6. Impacts of climate change on the evolution of water resources in the context of the Mediterranean islands using as an example two Aegean Sea islands: consequences for touristic activities in the future

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Abstract

The ecological and economic stakes of the climate change impacts are posed in particular terms on islands, especially in the Mediterranean, where summer tourism is one of the pillars of the activity of island communities. The climate scenarios for the Mediterranean islands up to 2050 make it possible to better identify, at the scale of each island, the modifications that Climate Change (CC) is likely to imply on the water balance.

The results for 360 islands (104,263 km²) over the whole basin give an average temperature evolution of +2.3°C with values between +1.8 and +2.9°C. This means a rise of potential evapotranspiration of the order of 135 mm/year with local values varying between 110 mm/year and 170 mm/year. The change in relative annual precipitation varies between -11.6% and +2.9% with an average of -6.5%. The regional analysis shows that the water balance should be more impacted in the eastern part especially in the Aegean Sea and along the southern shore of the Mediterranean.

The rainfall deficit coupled with the increase in evapotranspiration would result locally in a significant reduction of surface runoff and underground water recharges, which could be of the order of 40% on average over the year. On top of interannual variations, there is a high degree of uncertainty about water resources in 2050.

At the same time, mass tourism and other forms of tourism have become the backbone of the economies of many Mediterranean islands and the trend is expected to strengthen. The water demand of this sector during the summer

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dry season only complicates the problem and is at the expense of other sectors of activity, including agriculture. Case studies are presented on the islands of Rhodes and Samos comparing the evolution of water resources and demand from the tourism sector. Results suggest that foreseeable lowering of water resources in close future should be tackled with a more efficient Integrated Water Resources Management (IWRM) especially on Mediterranean islands whose economy is based on mass tourism. An alternative would be to lesser water consumption per capita combined with a more effective recycling of sewage.

Keywords: Climate Change, Mediterranean islands, Aegean Sea, Integrated Water Resources Management, Tourism, Ecolomy.

Résumé

Les enjeux écologiques et économiques de l'impact du changement climatique se posent en des termes particuliers sur les îles, notamment en Méditerranée, où le tourisme estival est l'un des piliers de l'activité des communautés insulaires. Les scenarii climatiques pour les îles méditerranéennes à l'horizon 2050 permettent de mieux identifier, à l'échelle de chaque île, les modifications que le CC est susceptible d'impliquer sur le bilan hydrologique.

Les résultats pour 360 îles (104 263 km²) sur l'ensemble du bassin donnent une évolution moyenne de la température de +2,3°C avec des valeurs comprises entre +1,8 et +2,9°C. Cela signifie une augmentation de l'évapotranspiration potentielle de l'ordre de 135 mm/an avec des valeurs locales variant entre 110 mm/an et 170 mm/an. La variation des précipitations annuelles relatives varie entre -11,6% et +2,9% avec une moyenne de -6,5%. L'analyse régionale montre que le bilan hydrique et hydrologique devrait être plus affecté dans la partie orientale, en particulier dans la Mer Égée et le long de la rive sud de la Méditerranée.

Le déficit pluviométrique couplé à l'augmentation de l'évapotranspiration se traduirait localement par une réduction significative du ruissellement de surface et des recharges en eaux souterraines, déficit qui pourrait être de l'ordre de 40% en moyenne sur l'année. En plus des variations interannuelles, il existe un degré élevé d'incertitude sur les ressources en eau en 2050.

Dans le même temps, le tourisme dont en particulier le tourisme de masse est devenu l'épine dorsale des économies de nombreuses îles méditerranéennes et cette tendance devrait se renforcer. Les besoins en eau de ce secteur pendant la saison sèche estivale ne font que compliquer le problème et se font au détriment d'autres secteurs d'activité, dont l'agriculture. Des études de cas seront présentées sur les îles de Rhodes et de Samos afin de comparer l'évolution des ressources en eau et de la demande du secteur du tourisme. Les résultats suggèrent que la diminution prévisible des ressources en eau dans un avenir proche devrait être abordée avec une Gestion Intégrée des Ressources en Eau (GIRE) plus efficace, en particulier dans les îles méditerranéennes dont l'économie est basée sur le tourisme de masse. Une alternative serait de réduire la consommation d'eau par habitant tout en assurant un recyclage plus efficace des eaux usées.

Mots clés : Changement Climatique, îles Méditerranéennes, Mer Égée, Gestion Intégrée des Ressources en Eau, Tourisme, Ecolomie.

Περίληψη (abstract in Greek)

Οι οικονομικές και οικολογικές προκλήσεις της κλιματικής αλλαγής τίθενται με ιδιαίτερους όρους στα νησιά, ειδικά στη Μεσόγειο, όπου ο καλοκαιρινός τουρισμός είναι ένας από τους πυλώνες της δραστηριότητας των νησιωτικών κοινοτήτων. Τα κλιματολογικά σενάρια για τα νησιά της Μεσογείου έως το 2050 καθιστούν εφικτή την καλύτερη αναγνώριση, σε κλίμακα του κάθε νησιού, των μεταβολών που πιθανόν να επιφέρει η κλιματική αλλαγή στην υδρολογική ισορροπία.

Τα αποτελέσματα για 360 νησιά (104,263 km²) σε ολόκληρη την λεκάνη δείχνουν μία αύξηση της μέσης θερμοκρασίας κατά 2.3 °C με τιμές από 1.8 έως 2.9 °C. Αυτό θα έχει ως αποτέλεσμα αύξηση της δυνητικής εξατμισοδιαπνοής της τάξης των 135 mm/έτος με τοπικές τιμές που κυμαίνονται μεταξύ 110 και 170mm/έτος. Η μεταβολή στην σχετική ετήσια βροχόπτωση κυμαίνεται μεταξύ -11.6% και +2.9% με μέση τιμή -6.5%. Η περιφερειακή ανάλυση δείχνει ότι η υδρολογική ισορροπία θα επηρεαστεί περισσότερο στο ανατολικό κομμάτι και ιδιαίτερα στο Αιγαίο Πέλαγος και κατά μήκος της νότιας ακτής της Μεσογείου.

Το έλλειμα βροχόπτωσης σε συνδυασμό με την αύξηση της εξατμισοδιαπνοής μεταφράζεται τοπικά σε μια σημαντική μείωση της επιφανειακής απορροής και της επαναφόρτισης των υπόγειων υδάτων, η οποία θα μπορούσε να είναι της τάξης του 40% κατά μέσο όρο στο σύνολο

του έτους. Επιπρόσθετα των ετήσιων διακυμάνσεων υπάρχει υψηλός βαθμός αβεβαιότητας σχετικά με τους υδατικούς πόρους το 2050.

Ταυτόχρονα, ο μαζικός τουρισμός και άλλες μορφές τουρισμού έχουν γίνει η ραχοκοκαλιά της οικονομικής δραστηριότητας πολλών νησιών και η τάση αυτή αναμένεται να ενισχυθεί. Οι υδατικές ανάγκες αυτού του κλάδου κατά την διάρκεια της ξηρής περιόδου του καλοκαιριού περιπλέκουν το πρόβλημα και είναι εις βάρος των αναγκών άλλων τομέων της οικονομίας, συμπεριλαμβανομένης της γεωργίας. Παρουσιάζονται μελέτες περίπτωσης για τα νησιά της Ρόδου και της Σάμου προκειμένου να συγκριθούν η εξέλιξη των υδατικών πόρων και η ζήτηση από τον τουριστικό κλάδο.

Τα αποτελέσματα υποδεικνύουν ότι η αναμενόμενη μείωση των υδατικών πόρων στο άμεσο μέλλον θα πρέπει να αντιμετωπιστούν με την Ολοκληρωμένη Διαχείριση των Υδατικών Πόρων ειδικά στα μεσογειακά νησιά των οποίων η οικονομία βασίζεται στον μαζικό τουρισμό. Μια εναλλακτική λύση θα ήταν η μείωση της κατανάλωση ανά κάτοικο σε συνδυασμό με μια αποτελεσματικότερη ανακύκλωση των υγρών αποβλήτων

Λέξεις κλειδιά: Κλιματική αλλαγή, Μεσογειακά νησιά, Αιγαίο Πέλαγος, Ολοκληρωμένη Διαχείριση Υδατικών Πόρων, Τουρισμός, Οικοδιαχείριση Οικοέλεγχος / Οικοχειρισμός

Introduction

The impacts of Climate Change (CC) in the Mediterranean region in the forthcoming decades must be considered in the specific context of its islands, their water resources and tourism, which is one of the backbones of most insular economies. At the scale of the entire Mediterranean basin, the climatological data of WorldClim about 1 km² resolution[6] (Hijmans & al., 2005) make them compatibles with small sized areas like the Mediterranean islands. The scenarios for 2050 are derived from three General circulation models (GCM) models[7].The Mediterranean Sea includes 2718 islands greater than 0.05 km² but WorldClim data are available for only 432 islands of them[8]. This data will be used to estimate CC and its impacts on water resource balances on this set of Mediterranean islands, keeping in mind that island context tends to amplify the vulnerability of water resources and supplies (Depraetere & Morell, 2009).

