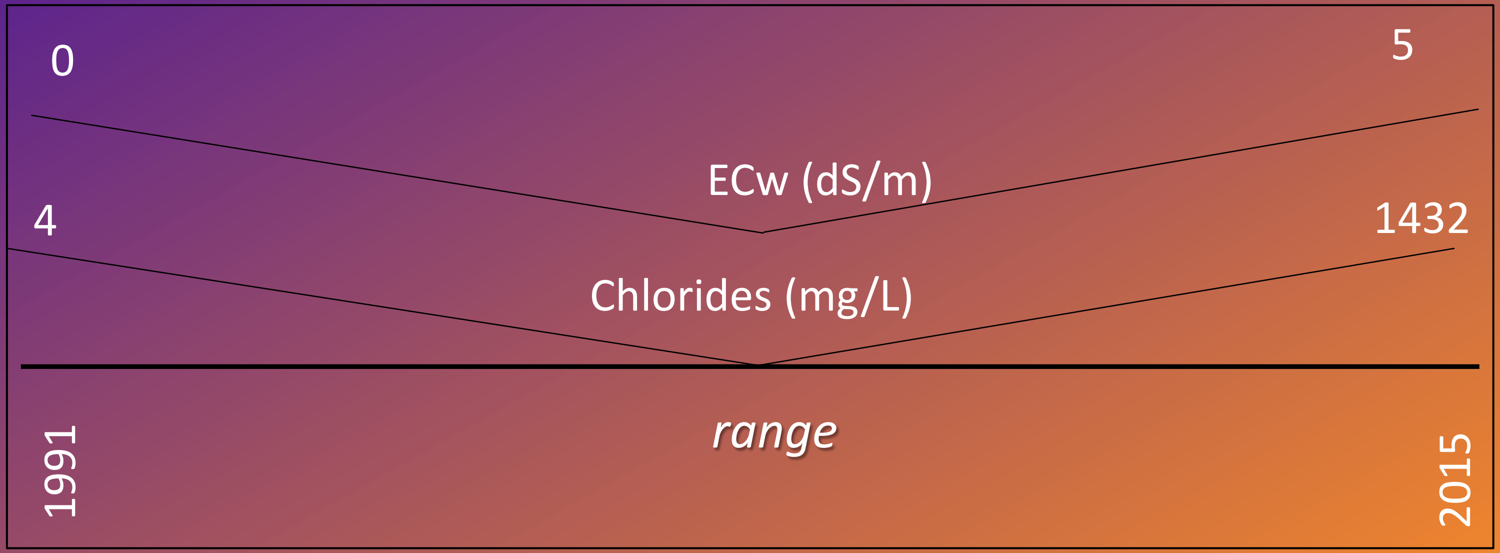
Salinity, Chlorides concentration, and Crop Yield

Salinity, Chlorides concentration, and Crop Yield

After reaching a maximum tolerance level, the crop output decreases in an idealized simple linear trend.

Salinity, Chlorides concentration, and Crop Yield

- In order to take into account, the saline implications of the seawater intrusion on agricultural output, the crop yields are adjusted using a **relative percentage of yield performance**.
- Electrical Conductivity and chlorides concentrations observations performed by various public and private organizations and former studies span from 1991 to 2015.



Agronomic Indices

$$Crop\ Water\ Productivity\ (CWP_I) = \frac{Crop\ Yield\ kg\ ha^{-1}}{Irrigation\ Water\ \ m^3 ha^{-1}}$$

$$Economic\ Water\ Productivity\ (EWP_I) = \frac{Profit\ \text{EUR}\ \ ha^{-1}}{Irrigation\ Water\ \ m^3 ha^{-1}}$$

$$Nitrogen\ Use\ Efficiency\ \ (NUE) = \frac{Crop\ Yield\ (kg\ ha^{-1})}{Nitrogen\ Applied\ (kg\ ha^{-1})}$$

Standardized Chloride Hazard Index (SCHI)

$$SCHI = (Cl_i - \overline{Cl})/\sigma_{Cl}$$

Application—Results

Salinity impacts on Crop Yield

Based on relevant measurements, it was possible to configure useful information for the relationship of chloride concentrations and electrical conductivity in the Almyros aquifer system.

$$EC_w(dS/m) = 0.0032 \cdot Cl_w\,(mg/L) + 0.6212 \quad (R^2 = 0.9)$$

$$Cl_w\,(mg/L) = 272.32 \cdot EC_w(dS/m) - 159.17 \quad (R^2 = 0.9)$$

Classification of the Standardized Chloride Hazard Index (SCHI) with regard to the salinity hazards.

SCH_W Index	Hazard
<–1.2	Low with normal yields
–1.2 : –0.9	Low moderate with yield decrease of sensitive crops
–0.9 : –0.1	Moderate with yield decrease of crops
–0.1 : 0.7	High with yield for tolerant crops
>1.5	Extremely high with yield for tolerant crops

Application—Results

Salinity impacts on Crop Yield

Crop production would be reduced under historical irrigation practices regardless of the development of surface water reserves by –0.3% in RCPs 4.5 and 8.5 in 2019–2050 due irrigation groundwater salinity.

The implementation of deficit and rainfed agriculture has a stronger positive influence on the decrease of salinization and thus, the contribution of the alteration of agronomic practices is evident with a 0.3% gain in productivity in 2019–2050.

However, rainfed agriculture is more efficient to maintain and increase the crop production in 2051–2100 since it is not affected by the operation of reservoirs and cessation of groundwater abstractions, and groundwater salinity.

Relative Yield changes of the future periods from the historical period for the water resources and agronomic scenarios for both RCPs (4.5 and 8.5).

