The Water-Energy-Food Nexus in Naxos Island: Enhancing Self-Sufficiency Through Traditional Techniques

Manthos Maravelakis, Theano Iliopoulou, and G.-Fivos Sargentis

National Technical
University of Athens
School of Civil Engineering

Δήμος Νάξου
και Μικρών Κυκλάδων

May 2026

Funded by
the European Union

Why Study Mediterranean Islands?

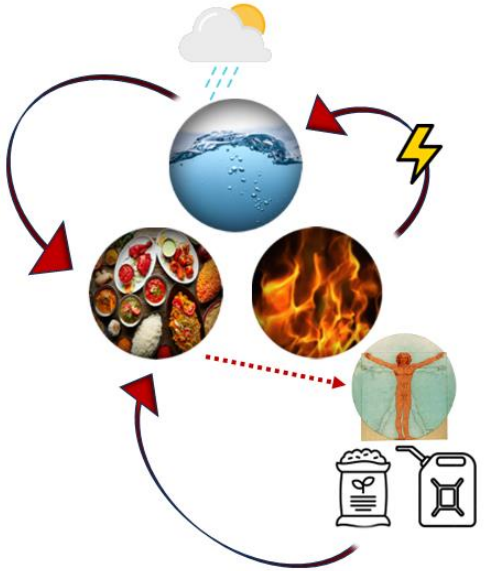
- Mediterranean islands face increasing water scarcity
- Strong seasonal tourism pressure
- Climate variability and decreasing rainfall trends
- High dependence on external energy and water inputs
- Need for resilient and decentralized solutions

The WEF Nexus Concept

- Water, energy, and food systems are interconnected
- Water needed for agriculture and energy production
- Energy required for pumping, desalination, irrigation
- Agriculture consumes both water and energy
- Integrated management improves sustainability

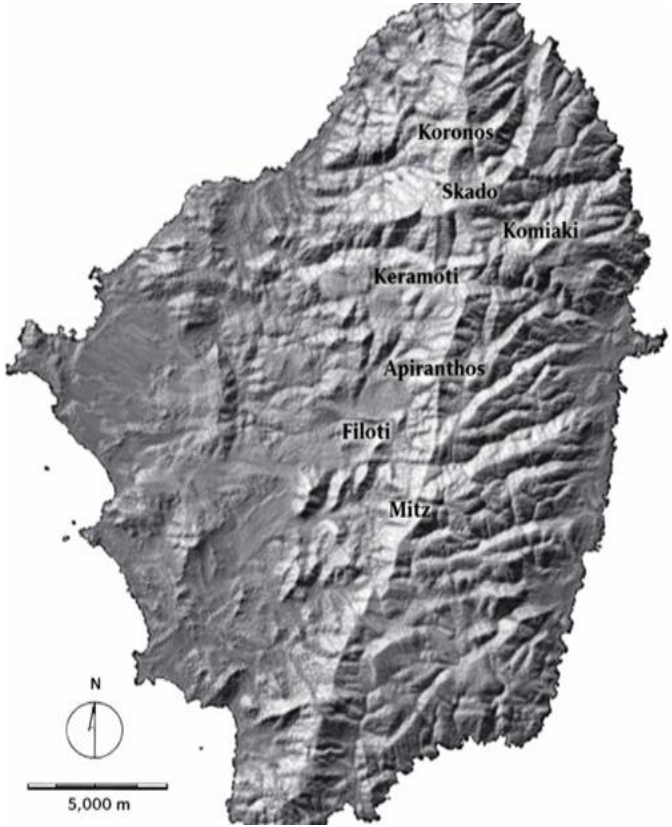
Pre-industrial nexus

Modern nexus



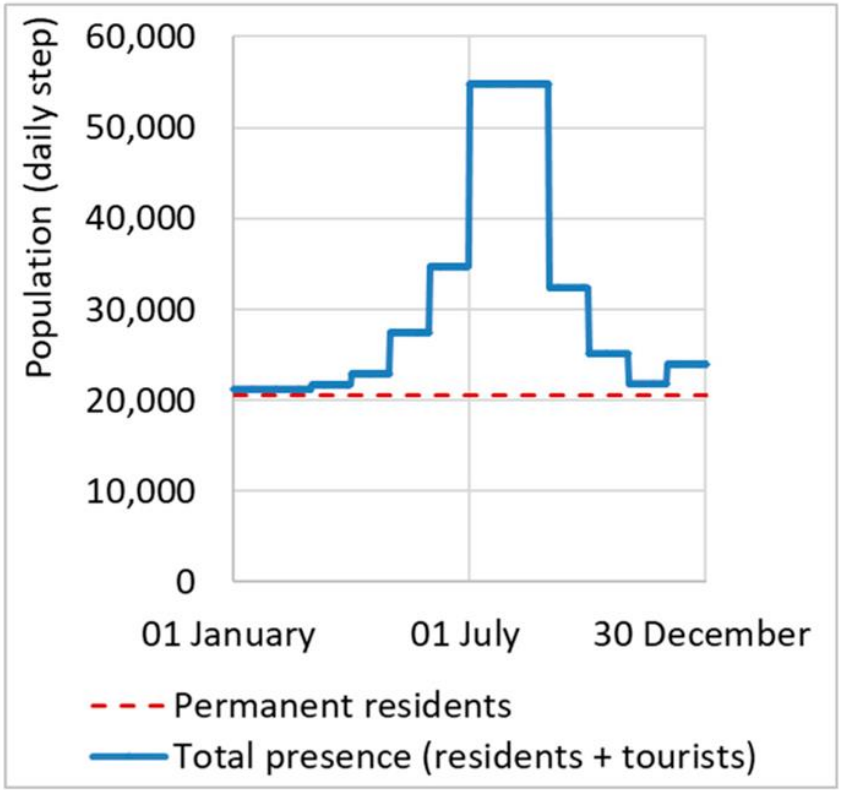
Study Area: Naxos Island

- Largest island of the Cyclades
- Area: 430 km²
- Mountainous interior (Mount Zas: 1004 m)
- Agricultural tradition
- Growing tourism sector