Mediterranean region is vulnerable to drought and water shortages and it is very sensitive to these phenomena with sometimes devastating environmental, social and economic impacts. Moreover, natural resources are often degraded and mostly used in an unsustainable way (Skondras & al., 2011) (Tsesmelis & al., 2019). The climate of Greece with focus on the Aegean islands will be treated in more depth later.

Generally speaking, water consumption from tourism is undermining local capacity to access fresh, uncontaminated water (Epler Wood & al., 2019, p. 14) and this phenomenon is even more intense on islands with mass tourism due to the high costs of the technical solutions or the importations from the mainland. This becomes very acute in the Mediterranean islands especially in the Balearic islands, Jerba, Mikonos or Porquerolles both from an economic and an environmental perspective. The problem becomes acute when islands face mass tourism: for instance, 14 and 20 tourists/inhabitants respectively for Rhodes and Kos (Kyriakou, Sourianos, & Vagiona, 2011) or even one million daily visitors each year[9]for Porquerolles on the French Riviera and its

[6] The resolution of WorldClim data densified from GCM (about 100 x 100 km) is in fact of 1 arc second, approximately 0.73 x 0.93 km at the Mediterranean latitudes.
[7] CSIRO (Australia, (Gordon & al., 2002)), CCCMA (Canada, (McFarlane & al., 1992)) and HADMC3 (UK, (Pope & al., 2000)).
[8]From Base de données Insulaires Mondiale BIM version 3, DATAsuds portal of the IRD (https://doi.org/10.23708/T37S0K).
[9] This means an average of 22 visitors/day/inhabitants in July and August.

130 inhabitants (Le Berre & al., 2013).With such frequentation, local water resources tend to be overexploited until it necessitates "externalize" it from the mainland or even more costliest alternatives. Nevertheless, tourism remains a major asset for islands communities despite it is considered as an “invisible burden” for local stakeholders and ecology. (Epler Wood & al., 2019, p. 11).

1. Regional analysis of CC from 1950-2000 to 2050

1.1. The regional Climate Change in 2050 on the Mediterranean islands

The regional analysis provides a general overview of CC tendencies over the Mediterranean islands from only one source of data for consistencies purposes. Sub-regional data from observation or models would be more accurate but can’t be homogenous and comparable.

Table 1 resumes the evolution of the mean annual precipitation (Pma) and temperature (Tma) over the entire set of Mediterranean islands considered in this regional survey[10]. Considering the average scenario given by the 3 GCM models (W123), the rise of temperature would be of 2.07 °C and the deficit of precipitation of 34 mm. There are small discrepancies between the GCMs:

- Temperatures: +1.93°C for HADMC3(WC3) to +2.23°C for CSIRO(WC1);
- Precipitations: -29 mm for CSIRO (WC1) to-38mm for HADMC3 (WC3).
- The CCCMA GCM (WC2) gives values that are in between and consequently are closer to the averaged dataset (WC123).

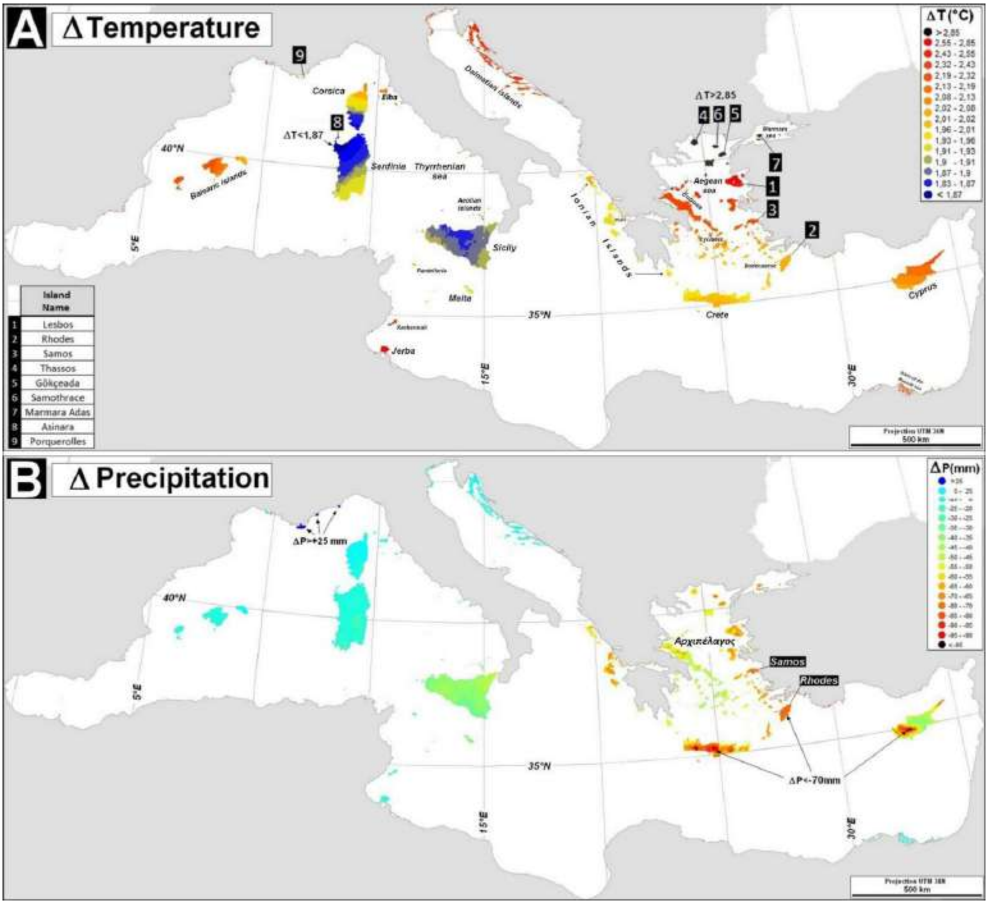
[10] This regional analysis is based on a presentation at the CEST 2015 conference held in the island of Rhodes (Depraetere, Depraetere, & Martin, 2015).

Name Data	WorldClim Data	Pma mm	Tma °C	PER Pma/(58.9 Tma)	ΔPma mm	ΔTma °C	ΔPER
WC0	**1950-2000**	**635**	**15,72**	**0,685**			
WC1	*1950 CSIRO*	*606*	*17,96*	*0,573*	*-29*	*2,03*	*-0,112*
WC2	*CCCMA*	*599*	*17,75*	*0,573*	*-36*	*2,03*	*-0,113*
WC3	*HADMC3*	*597*	*17,66*	*0,574*	*-38*	*1,93*	*-0,111*
WC123	**2050_3M**	**601**	**17,79**	**0,573**	**-34**	**2,07**	**-0,112**

Table 1: Evolution of temperatures and precipitations over the Mediterranean islands between the reference period 1950-2000 (WC0) and three GCM models (WC1, WC2 and WC3) in 2050.

WC123 corresponds to the average value of the three GCM (WorldClim data).

The Map 1 provides an overview of sub regional impact of CC regarding temperatures and precipitations. The pattern of temperature increases (Map 1A) depends on the distance between the islands and the surrounding continental mainlands: for Sicily, Sardinia, southern Corsica and Malta the rise is about 1.9°C or less for instance 1,87°C in north-west Sardinia and Asinara island. Despite their oceanic context, the Balearic archipelago, Northern Corsica, Crete and Cyprus present conditions that are close to the average values for the entire Mediterranean insular region with values between 2 and 2.2°C. For islands that are close to the continent, the evolution of temperatures tends to be much higher except for the Ionian archipelago, the Cyclades and the Dodecanese. Values above 2.6°C are only observed in the northern part of the Aegean Sea (2.85°C for Thasos), the sea of Marmara and the Tunisian island of Jerba (2.66°C). The sub regional repartition of precipitations evolution display is rather different and proceed from different climatologic factors (Map 1B). The main point is that the north-west part of the Mediterranean basin is stable with no significant depletion of the precipitations and even locally a slight rise (25 mm on the islands along the Provence). On the contrary, a sharp distinction is observed with the eastern part including the Ionian island with rainfall decrease between 50 and 100 mm: for instance the most parts of Crete, Cyprus and all the island of Rhodes have deficit above 70 mm.



Map 1: evolution of temperatures (T) and precipitations (P)
between 1950-2000 (WC0) and 2050(WC123) for the Mediterranean islands.

1.2. The evolution of humidity provinces according to the Holdridge method

The Holdridge's method will be put to contribution first because it gives general insights on regional trends on the entire Mediterranean including on the potential evaporation Etp which is supposed to be proportional to the mean annual temperature Tma (Holdridge, 1947)[11]:

[1] ETp = 58.9 Tma (ETp in mm, T in °C)

By combining the mean annual values for temperatures (Tma), precipitations (Pma) and ETp, the method defines biomes associated to specific bioclimate; the "humidity provinces" of Holdridge are based on the ratio between Pma and ETp called the Potential evaporation ratio (PER):

[2] PER = Pma/ETp = Pma/(58.9 Tma)

The CC tendencies can be resume by a graphic showing the "shift" of these humidity provinces between the two considered period this basin as summarized in Figure 1. From 1950-2000 to 2050, the mean annual rise of temperatures and depletion of precipitations at the regional scale tend to decrease the PER from 0.68 to 0.57: accordingly, this suggests a shift from humid to sub humid bioclimatic conditions.