Strategy	2019–2050	2051–2100
A0	–0.3%	–14.8%
A1/A3	0.30%	–0.4%
A2/A4	0.30%	0.40%
B0	–0.3%	–10.9%
B1/B3	0.30%	–0.7%
B2/B4	0.30%	0.40%

Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

Application—Results

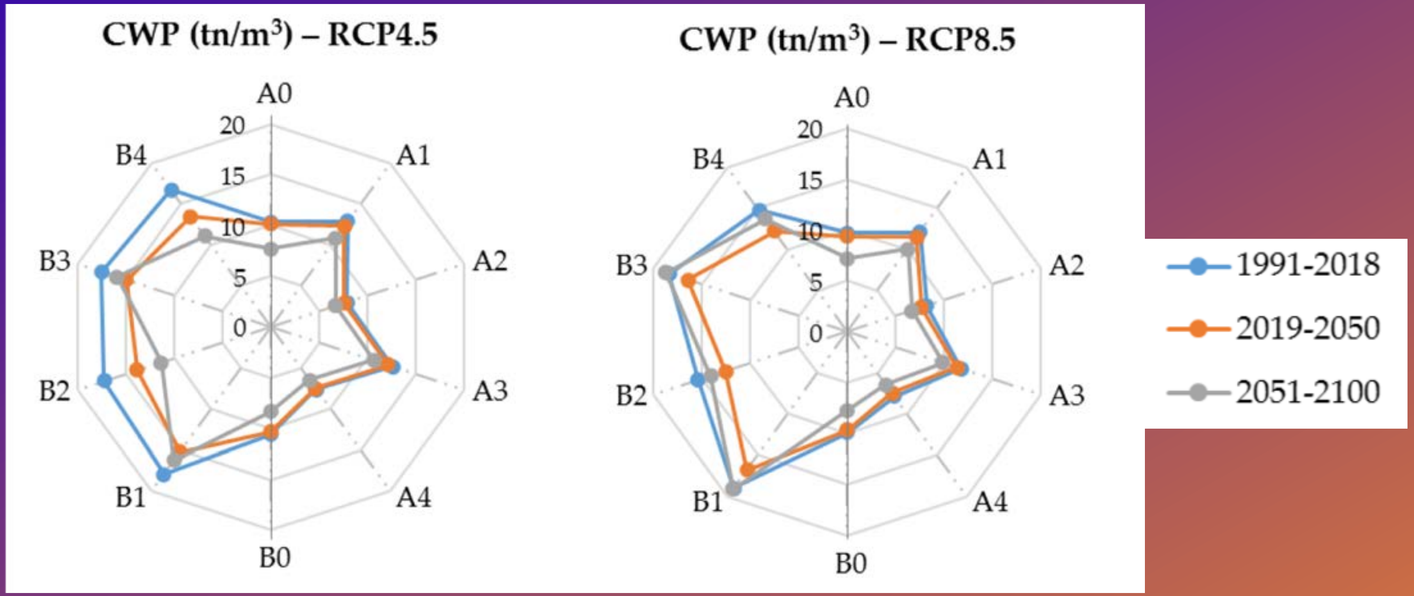
Agronomic efficiency indices and water resources adaptation for seawater intrusion

1. The agronomic efficiency indices and the water resources adaptation index for seawater intrusion have been estimated and summarized for the time periods of 1991–2018, 2019–2050, and 2051–2100.
2. The SCHI index has been calculated based on the results of the Integrated Modelling System(IMS) and especially the SEAWAT model.
3. The agronomic indices have been calculated based on simulations by the Integrated Modelling System(IMS). Crop yields are calculated by the REPIC model and the groundwater abstractions and quality by the MODFLOW and SEAWAT models.

Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

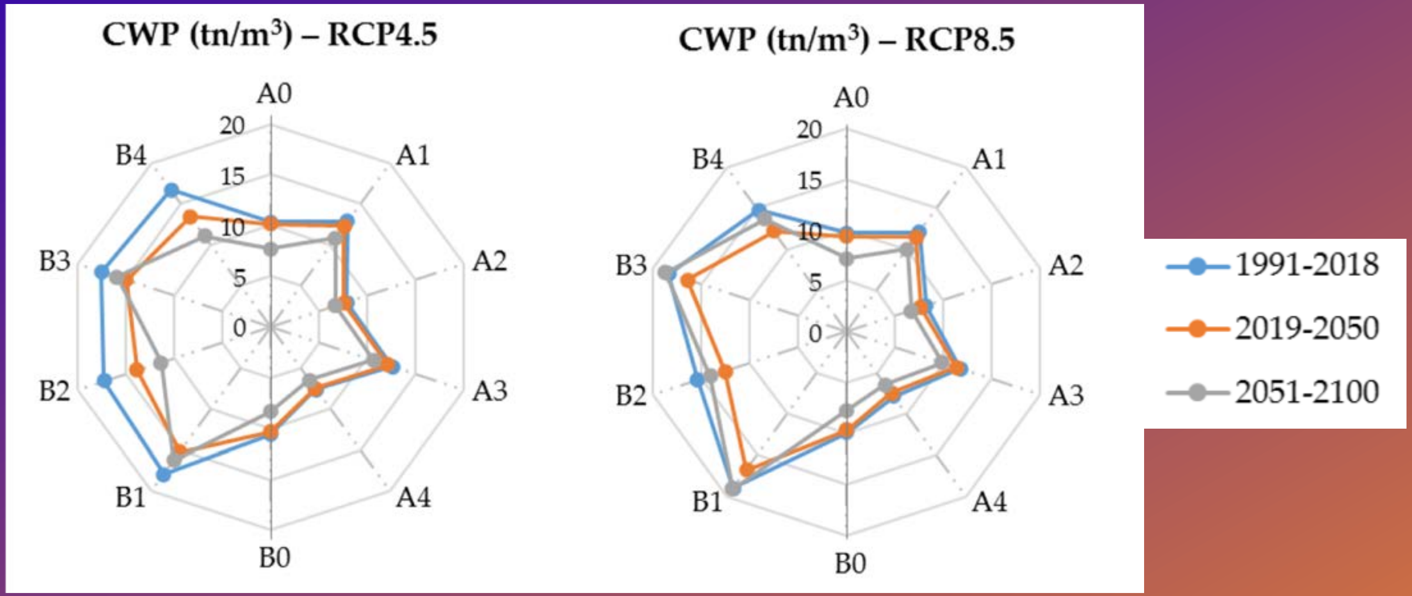
CWP weighted averaged values range from 6.4 tn/m^3 to 19.4 tn/m^3 in RCP8.5, and from 6.5tn/m^3 to 17.1 tn/m^3 in RCP4.5.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