Socioeconomic Characteristics

- Permanent population ~20,000 capita
- Strong seasonal tourism (>600,000 visitors annually)
- Agriculture and livestock remain important
- Tourism and agriculture coexist

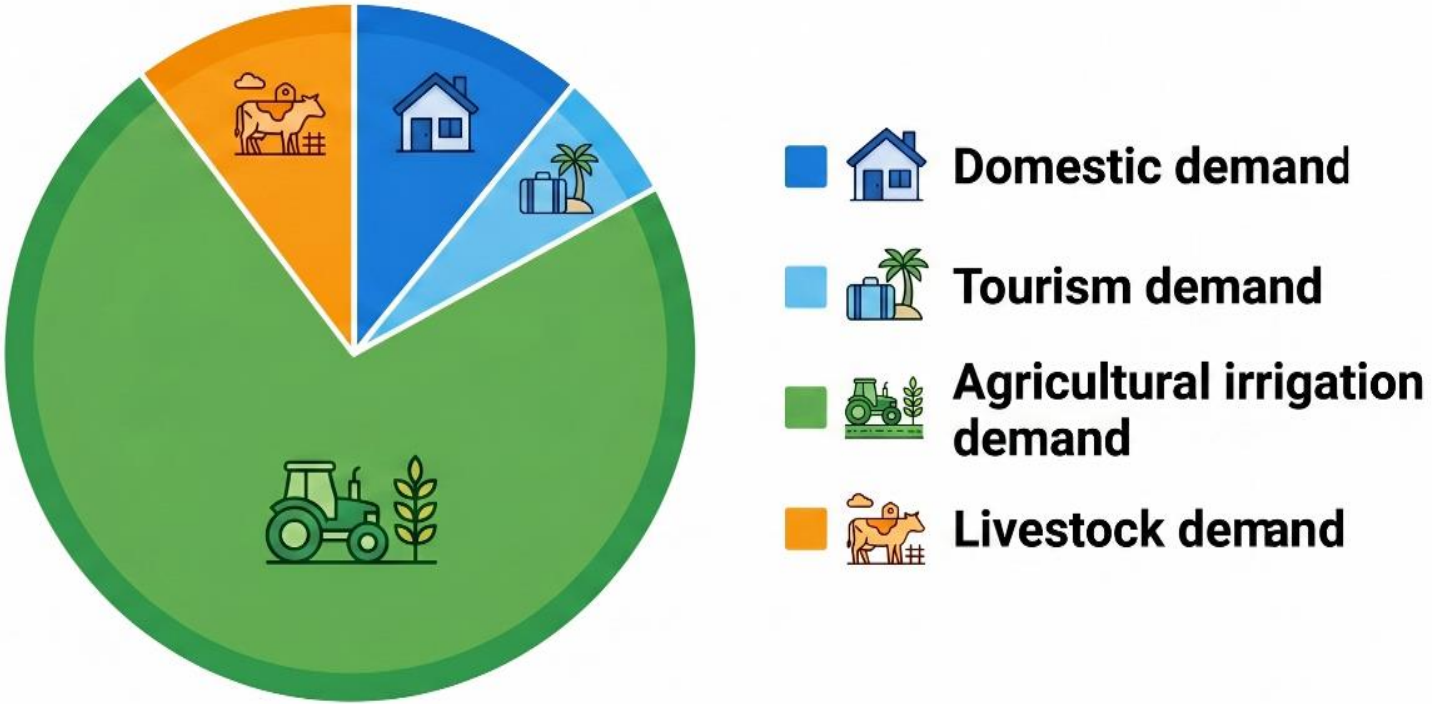


Natural Resources

- Average rainfall: 575 mm/year
- Significant spatial rainfall variability
- Agricultural land availability

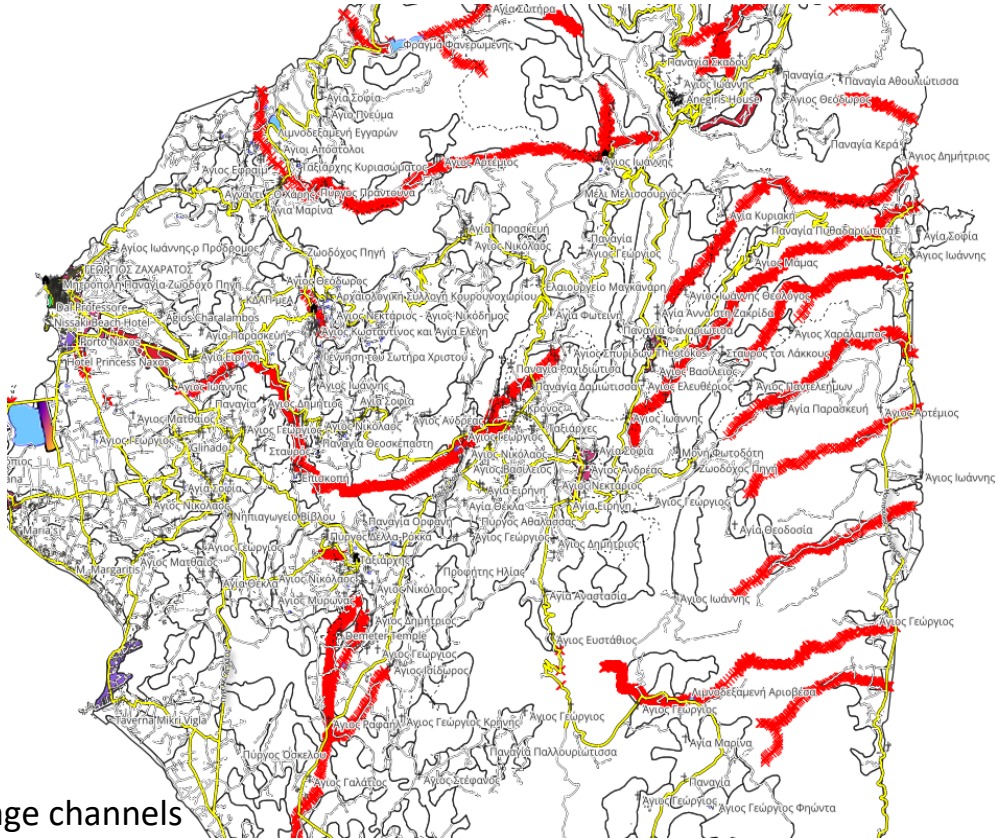
Rainwater in Naxos: ~250,000,000 m^3/year