[11] See also (UNESCO, 1963) (Holdridge, 1976) (Whittaker, 1975) (Prentice, 1990).

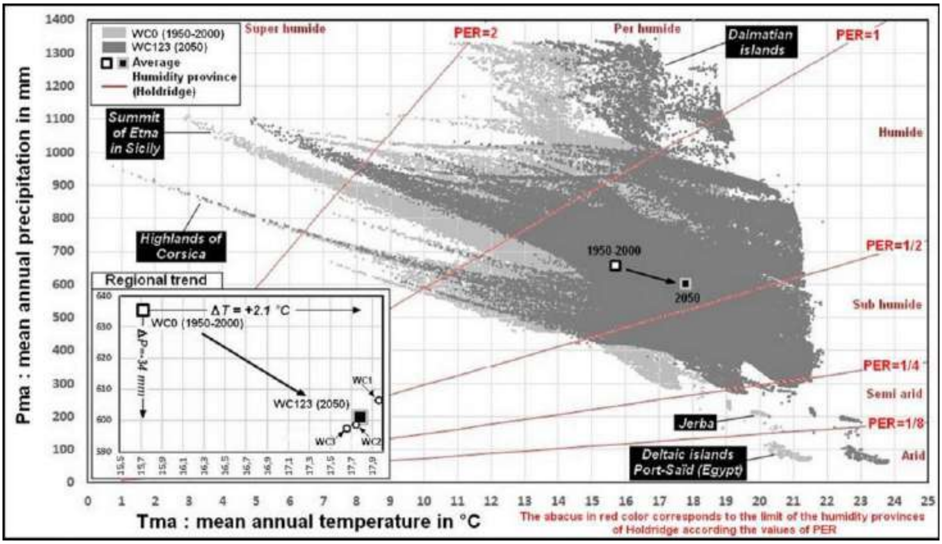


Figure 1 - *The Holdridge-Whittaker scatter plot showing the climatic evolution and subsequent « shift » of bioclimates over the Mediterranean islands between 1950-2000 and 2050. (From WC0 in 1950-2000, for 2050, WC1, WC2 and WC3 and the average evolution WC123).*

(NB: each dot represents a point of the WorldClim data and not an island average value).

A global analysis of the entire region provides a general estimation of this phenomenon by defining linear regression between the three geographical dimensions, that is to say latitude, longitude and elevation for the two climatic variables of temperature and precipitation and each of the two periods. The rise of temperatures of 2.1°C is globally independent of latitude (Figure 2A) and longitude (Figure 2B). It is worth noting that the gradient of temperatures versus latitude was -0.5°C/degree in 1950-2000 but only -0.46°C/degree in 2050, showing a lesser contrast between the southern and the northern areas of the region. The gradient of temperature according to longitude is stable for the two periods with +0.11 C/degree from west to east. Compared to the regional geographical trends of temperatures, precipitations are more scattered due to local conditions; the tendencies are also more variable depending on the period considered. The precipitation gradients of +50 mm/degree in 1950-2000 become +55 mm/degree in 2050, thus leading to a higher contrast between the southern and northern areas (Figure 2C). The precipitations in latitudes above 42°N remain more or less the same for the two periods. The correlation between precipitation and longitude appears to be very weak (Figure 2D) with almost no change in the western area and depletion of 50 mm or more in the eastern region (East of 18°E). This contrast probably reflects the stronger influence of continental anticyclonic conditions in winter in the *pars orientalis* compared to the *pars occidentalis* which remains under the influence of the Westerlies and cyclonic circulation coming from the Atlantic during the cold season.

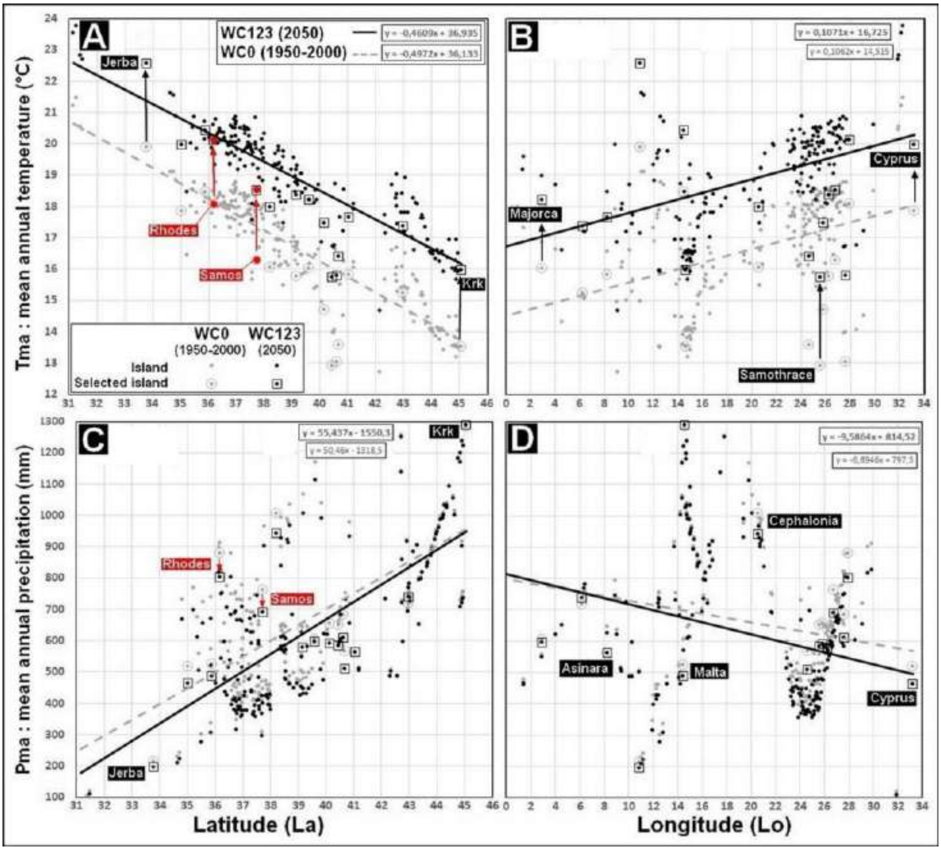


Figure 2 - *relationship between temperatures and precipitations versus latitude and longitude for 432 islands (each dot corresponds to an island average value).*

A./ Temperatures versus latitude. B./ Temperatures versus longitude.

C./. Precipitations versus latitude. E./ Precipitations versus longitude.

CC impacts also the ecosystems by forcing a latitudinal and altitudinal shift of biomes or shortly "biomic shift" (Yates, Kittel & Cannon, 2000). The dynamic of temperature is highly dependent of global and synoptic scale phenomenon whether precipitation processes are more related to mesoscale and microscale factors. Consequently, the pattern of temperature changes is more uniform on a region like the Mediterranean while it tends to be more complex for rainfall distribution which means that the spatial distribution of precipitations are more difficult to interpolate or modelized. Thus, temperatures values must be considered as more reliable than precipitations on both considered periods. To make it simple, temperature changes present a regional pattern while the precipitation evolutions depend on the dynamic of meteorological and climatic local conditions.

For the two periods, the gradient of temperatures and precipitation according to elevation remains the same: -0.55°/100m and 16 mm/100m. The Whittaker diagram (*Figure 1*) combining temperature on the X axis and precipitations on the Y axis depicts the effect of relief on the altitude belts of bioclimates and ther(efore vegetation and its shifting due to CC. For instance, the highlands of Corsica should not be impacted while the top part of Etna in Sicily would become warmer with no change in precipitations partly as snow in winter. The trends for Dalmatian islands are similar to the Etna: warmer conditions and no evolution for rainfalls. The bioclimatic shift for Jerba suggests that this island would be almost under arid condition in the sense of the humidity provinces of Holdridge.

The previous results illustrate the humidity province shift on the Mediterranean between the reference period 1950-2000 and 2050 and can be resume as follow:

- Thermal latitudinal shift of 4 degrees northward (gradient -0.5°C/degree);
- Precipitation latitudinal shift of 1 degree northward (gradient +50mm/degree);
- A thermal altitudinal shift of 400 meters upward (gradient-0.55°C/100m);
- A precipitation altitudinal shift of 250 meters upward (gradient 16mm/100m).

On the whole just by considering the annual figures, this means more xeric conditions resulting from combined effect of precipitation depletion and rise of temperatures; this means increase of fire hazards, ombrothermic stress on ecosystems and plants, lowering of water resources and modifications on landscapes and agricultural practices. Some submittal ecosystems may disappear entirely due to a sort of « shrinking island » effect due to the upward biomic shift previously mentioned. For the piémont formations, the two possibilities are adaptation on the spot or moving northward and upward. Along the coast, new ecosystems may expand for instance arid bioclimates along the southern coast of Crete. All these elements are threatening the touristic attractivities of the Mediterranean islands for tourism becoming an activity at risk from both economic and ecologic viewpoints. For instance, the island of Porquerolles (15 km², 200 permanent inhabitants) has 15000 visitors per day in July and August requiring the transfer of drinkable water from the continent via tanker for a total cost of 450,000 € after over exploitation of local underground water. By chance, this island along the French Riviera should not be heavily impacted by the CC but this is not the case for many islands and archipelagos in the eastern part of the Mediterranean as we will see down below.