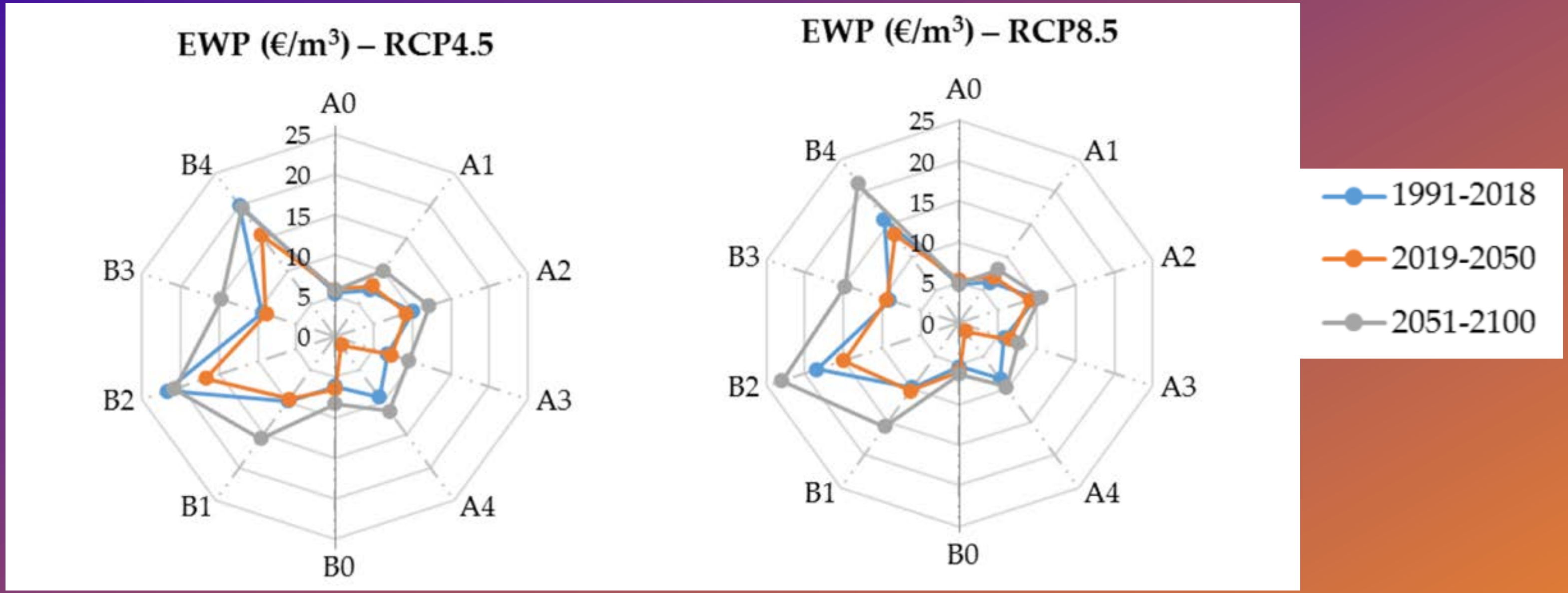
CWP variations are approximately 3 to 4 tn/m^3 between deficit irrigation and rainfed agriculture/deficit irrigation practices.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

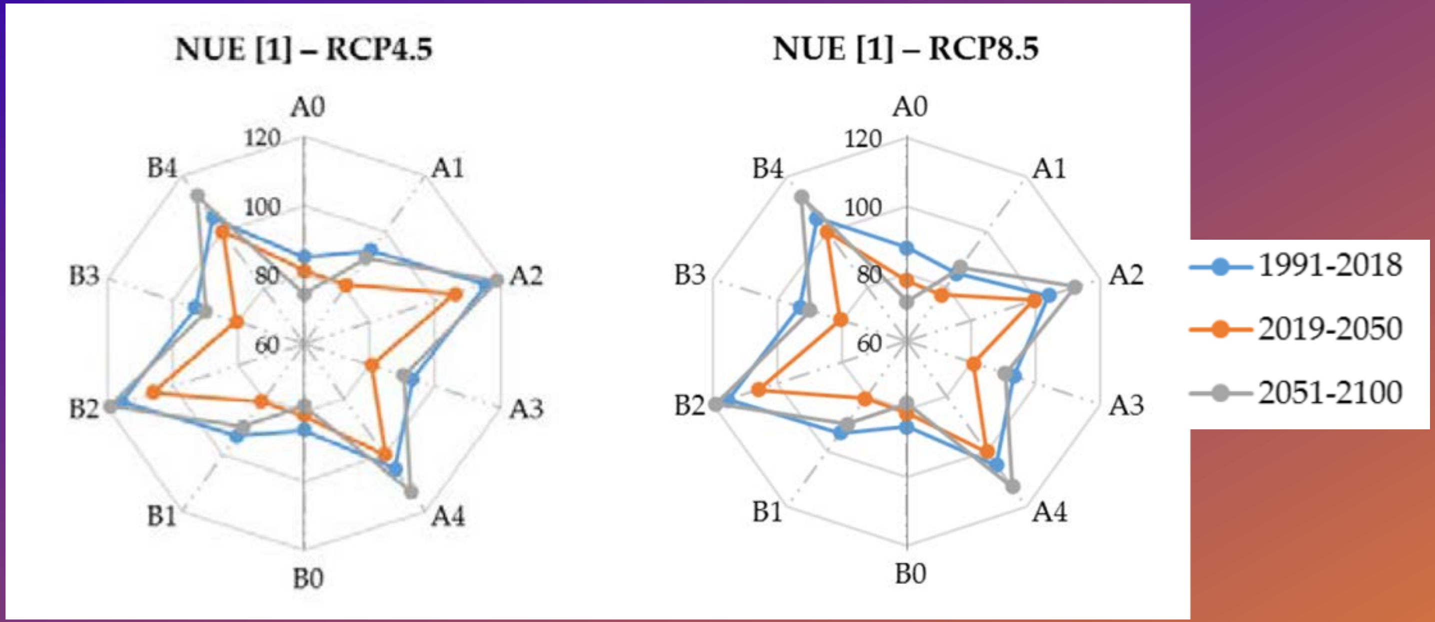
Commodity prices, for use in the EWP index of the crop pattern, were estimated on a weighted spatial average of 0.33 €/kg crop yield in 1991–2018, 0.49 €/kg in 2019–2050, and 0.65 €/kg in 2051–2100.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