Water Demand



Existing Water Infrastructure

- Groundwater extraction
- Small reservoirs
- Irrigation systems
- Desalination units



Streams and drainage channels

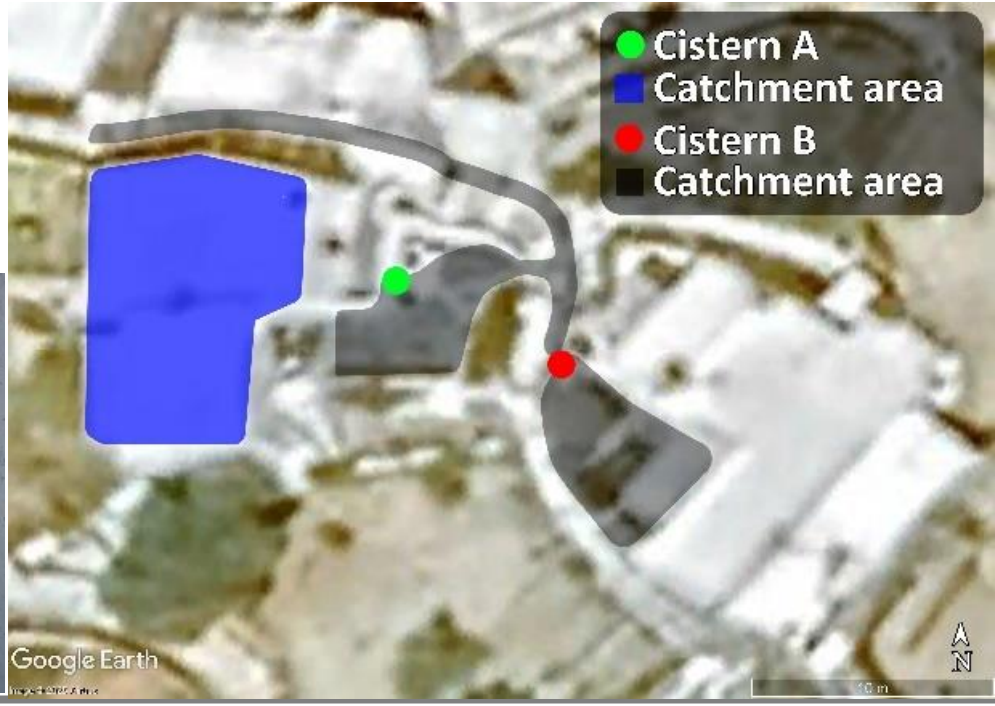
Traditional water infrastructures (Cisterns)

Rainwater Collection Sources

- Rooftops (blue water)
- Courtyards (grey water)
- Road networks (grey water)
- Natural runoff