Table 2 provides specific evolution on a subset of islands from various geographical contexts or presenting noteworthy trends. North-west islands like Porquerolles, Asinara[12] and Majorca show a moderate rise of temperature ($\Delta T<2.2°C$) and no depletion of rainfall ($\Delta P<2\%$). Mallorca is a major tourism spot with 10 million visitors each year. The Krk island along the Dalmatian coast is peculiar with a noticeable increase of temperature ($\Delta T=2.46°C$) and no change for precipitations while it is the opposite in Malta with moderate thermic change ($\Delta T=1.95°C$) and a 7% depletion of rainfalls. It is worth noting that the population of the mainland of Malta *per se* is equal to 1600 inhabitants/km² with very few surface water available in a mostly karstic geological context. On top of that, the island hosts 1 million tourists per year. The geological setting of Jerba along the desertic coast of southern Tunisia is fairly similar to Malta but in a semi arid environment and far more visitors, about few millions mostly from France. The rise of temperature would be of 2.66°C and 9% (18 mm) depletion for rainfall. Cephalonia within the Ionian archipelago has a low density of population with 36 Inh./km² and a limited number of visitors, about 100000/year. The thermal evolution would be inferior to 2°C but with a significant drop of rainfall ($\Delta P=-6{,}5\%$).

The projections of CC are more worrying for all the islands of the Aegean sea or close to the Anatolian peninsula. In the northern part of the "archipelago"[13], the CC is superior to the regional evolution both in terms of temperatures ($\Delta T>2.6°C$) and rainfalls ($\Delta P<-10\%$ or -57 mm) ; the maximal thermal evolution is taking place in Thassos and Samothrace ($\Delta T=2.83°C$) and the maximum depletion of rainfall is observed on Marmara Adas ($\Delta P=-10.8\%$ or -74mm) surrounded by the close mainland of Europe and Asia in the sea of Marmara. The two islands selected in the south-east of the Aegean sea are Rhodes and Samos whose main characteristic compared to the previous is a lower thermal rise ($\Delta T\approx 2.13°C$) combined with a similar rainfall

[12] Asinara is a nature reserve with few visitors apart from scientists. It is the largest Mediterranean island (52 km²) with no permanent human population.

[13] Former name of the Aegean Sea.

deficit (ΔP≈9.2% or -75mm). The comparison of the impact of CC on water budget for these two islands will be analyzed in detail in the following part.

	Name of the islands	Other name	Country	Area (km²)	Longitude	Latitude	Altitude	Temperature 1950-2000 (°C)	Temperature 2050 (°C)	Precipitation 1950-2000 (mm)	Precipitation 2050 (mm)	Climate change (CC) ΔT (°C)	Climate change (CC) ΔP (mm)	Climate change (CC) ΔP (%)	Population Inhabitants	Population density km²	Closest mainland (km)	Closest mainland Country
	Mallorca	Majorca	Spain	3645	2,958	39,608	159	16,01	18,19	604	594	2,18	-10	-1,7	924 000	254	170	Spain
	Porquerolles		France	15	6,213	42,999	16	15,23	17,35	717	738	2,12	21	2,9	200	13	2.3	France
West	Asinara		Italy	54	8,284	41,055	148	15,8	17,64	562	561	1,84	-1	-0,2	0	0	1.7	Sardinia
	Jerba	Djerba	Tunisia	514	10,881	33,791	13	19,89	22,55	213	195	2,66	-18	-8,5	164 000	319	2.5	Tunisia
	Malta		Malta	251	14,444	35,886	75	18,46	20,41	523	487	1,95	-36	-6,9	402 000	1599	85	Sicily
	Krk		Croatia	413	14,615	45,068	148	13,5	15,96	1284	1289	2,46	5	0,4	17 900	43	0.5	Croatia
to	Cephalonia		Greece	795	20,578	38,218	357	16,03	17,98	1006	941	1,95	-65	-6,5	35 800	45	33	Greece
	Thassos	Thasos	Greece	390	24,655	40,685	307	13,57	16,4	565	508	2,83	-57	-10,1	13 800	35	6.2	Greece
	Samothrace	Samothraki	Greece	184	25,586	40,455	436	12,9	15,73	649	582	2,83	-67	-10,3	2 800	15	36	Greece
	Gokceada	Imbros	Turkey	290	25,842	40,159	161	14,69	17,47	655	590	2,78	-65	-9,9	6 520	22	16	Turkey
	Lesbos	Mytilene	Greece	1653	26,243	39,168	213	15,76	18,34	640	577	2,58	-63	-9,8	86400	52	12.5	Turkey
East	**Samos**	**Anthemousa**	**Greece**	**486**	**26,812**	**37,731**	**321**	**16,26**	**18,49**	**762**	**689**	**2,23**	**-73**	**-9,6**	**33 000**	**68**	**1.7**	**Turkey**
	Marmara Adas	Prokonnisos	Turkey	117	27,623	40,623	204	13,02	15,78	683	609	2,76	-74	-10,8	6 310	54	9	Turkey
	Rhodes	**Rhodos**	**Greece**	**1413**	**27,956**	**36,182**	**199**	**18,07**	**20,11**	**879**	**801**	**2,04**	**-78**	**-8,9**	**115 500**	**82**	**17.7**	**Turkey**
	Cyprus		Cyprus	9317	33,223	35,042	303	17,83	19,96	517	463	2,13	-54	-10,4	1 190 000	128	71	Turkey

Table 2 - *List of islands from west to east with their climatic evolution from 1950-2000 to 2050.*

1.3. The evolution of water balances with the ombrothermic method

Let's consider now the seasonal impact of CC on the bioclimat of the Mediterranean islands. We make use of the Bagnouls and Gaussen method (Bagnouls & Gaussen, 1957) (Gaussen, 1960) which is specifically suitable to analyze the Mediterranean climate by providing insights on the water budget. From the monthly values, it gives crude figures on the hydrological seasonality all year long especially on the duration of the "xeric period" when the precipitation in mm is below twice the temperature in °C. The water budget is defined as follow:

[3] P = Sw + ETp and ETp=ETa – EDs

with P the precipitation
Sw the winter water surplus (If P>2T then P-2T)
ETp the potential evapotranspiration (2T), ETa actual evapotranspiration
EDs the summer evapotranspiration deficit due to water shortage with "hydric stress" for the vegetation (If P<2T then 2T-P) called the "xeric period" by Bagnouls and Gaussen.

Another point to mention stands on the fact that the potential evapotranspiration as estimated by the method of Holdridge-Whittaker on a yearly basis is based on the assumption that ETp=58.9 T, equivalent to 5 mm/month/°C. Compared to the Holdridge-Whittaker assumption applied to all bioclimates of the globe, the Bagnouls and Gaussen method just refers to Mediterranean contexts with a hypothesis of 2 mm/month/°C.

The Table 3 resumes the results given by Bagnouls and Gaussen method for the Mediterranean islands for the two periods. There is a drop of 43 mm for the winter water surplus (-12% for Sw), a rise of the potential evapotranspiration of 50 mm (+13% for ETp) and a significant increase of the summer evapotranspiration deficit of 40 mm (+38% for EDs).

	Month (mm)	CW0 1950-2000			CW123 2050		
		Sw	ETa	EDs	Sw	PE	EDs
	October	41	35	0	35	39	0
Autum	November	58	27	0	53	31	0
	December	80	20	0	74	24	0
Winter	January	72	17	0	63	21	0
	February	55	18	0	49	22	0
	March	43	21	0	38	24	0
Spring	April	18	26	0	11	30	0
	May	0	34	4	0	38	12
	June	0	42	26	0	46	33
Summer	July	0	48	39	0	52	46
	August	0	48	33	0	53	43
	September	0	43	7	0	47	16
	Year	367	377	109	324	427	150
	P=Sw+ETa-EDs			635			601
	Δ(CW123-CW0)				-43	50	40

Table 3 - *Monthly water budget over the Mediterranean islands during the periods 1950-2000 (WC0) and 2050 (WC123).*

The monthly water balance can also be presented as “ombrothermic curves,” as shown in Figure 3, within the graduation of precipitation in mm on the right being half the size of those of temperatures on the left. For the entire set of Mediterranean islands, the seasonal evolution cycle between the two periods indicates a 5% lessening of precipitation during the year and a higher temperature rise in summer and autumn (+2.23°C, maximum +2.53°C in August) than in winter and spring (+1,83°, minimum +1,76°C in March and April). Both tendencies induce a longer summer dry season in 2050 compared to 1950-2000 (Figure 3A). During the period 1950-2000, the summer dry season covers about 4.5 months starting from 10 May (Figure 3B) while it starts by the end of April and last 5 months in 2050 (Figure 3C). Daily deficits are 0.8 mm/day for the period 1950-2000 and 1 mm/day for 2050. These two tendencies suggest a significant amplification of the hydric stress on vegetation, both in terms of duration and intensity. The impact of CC is less drastic during the wet season in autumn and winter which remains more or less concomitant with the autumn equinox but stops two weeks earlier in the spring. The intensity of water surplus does not change much with 1.5 mm/day in 2050 instead of 1.57 mm/day in 1950-2000.