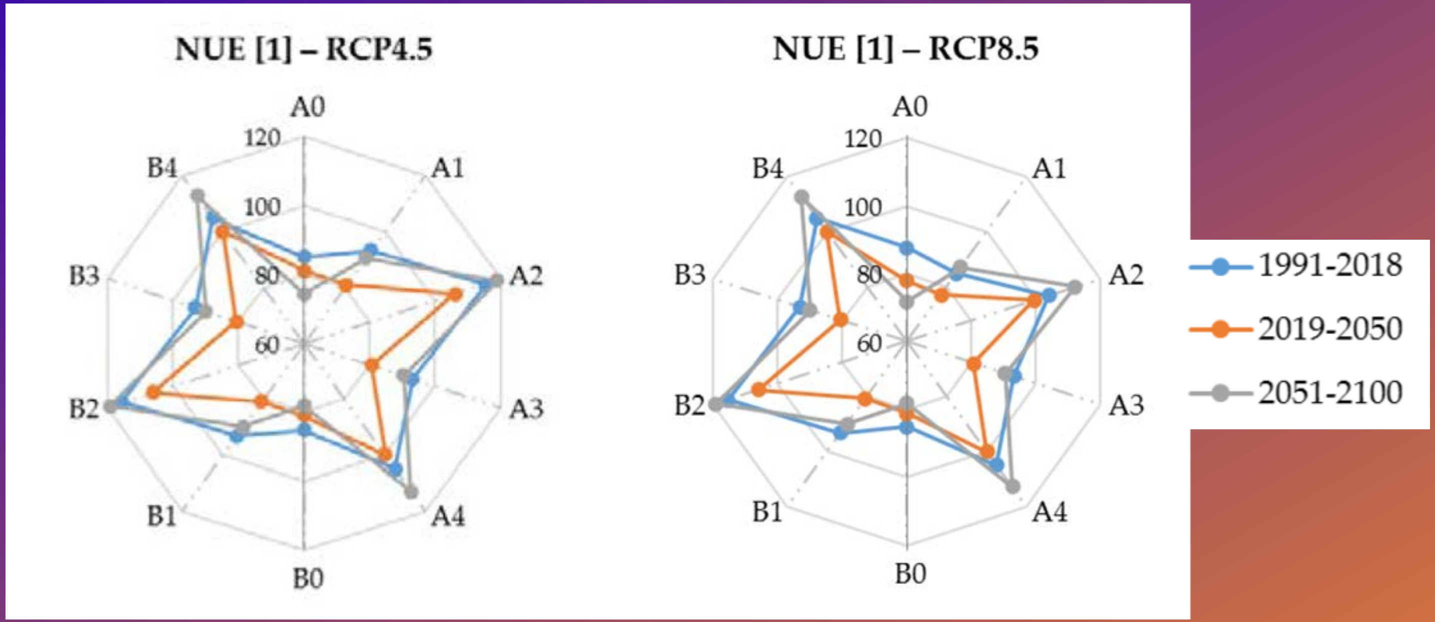
NUE index scores show a declining trend in ongoing fertilizer practices until 2100 in both Strategies and RCPs.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

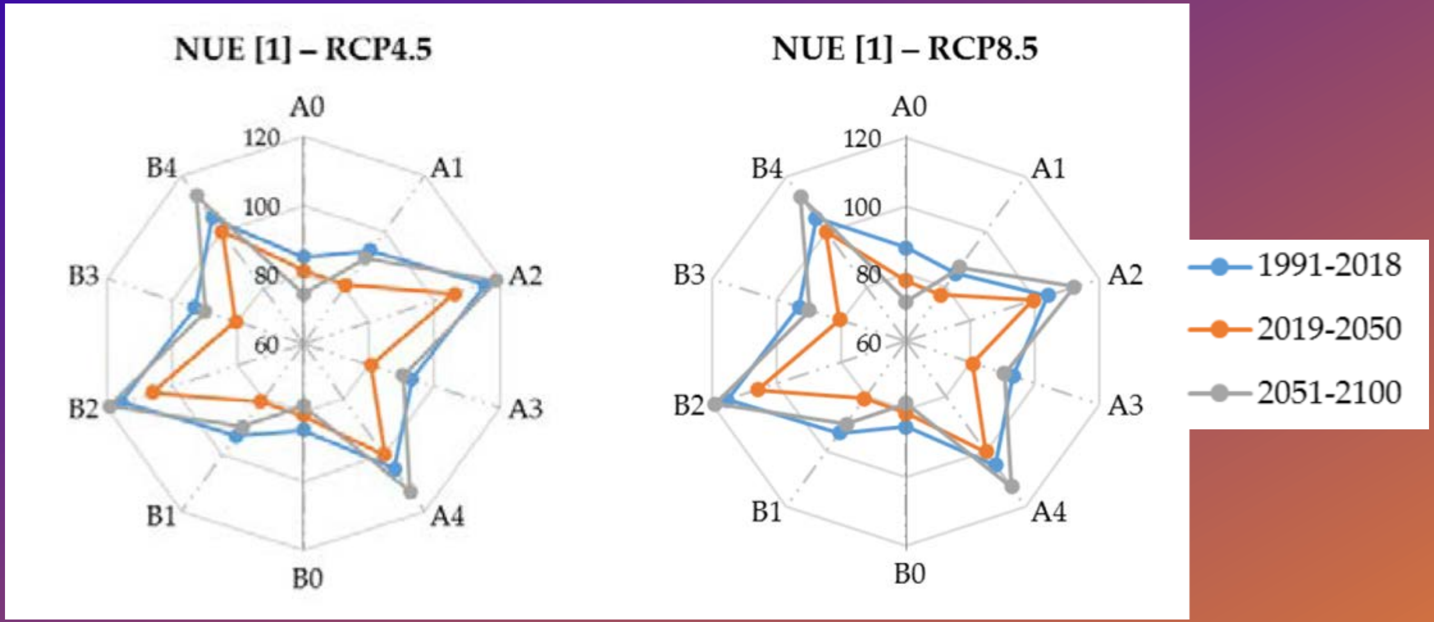
NUE values in deficit irrigation and rainfed agriculture/deficit irrigation form a V–shaped evolution with the lowest points to show in 2019–2050 in both Strategies and RCPs.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