Blue water

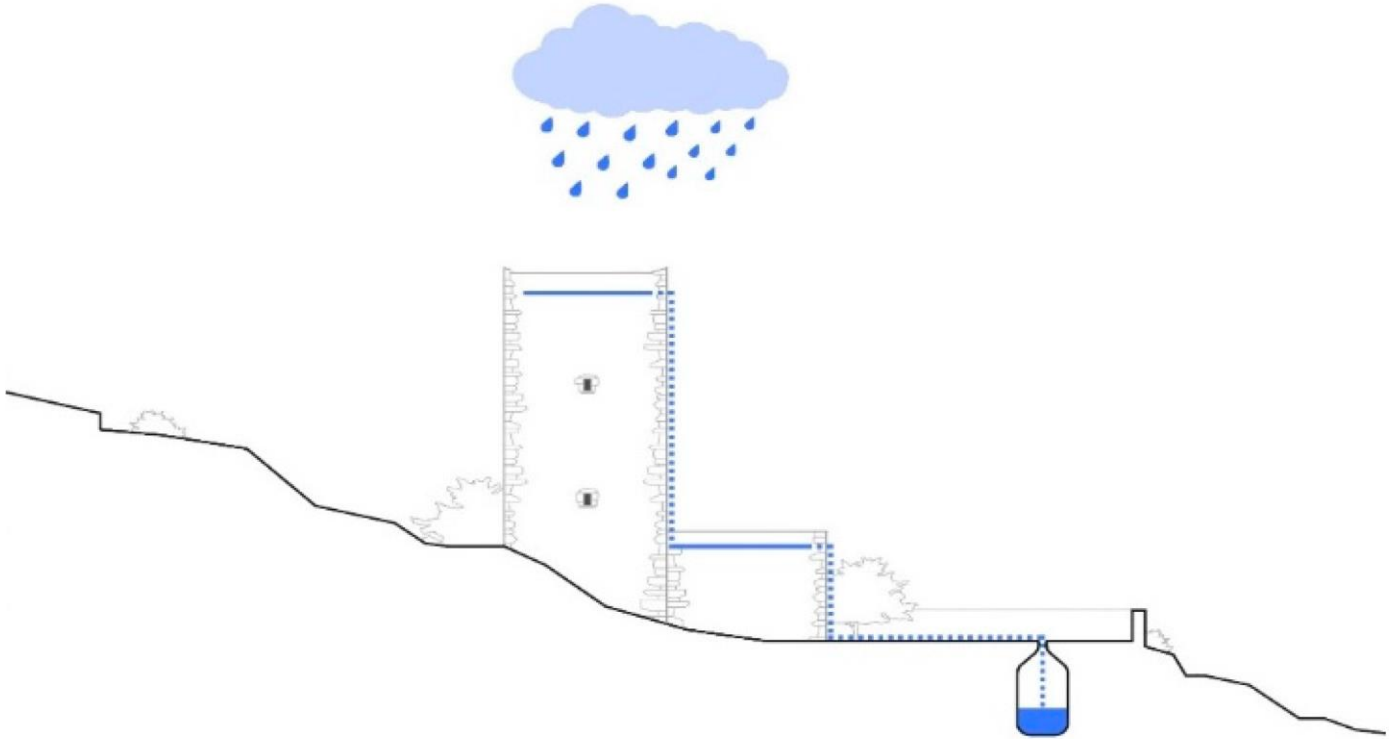
Grey water



Traditional water infastructures (Cisterns)

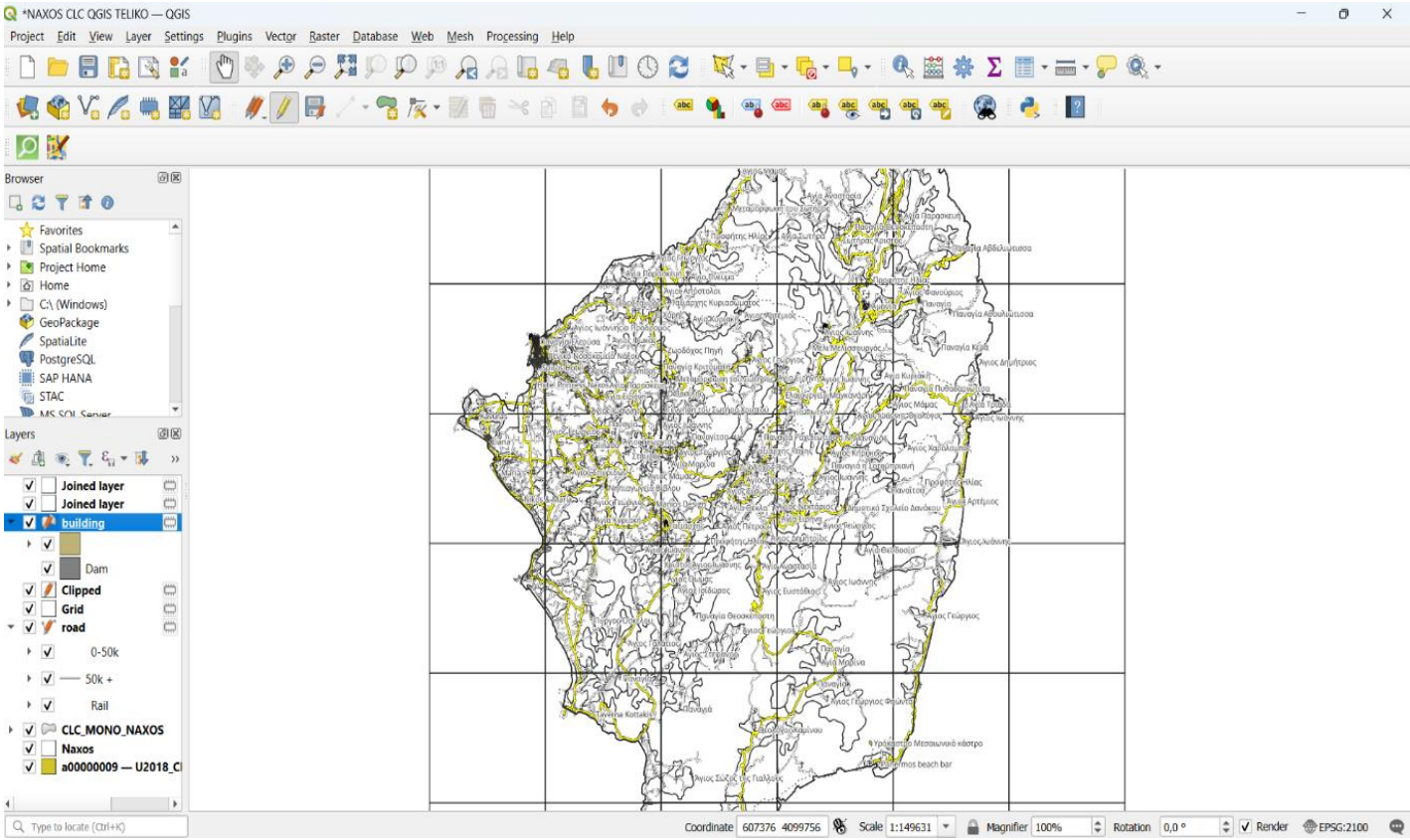
Characteristics

- Low-energy solution
- Historical use in Cyclades
- Decentralized water management



Research Methodology

- GIS-based spatial analysis
- QGIS processing
- Island divided into 28 grid cells
- Rainfall and land use integration
- Water balance calculations