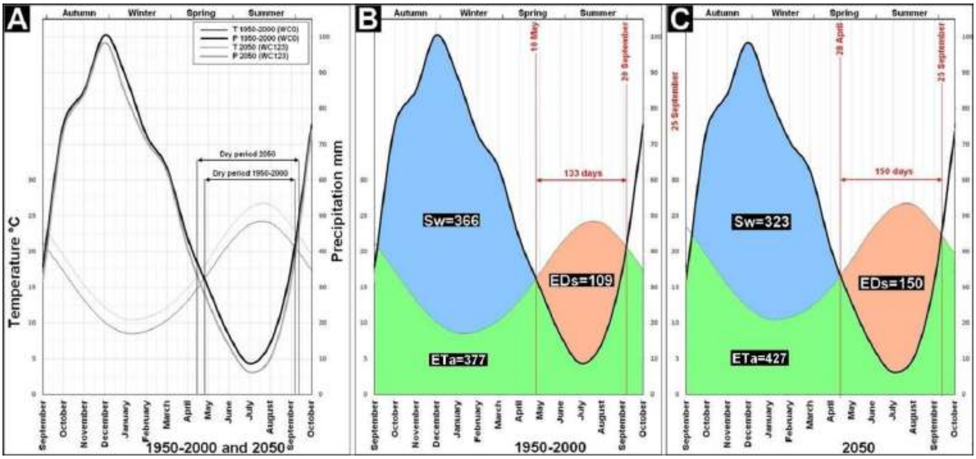


Figure 3 - *ombrothermic curves for the Mediterranean islands*
A./ Comparison between the periods 1950-2000 and 2050.
B./ Water budget for the period 1950-2000.C./ Water budget for the period 2050.

1.4. The cases of Rhodes and Samos islands

As shown on Map 1, the Aegean Sea should be more impacted by CC than other sub regions of the Mediterranean especially in its North West part. For instance in the cases of Rhodes and Samos (Figure 4), the precipitation deficit of 10% occurs mainly in winter while the dry periods of the two islands become more severe and last almost 5.5 or 6 months[14] instead of 4.5 to 5 months at regional scale. On both islands, the CC modifies significantly the water balance between winter surplus (Sw), potential evapotranspiration (ETp) and summer evaporation deficit (EDs). The following chapter presents a more detailed comparative analysis of these two Aegean islands. Those two islands were selected first of all because Rhodes appears to be a typical local economy based on mass tourism while the economy of Samos is less dependent on this activity. Second point, they are both close from the mainland of Anatolia but Samos further north into the Aegean sea whereas

[14] The results refer to the average values for each island and not a specific localization within them.

Rhodes is more "oceanic" due to its location at the limit of the Aegean inland sea and the Mediterranean open sea (cf. Map 1B). Last but not the least; climatic data from synoptic stations over a long period is available on the two islands.

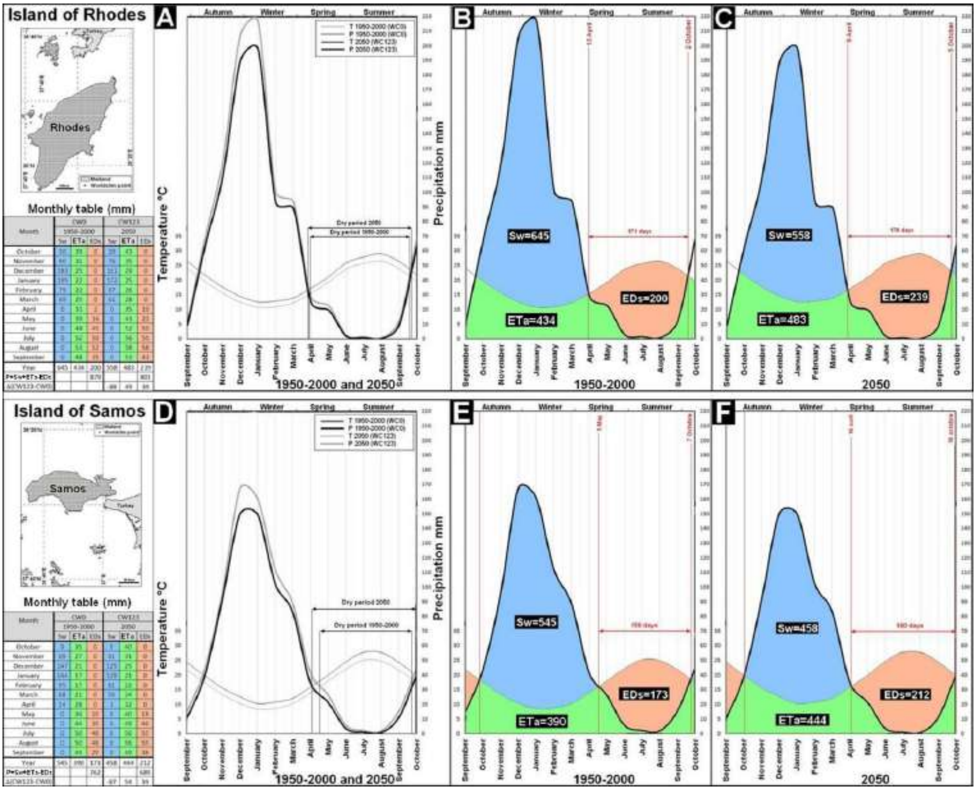


Figure 4 - *Ombrothermic curves of the periods 1950-2000 and 2050 for Rhodes and Samos*

A./ Comparison between the two periods for Rhodes.

B./ Water budget for the period 1950-2000 for Rhodes.C./ Idem for the 2050s.

D./ Comparison between the two periods for Samos.

E./ Water budget for the period 1950-2000 for Samos. F./ Idem for 2050.

2. Comparison between the islands of Rhodes and Samos

The climate of Greece is typical northern Mediterranean, with mild and wet winters, relatively hot and dry summers and, generally, long periods of sunshine for the most part of the year. Moreover, in the summer period, the tourism and agricultural sectors are the most significant water users and important for the country's economic welfare (Tsesmelis & al., 2019).

2.1. Comparison from meteorological stations for the period 1979-2019

The analysis of water budgeting at the scale of the two islands of Rhodes and Samos should reflect the general trends of the Aegean islands and Cyprus. For comparison purpose with the WorldClim data used previously, climatic observations are available at the meteorological stations of the airport of Rhodes (28.12°E 36.40°N) from 1955 to 2019 and the airport of Samos (26.92°E 37.7°N)[15] from 1979 to 2019. The linear regressions over the period 1979-2019 (*Figure 5*) suggest that the trend of rainfall decrease is far more accentuate for Samos compared to Rhodes with respectively -2.8 mm/year instead of -1.5 mm/year. Compared to the mean annual rainfall at the Samos and Rhodes stations (respectively 675 and 641 mm) for the period 1979-2019, the depletions are of 17% for Samos and 10% for Rhodes. For temperatures during the period 1979-2019 (41 years), the evolution is +1.71°C (+0.042°C/year) for Samos and +1.32°C (+0.032°C/year) for Rhodes. These trends observed on meteorological stations prove that CC was more acute in Samos than in Rhodes between 1979 and 2019.

[15] Both stations are located in the coastal lowlands and are not representative of the mountainous hinterland.

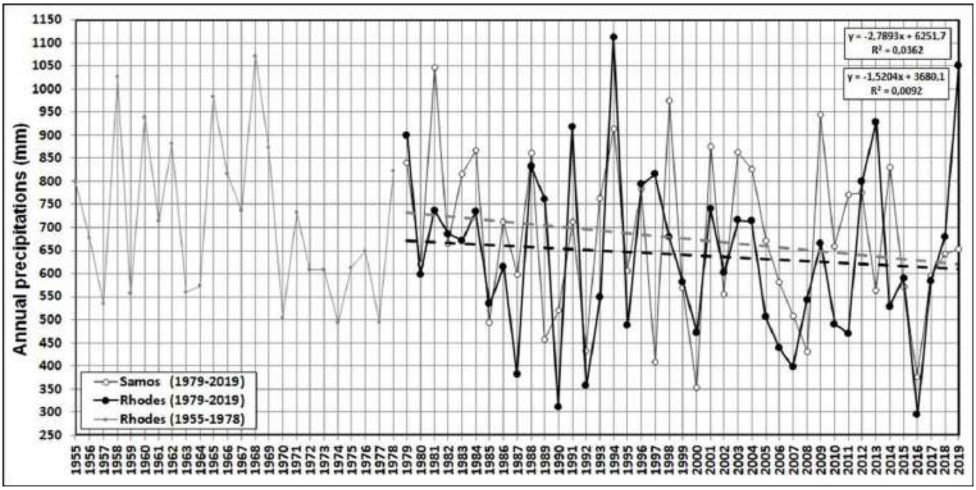


Figure 5 - *Evolution of temperatures and precipitations at the meteorological stations of Rhodes and Samos from 1979 to 2019.*