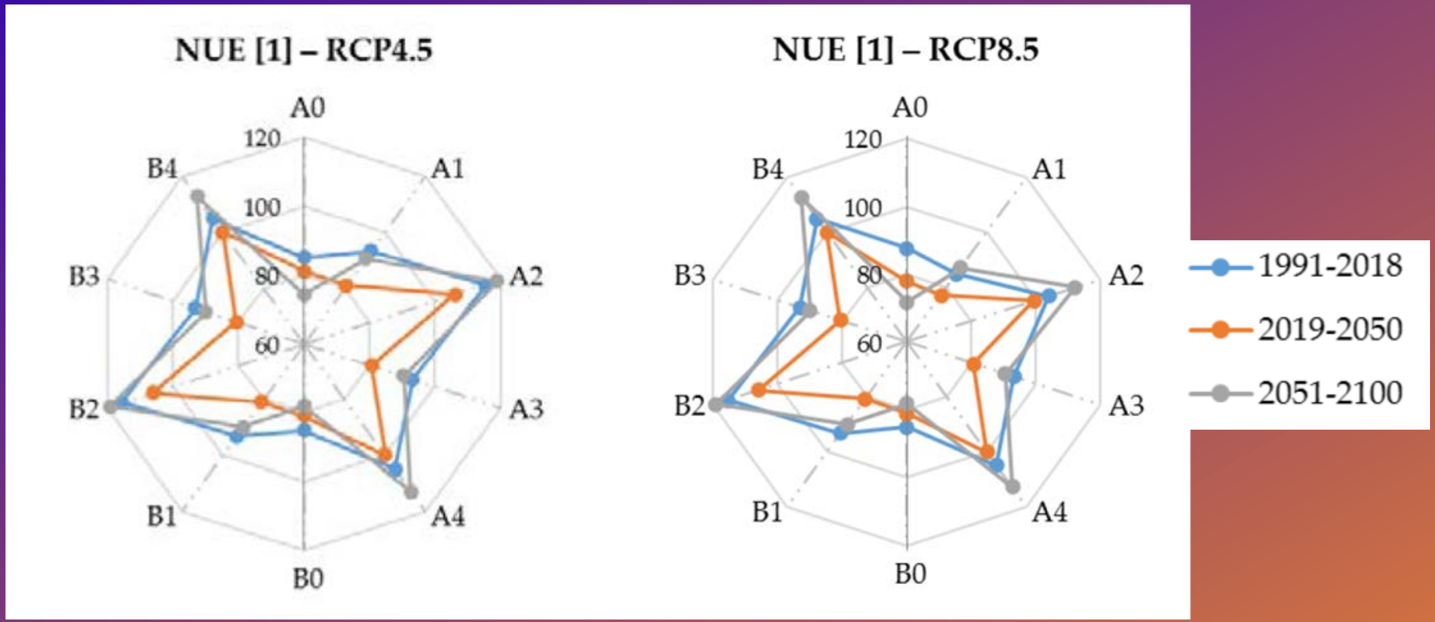
NUE maximizes under the alternative practice of reduced fertilization in both Strategies and RCPs.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

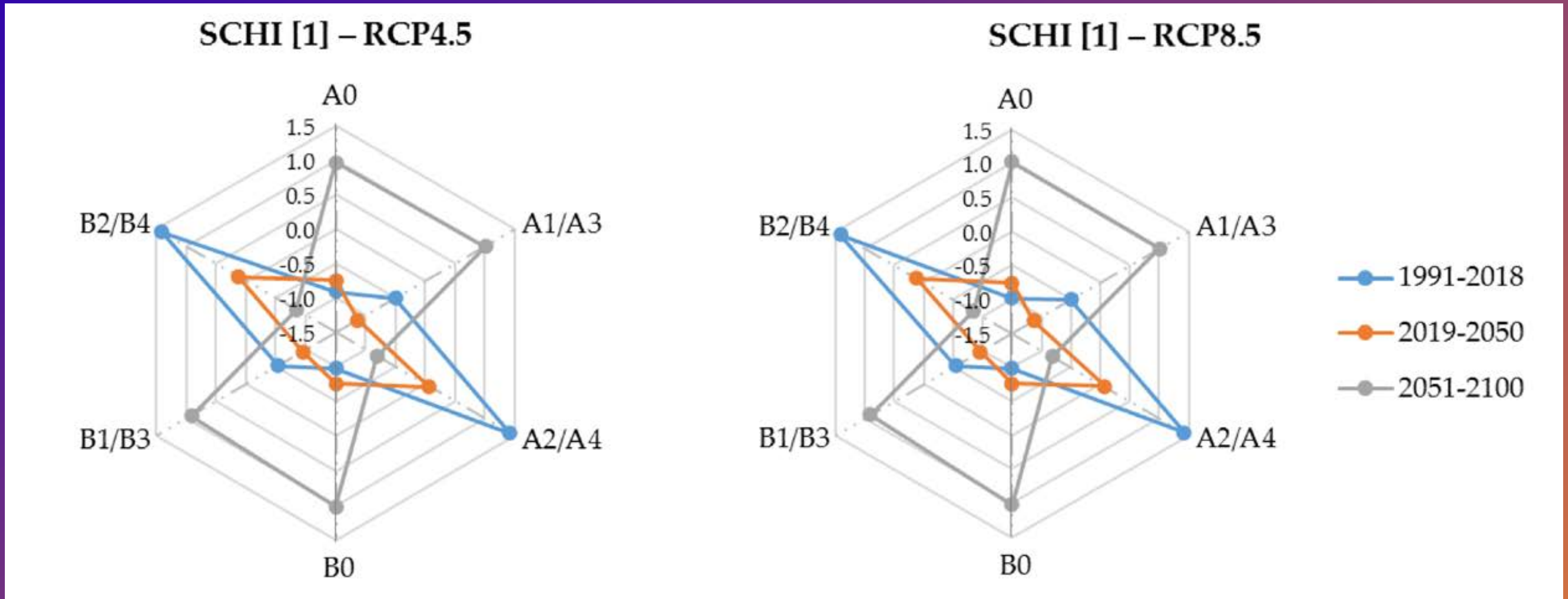
In reduced fertilization NUE gets scores higher than 100 kg of crop yield per kg nitrogen applied, while in other alternatives the values range from 71.2 kg yield/kg nitrogen to 93.2 kg yield/kg nitrogen