Research Methodology

- $V = P \cdot A \cdot Cr$

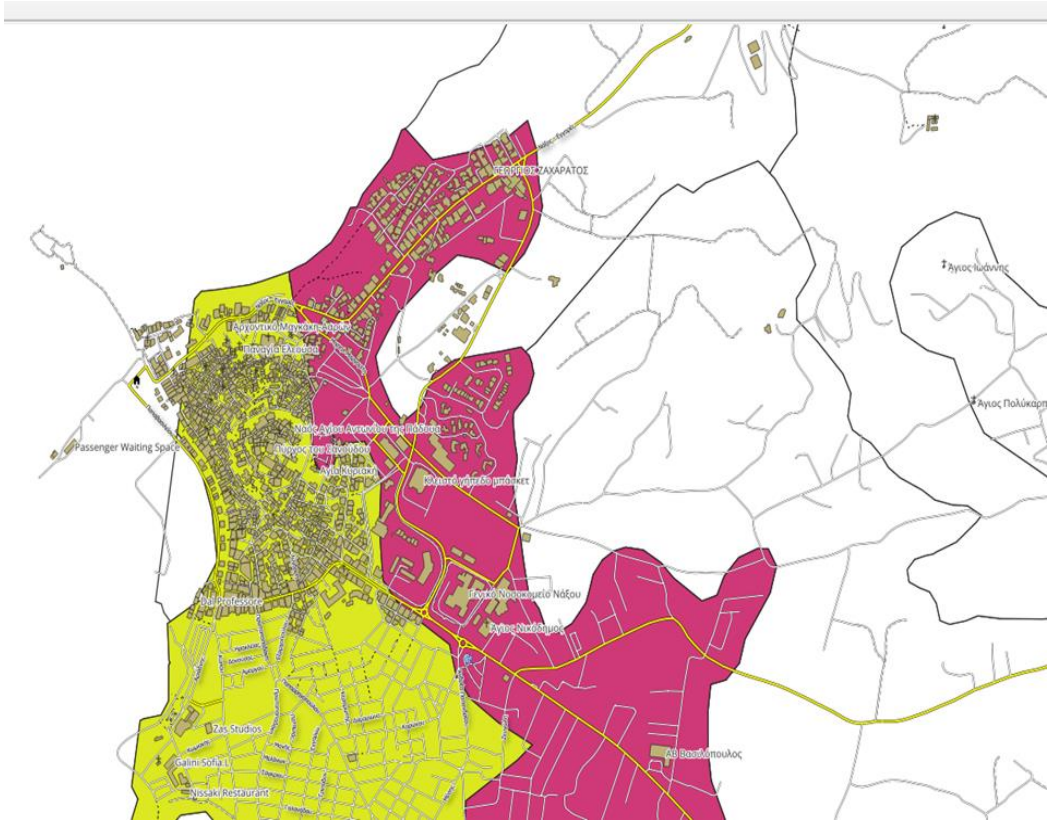
V is the annual volume (m^3),

P is the annual precipitation (m)

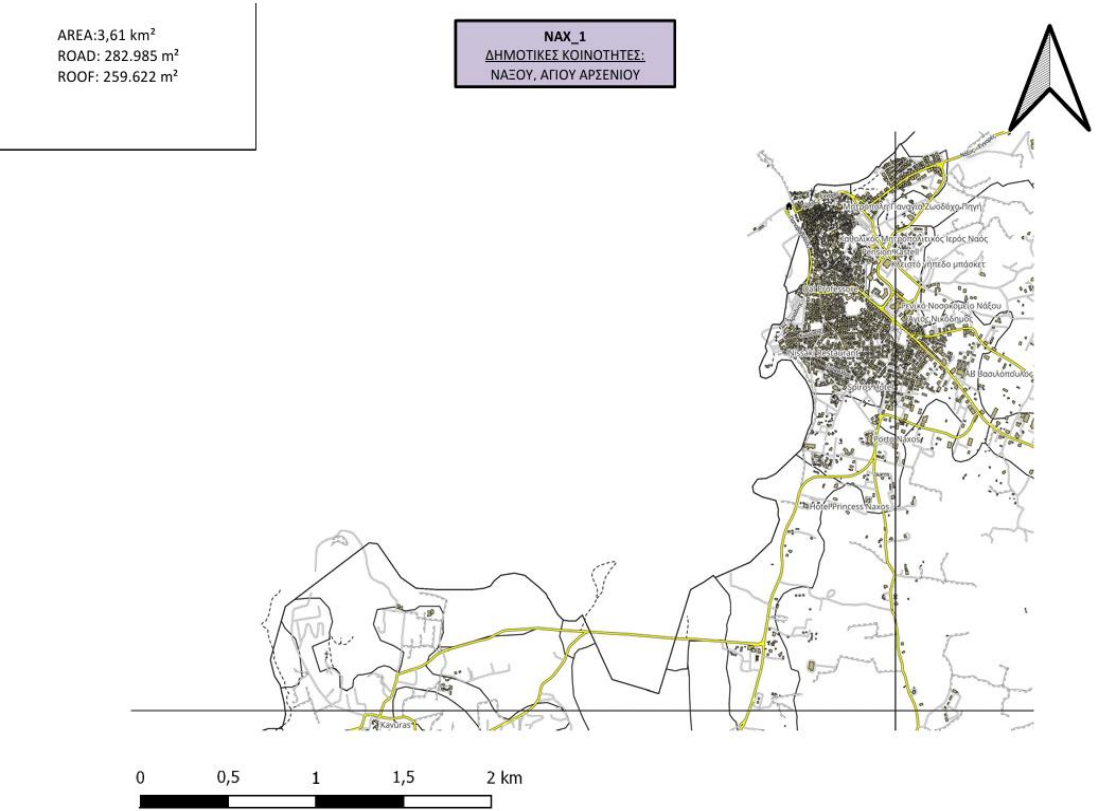
A is the area (m^2)