Comparison of climatic values between the two stations is worthwhile to understand the spatial relationship of rainfall and temperature knowing that the distance between the two islands is 200 km. While yearly temperatures are significantly correlated (*Figure 6*A, R=0.85), this is not the case for precipitation which is more under the control of microclimatological factors, for instance windward and leeward localization depending on the dominant of advective air masses (*Figure 6*B, R=0.23)

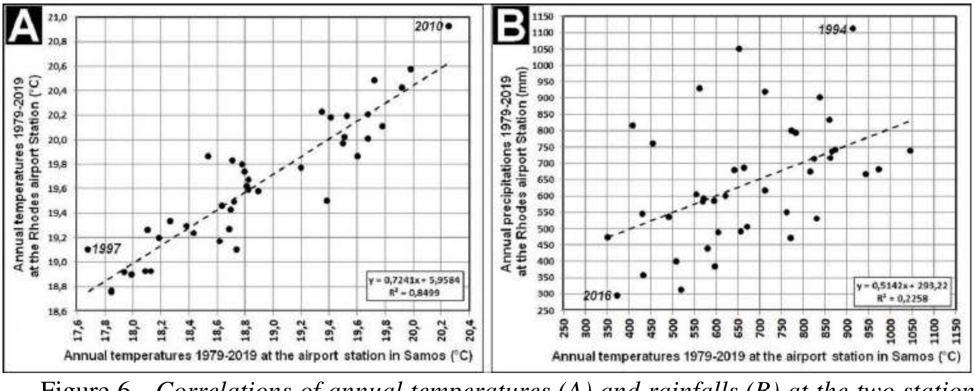


Figure 6 - *Correlations of annual temperatures (A) and rainfalls (B) at the two stations of Rhodes and Samos from 1979 to 2019.*

The seasonal cycles on the two islands as given on Figure 7 are fairly similar; the minor differences concern more precipitation in Samos in December and a "xeric" period starting one week later in Samos but with the same duration of 181 days, about 6 months. Consequently, their water budgets are almost identical with about 457 mm for the actual evapotranspiration (ETa), between 381 and 453 mm for winter surplus (Sw) and 225 mm for summer deficit (EDs xeric period). We notice also that the annual amplitude of temperature is slightly higher is Samos compared to Rhodes[16].

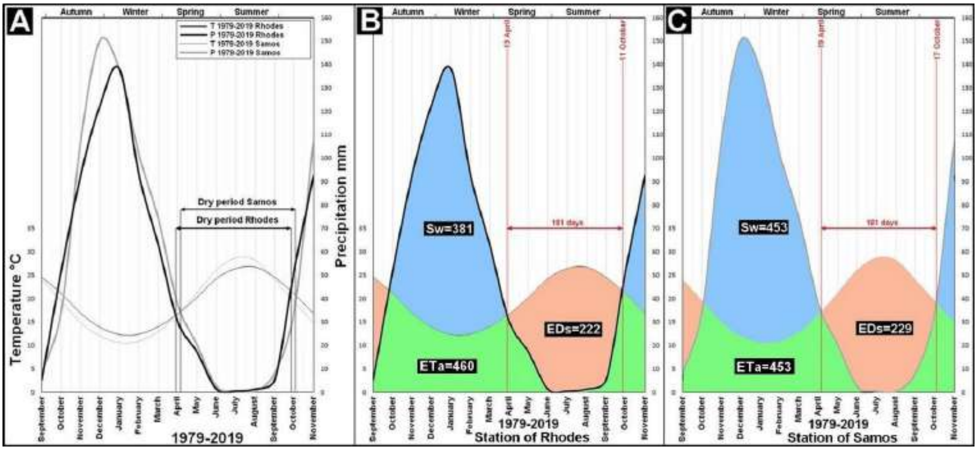


Figure 7 - Ombrothermic curves for the stations of Rhodes and Samos for 1979-2019.
A./ Comparison between the two stations.
B./ Water budget for the ARIMA
station of Rhodes (28.12°E 36.40°N).
C./ Water budget for the station of Samos (26.92°E 37.7°N).

2.2. Evolution from 1950-2000 (current, WC0) and 2050 (WC123)

It is worth comparing the figures at the meteorological airport station of Rhodes for the period 1955-2000 (691 mm/year) with the interannual data at the equivalent WorldClim grid point for 1950-2000 (894 mm/year) (*Figure 8*A). The major discrepancy occurs from November to January with a 44% over estimation of rainfalls of WorldClim data (568 mm) compared to data of the meteorological station (395 mm). The same calibration was done at the meteorological station of Samos for 1979-2000 with also an over estimation of rainfalls with 762 mm instead of 683 mm/year resulting from precipitation from September to January (496 mm at the grid point instead of 429 mm at

[16] These results can be compared to the same ombrothermic curves computed from WorldClim data over the period 1950-2000 and 2050 in Figure 4.

the station). Those discrepancies will mostly affect the cold season water surplus (Sw) as it is the case on Rhodes.

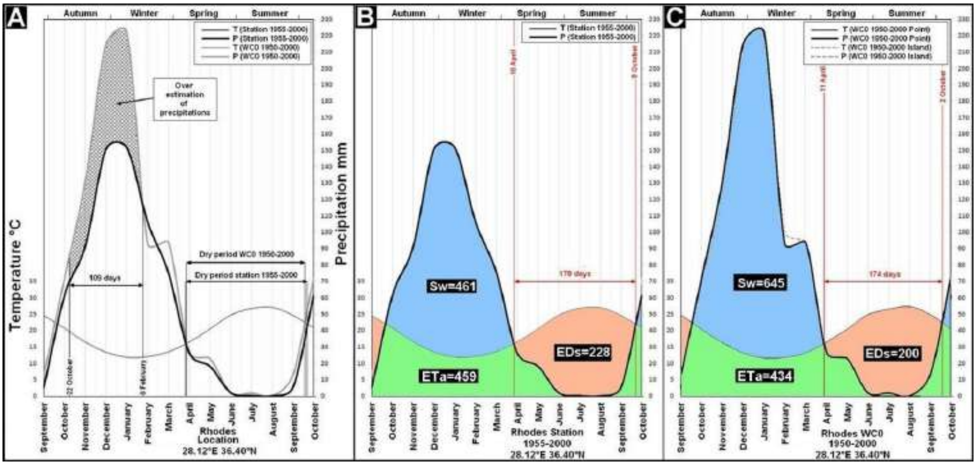


Figure 8 - *Ombrothermic curves at the location of the station of Rhodes airport*

A./ Comparison between the station (1955-2000) and the WorldClim point (WC0 1950-2000).

B./ Water budget et the meteorological station of Rhodes airport (1955-2000).

C./ Water budget of the WordClim grid point (WC0 1950-2000) at same location.

These differences can be interpreted as an interpolation bias in the WorldClim data. For consistency between the various sets of data, this suggests that specific correction factors[17] have to be applied for both islands and the two periods 1950-2000 and 2050 on the WorldClim data (WC0 and WC123). The same calibration has been performed for Samos:

[4] Correction factors for Pma 1950-2000 and 2050:
for Rhodes $CF_{Rhodes}=691/894=0.77$, *for Samos* $CF_{Samos}=683/762=0.9$

[17] As shown on Figure 8A for Rhodes, rainfalls over the months November to January given by the WorldClim dataset are overestimated compared to the data from the synoptic station. This also true from Samos.

2.3. Estimation of streamflow depletion due to rainfall deficit

This climatic evolution has direct consequences on the water balance of islands and their catchment basins within them, including streamflow. The conceptual model MEDOR[18] specifically developed for mountainous Mediterranean basins is used to transform the annual precipitation *Pma* into mean annual streamflow *Qma* (Hreiche, Najem, & Bocquillon, 2007) and provide an adjusted function as shown on Figure 9:

[5] Qma = 1.23 Pma²/(Pma+2500) with Qma and Pma in mm.
Relative percentage of streamflow : S%= 100.Qma/Pma

This proves that river discharges are drastically influenced by the variability of annual precipitations on mountainous Mediterranean catchments.