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

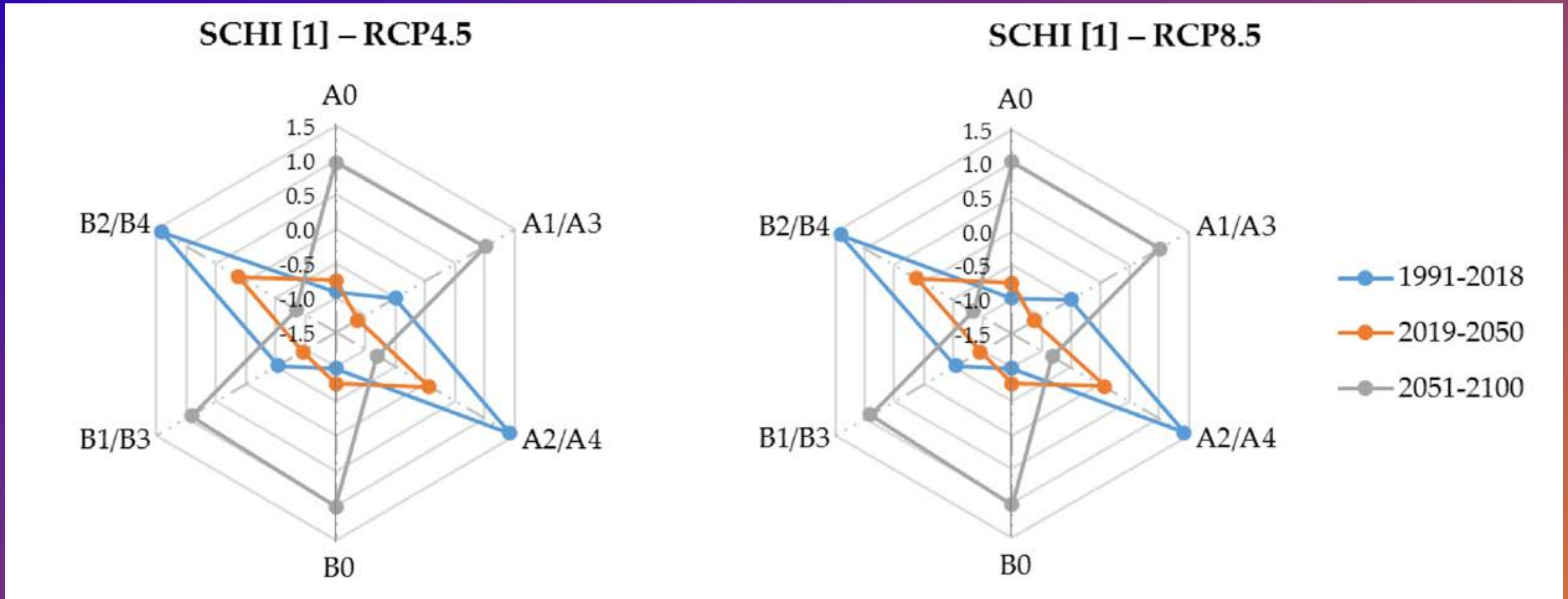
SCHI index scores range for all scenarios and time periods



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

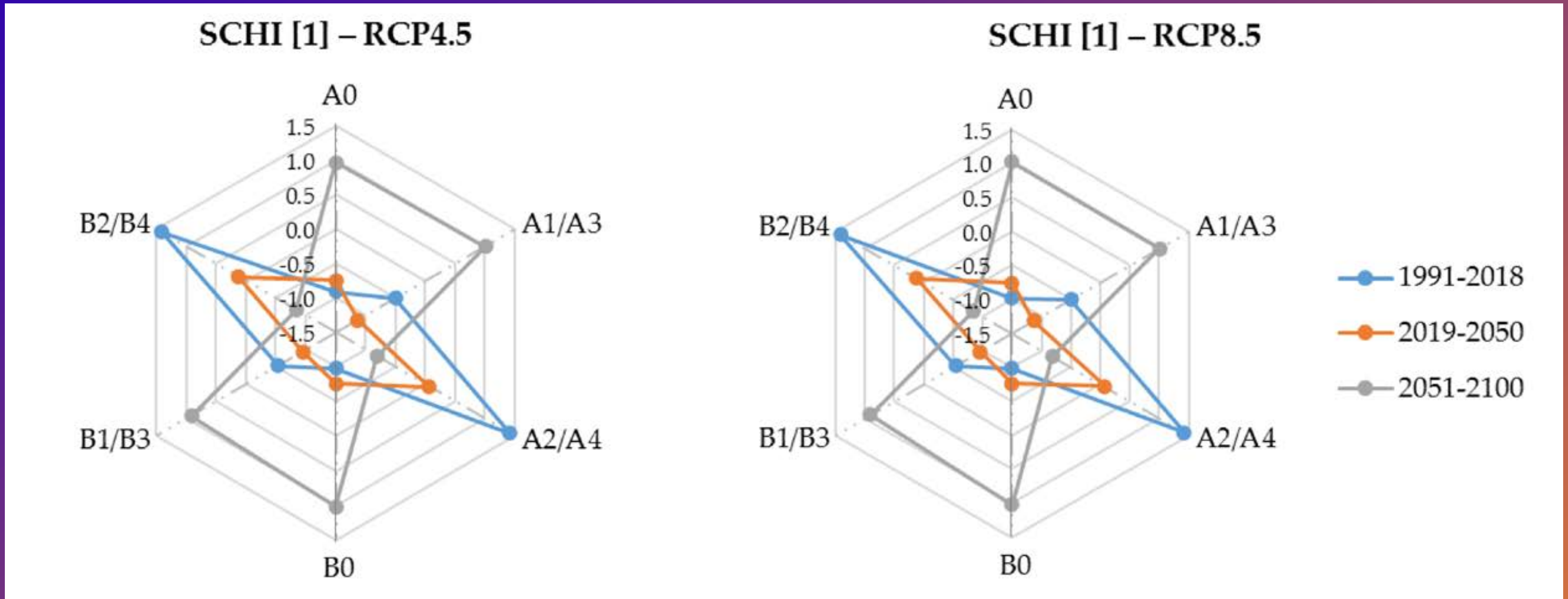
from low salinity hazard, –1.14, in the historical period, to almost extremely high salinity hazard, 1.42 in the future period, proving the downgrading of the groundwater from non–saline to very saline.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