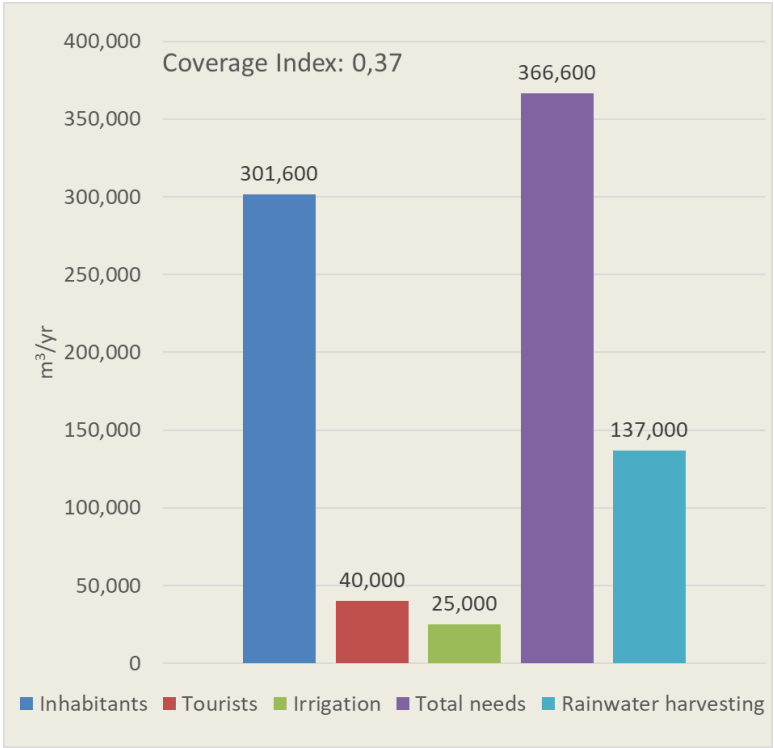
Cr is the runoff coefficient,

which depends on the surface material and slope.



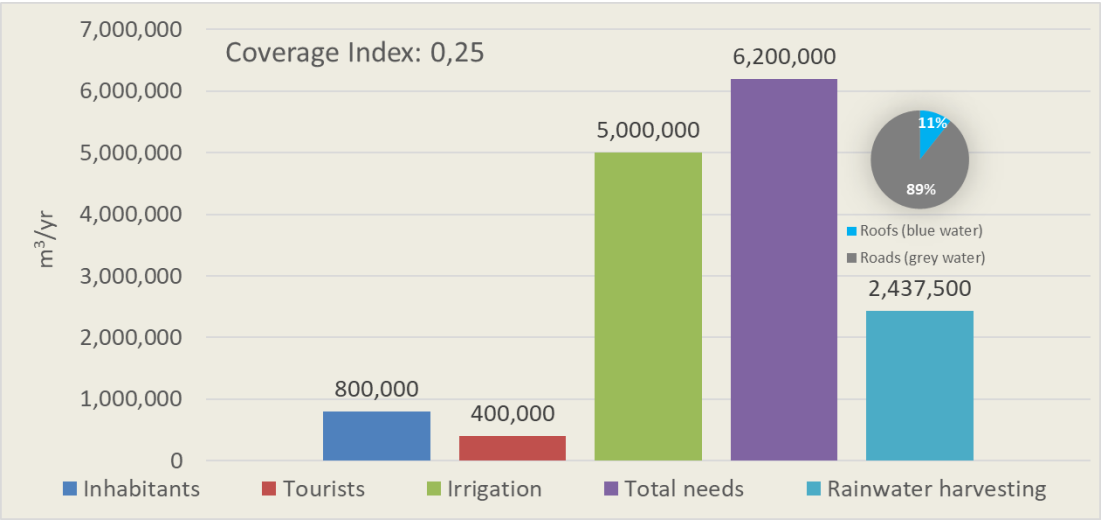
Research Methodology (example)

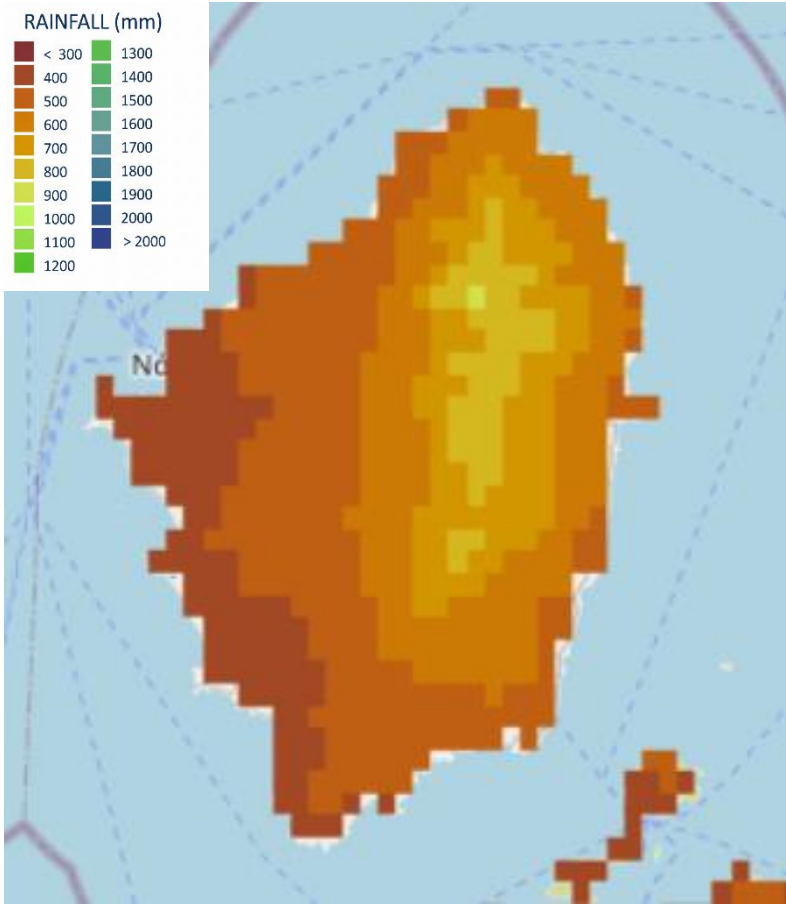




Results

- Harvestable Water per Cell
- Coastal areas: 5,800 m³/year
- Mountainous areas: >200,000 m³/year
- Strong spatial variability