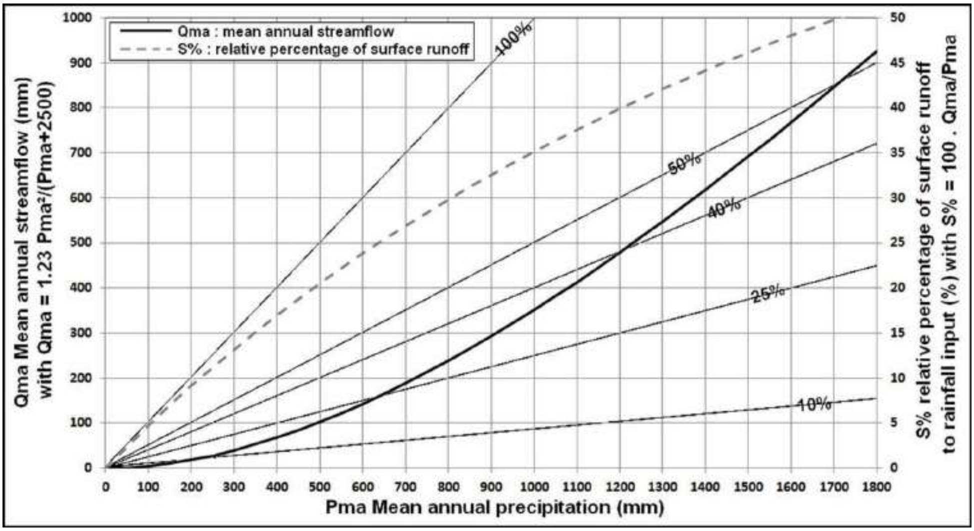
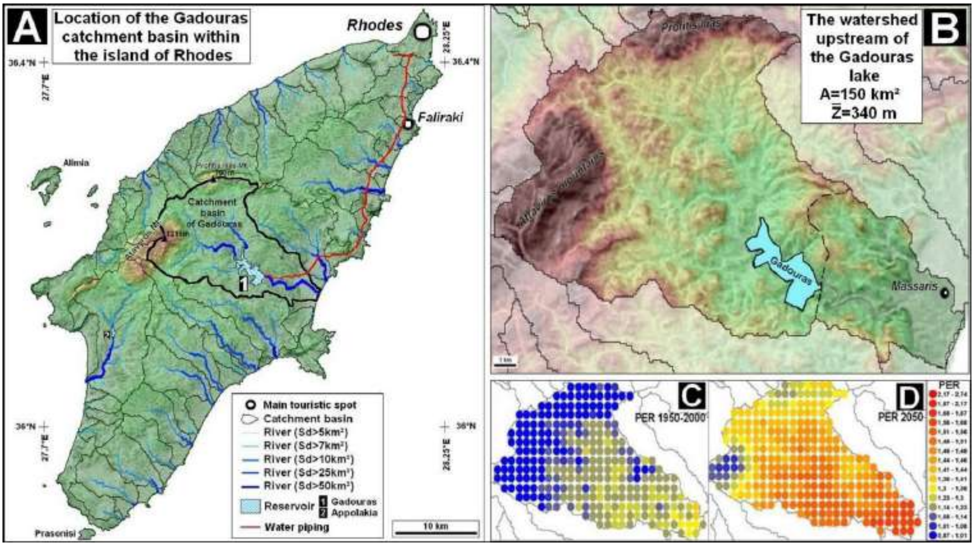


Figure 9 - *relationship between the mean annual precipitation (Pma) and the mean annual streamflow (Qma) according to the MEDOR model.*
The lines correspond to the abacus of the streamflow percentages (S%).

[18] This model has been calibrated on the Nahr-Beyrouth catchment basin with 216 km² in Lebanon. This simple empirical model is used because the general bioclimatological and morphostructural setting of the Gadouras basin is quite similar to the Nahr-Beyrouth watershed. It reflects a more generic relationship between rainfall and streamflow not only observed in the Mediterranean region but also on other climatic zones.

For instance, the Gadouras is the main watershed of Rhodes (190 km²). The construction of the Gadouras dam began in 2001 but the fill up of the reservoir from the upstream area (150 km²) only started in 2005 and finally reached full capacity (67.5 million m^3) and extent (4.37 km²) during winter 2011, after a prolonged period of rainfall (Corsini-Foka, 2009). The averaged streamflow per year minus the water balance of the lake itself (Q_{MEDOR}-WB_{LAKE}) is consistent with observation of Corsina-Foka (Figure 10). Considering the average values for the period 2005-2019, the possible water abstraction should be about 23 million m^3 per year thus 63 000 m^3 per day. Nevertheless after 2011, precipitation and even more streamflow show a strong interannual variation with almost no river flow during the dry year of 2016 (300 mm); conversely the streamflow in the wet year of 2019 (1050 mm) is five time superior to the average annual figures.



Map 2 - The island of Rhodes with the catchment basin Gadouras and its reservoir.
A./ Hydrographic map of Rhodesand location of the Gadouras catchment.
B./ The Gadouras catchment (184 km²)and its reservoir with upstream area of 150 km².
C./ Potential Evaporation ratio (PER) 1950-2000 on the Gadouras catchment D./ PER 2050.

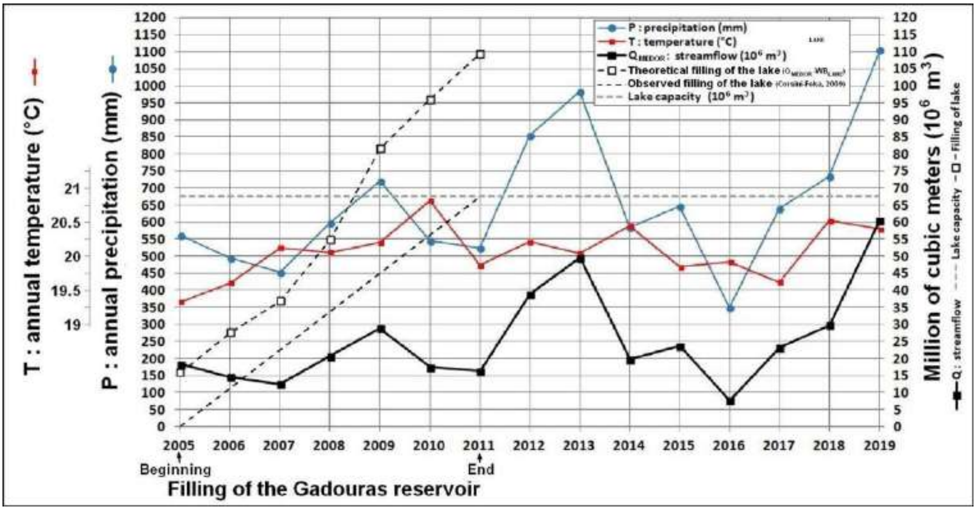


Figure 10 - *The catchment basin upstream from the Gadoura dam (150 km²) from 2005 to 2019.*
(Temperature T and precipitation P from the station at the airport,
Q estimated from Pwith the MEDOR method)

The water balance of the Gadouras prior to the beginning of the dam construction (2001) was estimated from previous hydroclimatic data more or less equivalent to the WorldClim data over the period 1950-2000 (WC0). The impacts of CC (Tma and Pma) in 2050 on the water balance of the upper Gadouras catchment (145.5 km² Table 4A) should be as follow: depletion of precipitation (-8.8%), streamflow (-13.5%), groundwater recharge (-18.8%), rise of summer water deficit (+28%) and actual evapotranspiration (+4.9%). For the lake itself (4.75 km² Table 4B), the loss resulting from free surface evaporation may increase of 85% by comparing the reference period 1950-2000 (WC0) with the projection for 2050 (WC123).

As a reminder, the mean annual precipitations Pma of the reference period 1950-2000 (WC0) are overestimated as described before in Figure 8. Therefore, the correction factor CF_{Rhodes} has been used for precipitations for period 1950-2000 and also for 2050.

Upper Gadouras basin (145.5 km²)			
	1950-2000	2050	Trend (%)
Tma (°C)	17,3	19,4	2,03
EDs (mm)	116	144	28
Pma=ETa+Q+GWr	10^6 m^3	10^6 m^3	%
Pma*	112	102	-8,9
ETp	148	166	11,9
ETa	33	35	4,9
Sw=Q+GWr	79	67	-14,6
Q_{MEDOR}	32	28	-15,2
GWr=Sw-Q_{MEDOR}	46	40	-14,3

Gadouras lake (4.37 km²)			
	1950-2000	2050	Trend (%)
Tma (°C)	18,6	20,7	2,03
EDs (mm)	138	151	13
Water Balance	10^6 m^3	10^6 m^3	%
Pma	*2,78*	2,54	-8,7
ETp	*4,79*	5,32	11,1
WB_{LAKE}= Pma-Etp	*-2,01*	-2,78	38,3

Table 4 - Water balance of the upstream area of the Gadouras reservoir (A) and of the lake (B):

Tma and Pma from WorldClim WC0 and WC123, ETp, ETa et Sw by Bagnouls and Gaussen method, Q(MEDOR) from the MEDOR method.

**with correction factor of 0.7 for November, December and January (Cf. Figure 8A)*

This case study on the Gadouras reservoir and its upstream catchment basin illustrates the issues of the surface water damming and exploitation on Mediterranean islands in the context of CC.

2.4. Estimation of the water balance evolution with a hydrological model

For consistencies purposes, the water balance can be estimated and projected with other methods than the previous noticeably from hydrological models. The AgroHydroLogos model (Soulis & Tsesmelis, 2017) computes the water balance from current climatological conditions or from 2021-2050 scenario estimated with the seasonal ARIMA[19] forecasting method (Table 5). This method deserves some explanations; Statistical forecasting has been widely used in a plethora of disciplines and especially in cases where management and decision making should take place. However, a variety of forecasting methods and trend extrapolations seems to be the one predominantly used (Karavitis, Vasilakou, & Tsesmelis, 2015). According to Shatanawi (Shatanawi, Rahbeh, & Shatanawi, 2013), various methods can be used for extrapolation and predictions based on historical records assuming no threshold phenomena. However, the ARIMA models introduced by Box and Jenkins (1976) may be considered as the most relevant tools for the study

[19] Precipitation and temperature values from January 2021 to December 2050 were used as input for the future projections in the AgroHydroLogos mode, including Seasonal ARIMA (Auto Regressive Integrated Moving Average) model with a seasonality of 15 years (https://www.ewra.net/ew/pdf/EW_2015_49_04.pdf).

of time series. These particular models have been widely used in water resources management and drought forecasting. The generalized form of ARIMA models, as well as their customization according to the needs are called to serve, is described in pertinent literature."[20]

The depletion of precipitation is about the same on both islands and equal to the previous estimation: between 9 and 10%. The runoff evolution is also similar on both islands with a decrease of 6% which is far less than the 15% expected with the MEDOR statistical method. The case of groundwater recharge appears to be more contrasted between the two islands. While the figure for Samos indicates a lessening of nearly 50%, it becomes even worse for Rhodes with a drastic reduction of 71% of the recharge. These scenarios for the groundwater evolution as given by the hydrological model are far superior to the estimate of 15% depletion coming from previous method in particular on the upper Gadouras catchment basin (cf. table 4).The drastic reduction of ground water recharge could be attributed to the reduced rainfall depths in conjunction with higher potential evapotranspiration rates under future projections as well as to the expected more uneven distribution of rainfall (i.e. fewer and more intense storm events) favoring surface runoff. The above results highlight the vast uncertainties involved in any future projections hampering management plans.