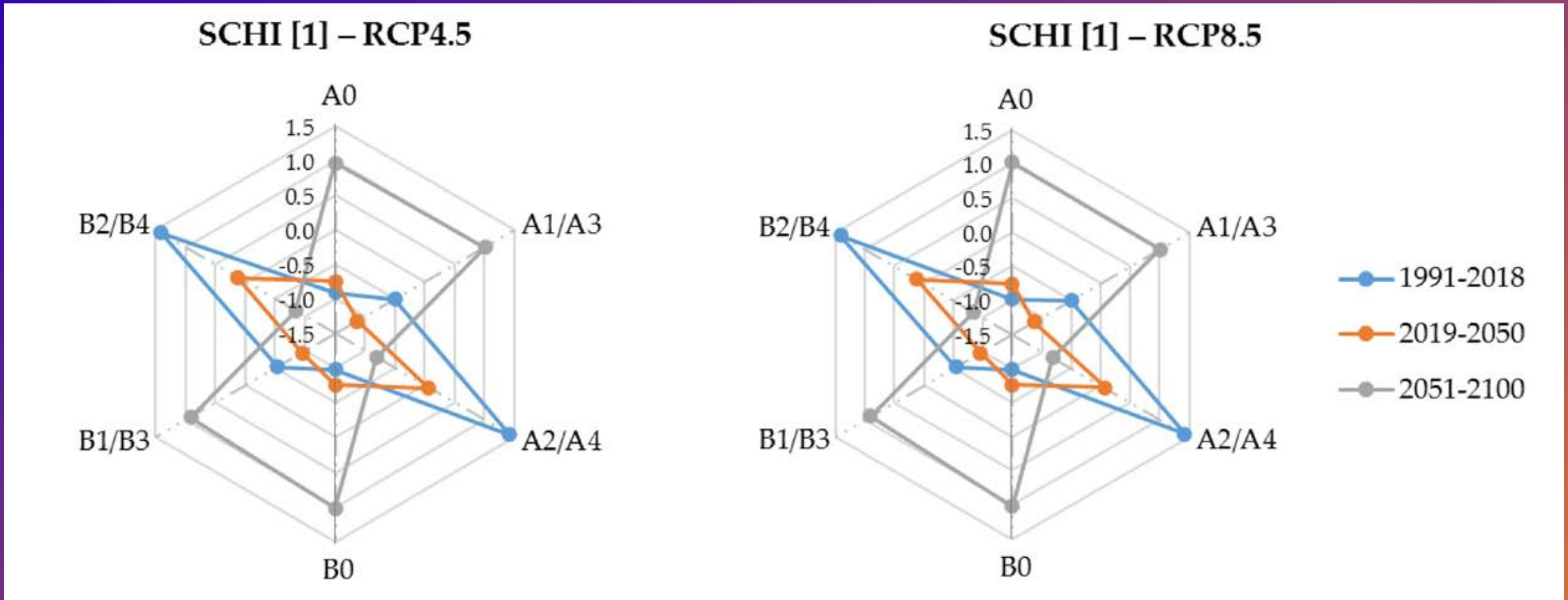
In 2019–2050 under historical and deficit irrigation practices, groundwater use for irrigation will pose low-moderate salinity hazards



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

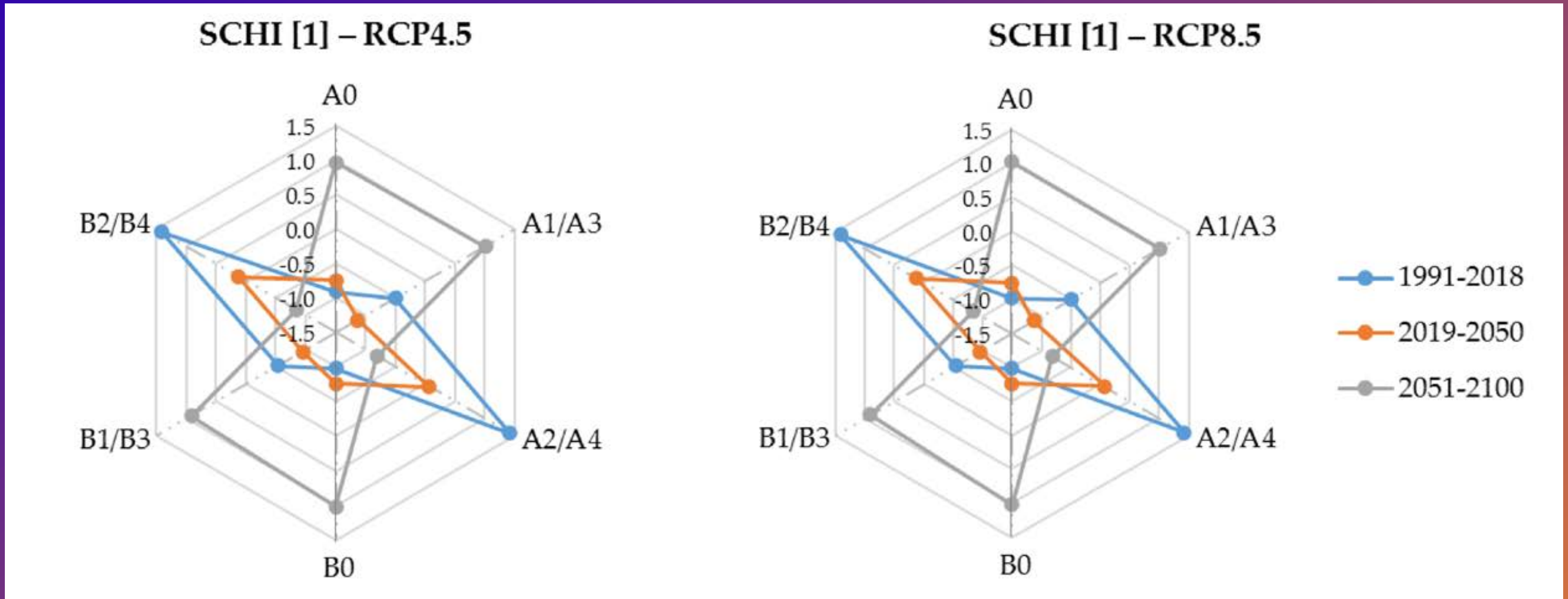
whereas rainfed agriculture/deficit irrigation will pose moderate rates, in both Strategies A and B, and in both RCPs.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