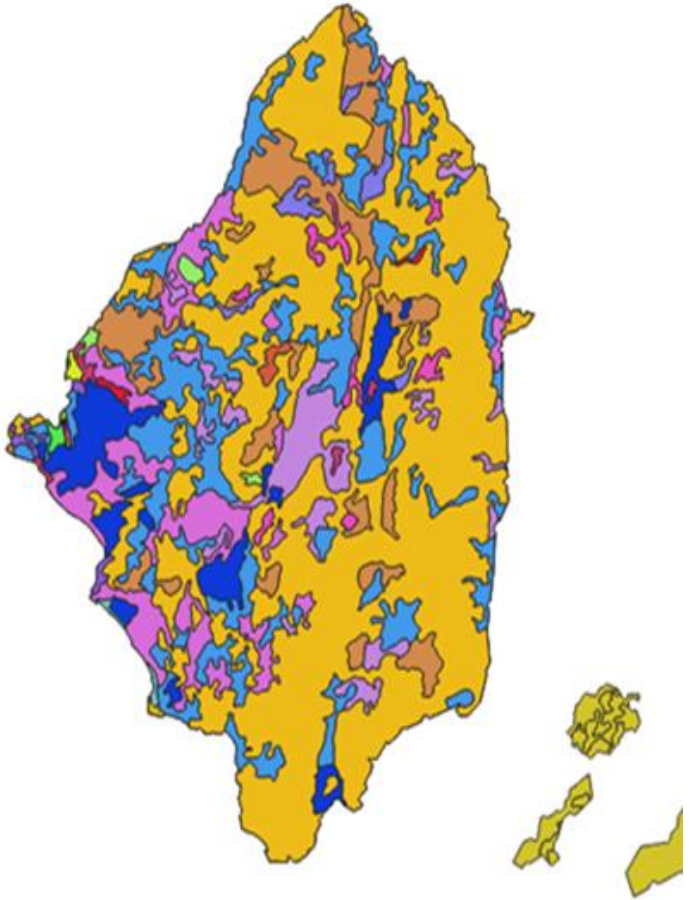
Agricultural Focus

Main Crops

- Potatoes
- Olives
- Vineyards
- Cereals

	111	Συνεχής αστική δόμηση
	112	Ασυνεχής αστική δόμηση
	121	Βιομηχανικές ή εμπορικές περιοχές
	123	Λιμένες
	124	Αεροδρόμια
	131	Λατομεία, χωματερές
	142	Αθλητικές και ψυχαγωγικές εγκαταστάσεις
	211	Αροτραίες μη αρδευόμενες καλλιέργειες(ΥΨΗΛΗ)
	223	Ελαιώνες
	231	Βοσκότοποι(ΧΑΜΗΛΗ)
	242	Μωσαϊκό καλλιεργειών και φυσικής βλάστησης(ΜΕΤΡΙΑ)
	243	Μωσαϊκό καλλιεργειών και δασών(ΜΕΤΡΙΑ)
	321	Φυσικοί χορτολιβαδικοί βοσκότοποι(ΧΑΜΗΛΗ)
	323	Φρυγανώδης βλάστηση
	324	Μεσογειακοί θάμνοι
	331	Γυμνές εκτάσεις βράχου (κωδικός μη τυπικός*)
	333	Σκληρός βράχος
	421	Θαμνώδεις εκτάσεις με μεταβατικό χαρακτήρα
	512	Περιοχές μερικώς ή ολικώς βυθισμένες

CROP CATEGORY (PLOWED CROPS)	Area (ha)
Legumes for dried nuts	1.8
Potatoes	375.6
Industrial plants	2.6
Fresh vegetables, melons, strawberries	129.8
Forage crops	1,487.7
Set-aside periods	257.5
Total:	**2,255**



Livestock Integration

- Animal Manure Use
- Nutrient recycling
- Reduced fertilizer dependency
- Reduced embedded energy
- Circular agriculture

- Total annual production: 170,000–190,000 t/year, for 5,600 cattle, 50,000 sheep, and 40,000 goats.
- Nitrogen content by species (cattle, sheep and goats): conservatively estimated average content of 0.5% N.
- For 180,000 t/year → 900 t of nitrogen annually.
- Utilization of 30–50% of total nitrogen during the first year → immediately available nitrogen: 270–450 t N/year.
- Coverage of needs: 1,100–3,000 ha of potato crops (375 ha) and fresh vegetables (129 ha).

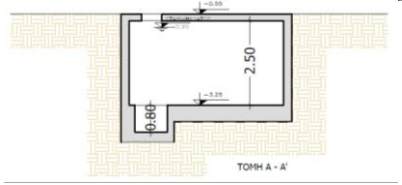
Energy Implications

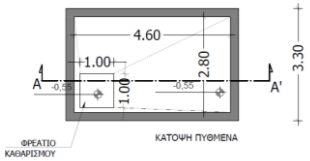
- Energy Savings
- Reduced desalination demand
- Reduced pumping
- Lower fossil fuel use
- Renewable energy integration

Conclusions

- Decentralized water management is feasible
- Traditional techniques remain effective
- Optimization of WEF Nexus means sustainability
- Model applicable to Mediterranean islands

Further research: Experimental cistern





Contact:

- marabelakes@gmail.com
- tiliopoulou@hydro.ntua.gr
- fivos@itia.ntua.gr

Funded by the European Union

References (1)

1. Angelakis, A.N.; Sargentis, G.-F.; Gigourtakis, N.; Kourgialas, N.N. Hydro-Technologies in Greece from Prehistory to Modern Times: A Review of Water Management, Sustainability, and Resilience. Water 2026, 18, 560. https://doi.org/10.3390/w18050560
2. Angelakis, A.N.; Capodaglio, A.G.; Tzanakakis, V.A.; Sargentis, G.-F. Learning from the Past to Secure the Future: Greek Hydro-Technologies and the Evolution of Water Management. Sustainability 2026, 18, 3753. https://doi.org/10.3390/su18083753
3. Arvanitidis, I. and Sargentis, G.-F.: Spatial Indicators of Dynamic Self-Sufficiency and Resilience in the Water–Energy–Food Nexus. Case study: Small Rural Village in North Euboea, Greece, EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-14761, https://doi.org/10.5194/egusphere-egu26-14761, 2026.
4. Gleick, P.H. Basic Water Requirements for Human Activities: Meeting Basic Needs. Water Int. 1996, 21, 83–92.
5. Iliopoulou, T.; Dimitriadis, P.; Siganou, A.; Markantonis, D.; Moraiti, K.; Nikolinakou, M.; Meletopoulos, I.T.; Mamassis, N.; Koutsoyiannis, D.; Sargentis, G.-F. Modern Use of Traditional Rainwater Harvesting Practices: An Assessment of Cisterns' Water Supply Potential in West Mani, Greece. Heritage 2022, 5, 2944-2954. https://doi.org/10.3390/heritage5040152.

References (2)

6. Kirkmalis, G.; Sargentis, G.-F.; Ioannidis, R.; Markantonis, D.; Iliopoulou, T.; Dimitriadis, P.; Mamasis, N.; Koutsoyiannis, D. Fertilizers as batteries and regulators in the global Water-Energy-Food equilibrium, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-11915, https://doi.org/10.5194/egusphere-egu23-11915, 2023.
7. Papadodimas, N., Laoutaris, G. D., Mamassis, N., and Sargentis, G.-F.: Reverse Engineering for the Chronology of Medieval Aqueducts: A Case Study of the Holy Monastery of Dochiariou, Mount Athos, EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-14910, https://doi.org/10.5194/egusphere-egu26-14910, 2026.
8. Sargentis, G.-F.; Dimitriadis, P.; Ioannidis, R.; Iliopoulou, T.; Frangedaki, E.; Koutsoyiannis, D. Optimal utilization of water resources for local communities in mainland Greece (case study of Karyes, Peloponnese), Procedia Manufacturing, Volume 44, 2020, Pages 253-260, ISSN 2351-9789, https://doi.org/10.1016/j.promfg.2020.02.229.
9. Sargentis G.-F. and N. Mamassis Water Collection in Complexes & Residences – Design for Small Scales, KTIRIO 6/2021, 75–80, 2021. https://www.itia.ntua.gr/en/docinfo/2131/
10. Sargentis, G.-F.; Iliopoulou, T.; Dimitriadis, P.; Mamassis, N.; Koutsoyiannis, D. Stratification: An Entropic View of Society's Structure. World 2021, 2, 153-174. https://doi.org/10.3390/world2020011.

References (3)

11. Sargentis, G.-F.; Defteraios, P.; Lagaros, N.D.; Mamassis, N. Values and Costs in History: A Case Study on Estimating the Cost of Hadrianic Aqueduct's Construction. World 2022, 3, 260-286. https://doi.org/10.3390/world3020014
12. Sargentis, G.-F. Issues of Prosperity: Stochastic Evaluation of Data Related to Environment, Infrastructures, Economy and Society. Ph.D. Thesis, National Technical University of Athens, School of Civil Engineering, Athens, Greece, 2022. https://doi.org/10.5281/zenodo.6785733
13. Sargentis, G.-F.; Iliopoulou, T.; Dimitriadis, P.; Mamassis, N.; Koutsoyiannis, D. Stratification: An Entropic View of Society's Structure. World 2021, 2, 153-174. https://doi.org/10.3390/world2020011
13. Sargentis, G.-F.; Koutsoyiannis, D.; Angelakis, A.; Christy, J.; Tsonis, A.A. Environmental Determinism vs. Social Dynamics: Prehistorical and Historical Examples. World 2022, 3, 357-388. https://doi.org/10.3390/world3020020
14. Sargentis G.-F.; Mamassis N.; Kitsou O.; Koutsoyiannis D. The role of technology in the water–energy–food nexus. A case study: Kerinthos, North Euboea, Greece. Front. Water 6:1343344, 2024. https://doi.org/10.3389/frwa.2024.1343344
15. Sargentis, G.-F. Fragility in Human Progress. A Perspective on Governance, Technology and Societal Resilience Front. Complex Systems 2025. https://doi.10.3389/fcpxs.2025.1609467

References (4)

16. Sargentis G.-F.; Markantonis D. Water-energy-food nexus and its stochastic dynamics: case study Greece. Discover Sustainability, Springer-Nature, 2024, 5, 511. https://doi.org/10.1007/s43621-024-00751-z
17. Sargentis, G.-F.; Markatos, E.; Malamos, N.; Iliopoulou, T. Enhancing Resilience and Self-Sufficiency in the Water–Energy–Food Nexus: A Case Study of Hydroponic Greenhouse Systems in Central Greece. Earth 2025, 6, 95. https://doi.org/10.3390/earth6030095
18. Sargentis G.-F.; Ioannidis R.; Dimitriadis,P.; Malamos N.; Lyra O.; Kitsou O.; Kougkia M.; Mamassis N.; Koutsoyiannis D. Energy Self-Sufficiency in Rural Areas, Case Study: North Euboea, Greece. Advances in Environmental and Engineering Research, 2024, 2766-6190. https://doi.org/10.21926/aeer.2404025
19. Sargentis G.-F., Baroudi S, Angelidis M.-A., Arvanitidis I, Mamassis N, Ioannidis R. Restoring the Resilience of Water-Energy-Food Nexus Based on Desalination through Biomass Management: Case Study West Mani, Greece. Adv Environ Eng Res 2026, 7(1): 005; http://dx.doi.org/10.21926/aeer.2601005
20. Sargentis, G.-F.; Palamarczuk, E.; Iliopoulou, T. Swimming Pools in Water Scarce Regions: A Real or Exaggerated Water Problem? Case Studies from Southern Greece. Water 2025, 17, 2934. https://doi.org/10.3390/w17202934
21. Sargentis G.-F.; Ioannidis R. The impacts of altering biodiversity to the Water–Energy–Food nexus: case study North Euboea, Greece. Discover Water, Springer-Nature, 2024, 4, 105. https://doi.org/10.1007/s43832-024-00165-y