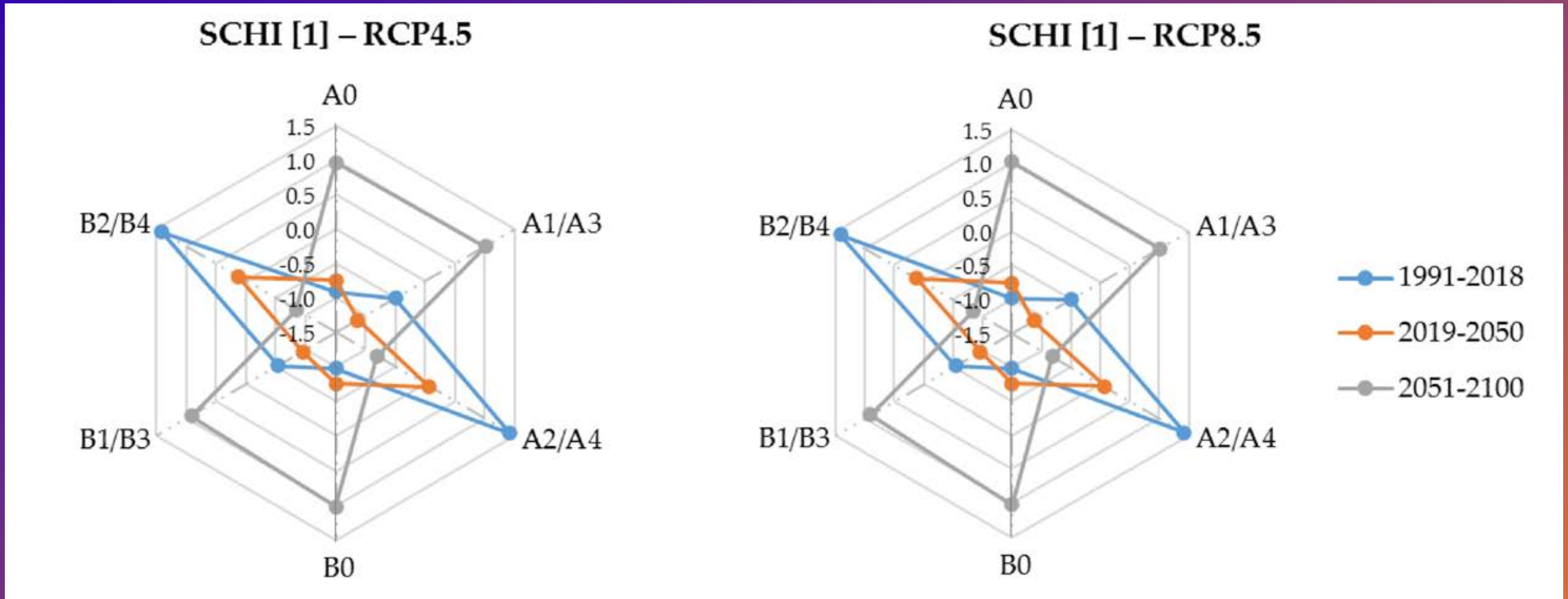
However, in 2051–2100 the situation will be reversed.



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

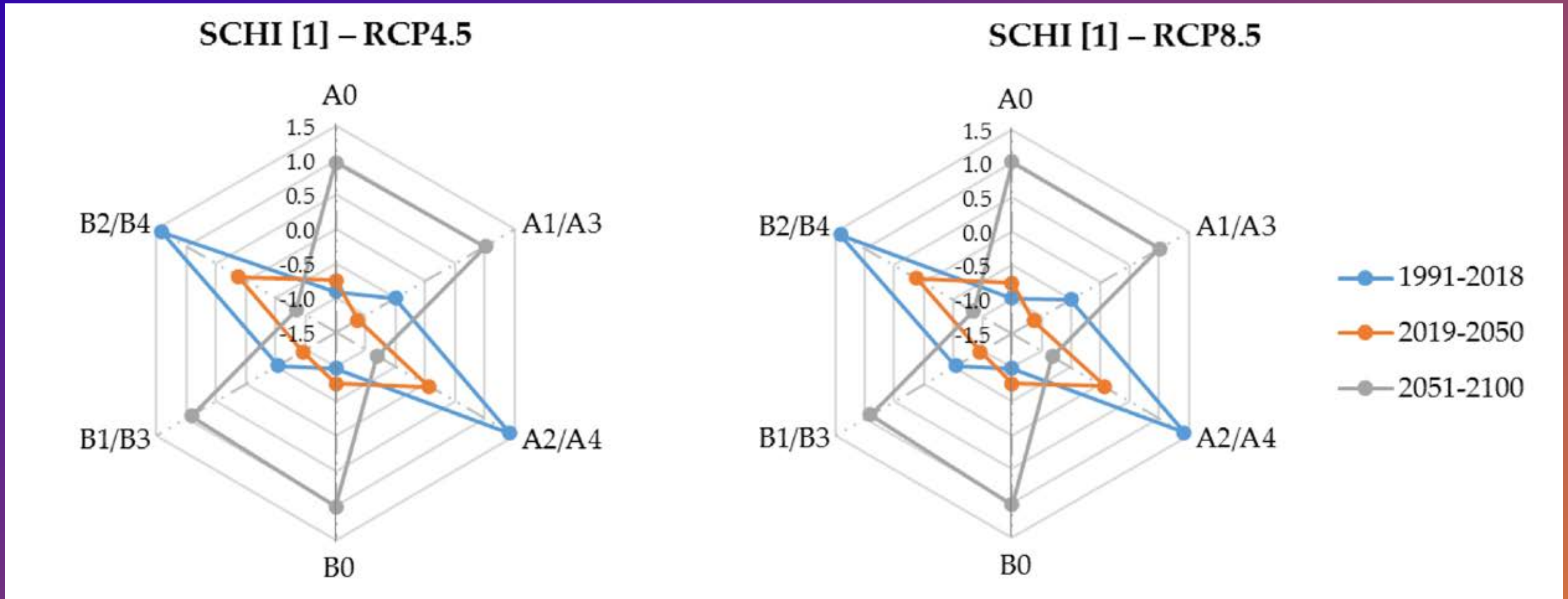
Low-moderate salinity hazards will appear during rainfed agriculture/ deficit irrigation



Application—Results

Agronomic efficiency indices and water resources adaptation for seawater intrusion

and moderate salinity hazards for the remaining scenarios for both RCPs.



Conclusions

Water resources adaptation and agronomic efficiency scenarios have been applied under two ensemble RCPs (4.5 and 8.5) in the Almyros basin in Thessaly, Greece, using an Integrated Modeling System (IMS).

1. SCHI scores indicate that the groundwater used for irrigation will pose moderate salinity hazards in 2019–2050 in all strategies.
2. Crop yields are expected to decline for most of the cultivars due to irrigation with salinized water, except for the rainfed agriculture/ deficit irrigation alternative.
3. CWP could be improved in the future in Strategy B and EWP scores might be, also, greatly increased.
4. NUE ratings are equivalent to crop yields, which are affected by the salinity status of groundwater used for irrigation.

Conclusions

Hence, the **future course of seawater intrusion in the Almyros aquifer** is a crucial problem that should be addressed in the near future

with drastic measures of water resources adaptation to climatic changes and water needs

in order to ensure the success of adaptation measures to climate change and the sustainability of local agriculture.

ECWS–7
2023

water

MDPI

The 7th International Electronic Conference on Water Sciences

15–30 MARCH 2023
ONLINE

«This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project “Strengthening Human Resources Research Potential via Doctorate Research” (MIS-5000432), implemented by the State Scholarships Foundation (IKY)»

Ευρωπαϊκή Ένωση
European Social Fund

Operational Programme
Human Resources Development, Education and Lifelong Learning
Co-financed by Greece and the European Union

ΕΣΠΑ
2014-2020
ανάπτυξη - εργασία - αλληλεγγύη

THANK YOU FOR YOUR ATTENTION!