To conclude about the various estimations, the AgroHydroLogos model suggests a moderate reduction of runoff of only 6% while the MEDOR statistical method predicts a streamflow decrease superior to the rainfall depletion of 10%. The most striking fact, if the evolution of the groundwater recharge given by the model would be confirmed, is that most of aquifers and coastal water lenses might be shrinking to the point where this resource could not be exploitable anymore in the forthcoming decades or even earlier. Considering also that coastal aquifers are more sensitive to sea water intrusion, the problem may be even worst in smaller islands.

[20] Cf. (Box, Jenkins, & Reinsel., 1994), (Papamichail, Antonopoulos, & Georgiou, 2000), (Montanari, Rosso, & Taqqu, 2000), (Mishra & Desai, Drought Forecasting Using Stochastic Models, 2005), (Hana, Wang, Zhang, & Zhu, 2010), (Mishra & Singh, 2011) and (Manakos, Georgiou, & Mouratidis, 2011).

Water balance (Pma=Gwr+R+ETa) and total abstraction		Rhodes (1408 km², 152 538 inhabitants)							Samos (479 km², 33 339 inhabitants)						
		Current			2050			Trend	Current			2050			Trend
		mm	10^6 m^3	%	mm	10^6 m^3	%	%	mm	10^6 m^3	%	mm	10^6 m^3	%	%
Pma	Mean annual precipitation	593	835	100	535	753	100	-10	714	342	100	649	311	100	-9
Gwr	Ground water recharge	83	117	14	24	34	4	-71	153	73	21	78	37	12	-49
R*	Runoff	183	258	31	172	242	32	-6	242	116	34	227	109	35	-6
ETa	Actual ET	327	460	55	339	477	63	4	319	153	45	344	165	53	8
A**	Total Water abstractions	26	36	10	No scenario				10	5	3	No scenario			

** From runoff plot 1000 m². ** the percentage (%) refers to 100 A/(Gwr+R).*
Table 5 - Water balance estimated for the current period and 2050 (from AgroHydroLogos and ARIMA models)

3. Consequences for future development of tourism in the Mediterranean islands from the examples of Samos and Rhodes

3.1. Tourist abstractions on Rhodes and Samos

The ability to provide sufficient water quantity to various settlements has always been a major concern for islands. In Samos, the Tunnel of Eupalinos, constructed in the 6th century BC, was an aqueduct transferring water from the north to the south part of the island, where the ancient capital (today Pythagoreio) was located. Cisterns, public and private, were a very widespread practice in order to collect rainwater during the rainy season and use it during the drought period. Until the beginning of the tourism era in the 1970s, important parts of the islands and almost all the villages did not have tap water; consequently, the water consumption was limited. The situation in agriculture regarding irrigation was not very different; most of the cultivations were arid using seeds adapted to the local conditions. The electrification of the Greek islands allowed the easier transfer of water and consequently the situation changed substantially. The consumption of water skyrocketed even when local population and agriculture activity were declining, at the exception of Rhodes where the population increased. At the same time, the building of new hotels, rooms to let and private houses used for resorts as well as tourist arrivals were increasing dramatically.

Figure 11 shows the evolution of arrivals at the islands both by air (domestic and international/charter flights) and by sea (ferryboat). The two islands had a quite different evolution during the last 20 years; Rhodes saw an increase of total arrivals by 48%, but Samos had a decrease of -18.6%. In 2018, 2,431,397 tourists arrived on Rhodes and 207,591 on Samos. They stayed for 15,487,998 and 1,370,100 overnights respectively.

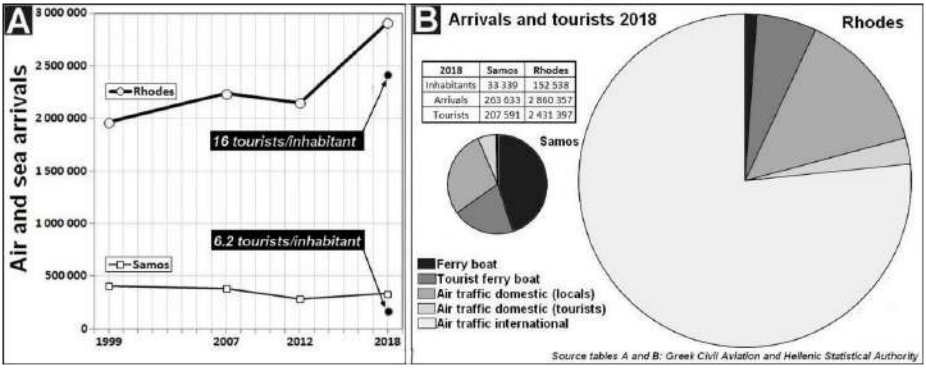


Figure 11 - *Air and sea arrivals in the islands of Rhodes and Samos.*
A./ Evolution from 1999 to 2018. *B./ Tourism data on the islands in 2018.*

Tourism pressure on an island can be estimated through the following indicators (Spilanis, Vayanni, & Glyptou, 2009):

(1) Number of tourism beds per population: There are two possible calculations: the first considers only the commercial tourism beds while the second also incorporates the private houses that are used as summer resorts. Rhodes has a higher pressure (0.85 and 1.42) compared to Samos (0.43 and 1.62), the latter having a higher number of private houses. This means that any day of the year (mainly the pick of the season) the population on the island of Rhodes can be almost two times higher than the local population. These scores place them in the middle of the Aegean Islands' scale as there are islands with very few beds (even lower than 0.1 bed per inhabitant) while others that have more than 2.0 (i.e. Santorini has 2.39 and 3.93 respectively).

(2) Number of tourism beds per surface: For this indicator, the pressure on Rhodes and Samos is even lower: 29.8 for Samos and 70.5 for Rhodes when in Santorini there are 480 beds per square kilometre.

(3) Number of tourist overnights per number of locals: Based on the total arrivals on the islands by the two only ways that someone can enter an island (by boat and by plane), we estimate the number of tourists and their total number of nights spent. By dividing the total amount of tourist overnights with 365 we calculate the "*inhabitant equivalent tourist*" which gives us a better grasp of the total tourism pressure on an island (+36.7 for Rhodes, +11.4 for Samos).

The total consumption of drinking water in Rhodes is roughly 26,470,000 m^3 including surface and pumped water (Table 6A and Figure 12) for a total population of 157,922 inhabitants including 42,432 tourists (inhabitant equivalent) and 115,490 locals. Keeping in mind that the water piping system on both Rhodes and Samos is quite old and inefficient and that is in some Greek cities the water losses can be more than 50% (Moutsopoulos & Petalas, 2018), we assume that there is an approximately 30% water loss. So, the average consumption per capita about 117.33 m^3 per year and 0.32 m^3 per day, or 0.516 m^3 per tourist and 0.25m^3 per local and the yearly total consumption attributed to tourism is estimated at approximately 7,990,538 m^3. It is important to note that the consumption of drinking water is higher than the consumption for irrigation which shows that the pressure of human activity and mainly tourism is high on the island. The quality of the aquifer is considered as good on the whole island. Only in the Kalathou-Gadoura area at the centre of Rhodes the risk of salinization is high as 90% of the available water is consumed including 62% for drinking water.

The total consumption of drinking water in Samos (Table 6B and Figure 12) is approximately 4,690,000 m^3 for a total population of 36,730 inhabitants including 3,753 tourists (inhabitant equivalent) and 32,977 locals (:(Spilanis, Vayanni, & Karampela, 2007) (Spilanis, Vayanni, & Glyptou, 2014)). This gives an average per capita consumption of 89.38 m^3 per year and 0.245 m^3 per day. The daily average consumption is 0.288 m^3 per tourist and 0.24 m^3 per local and he yearly total consumption attributed to tourism is estimated at approximately 394,215m^3 [21].The consumption of drinking water is lower than the consumption of irrigation. The consumption is non-existent in the industry and extremely low in the animal husbandry. The pressure on the aquifers is not the same on the whole island as the availability and the consumption of water varies for different areas. From the available data we can conclude that there are two areas on south Samos in which the water consumption is more than the water infiltration and there are signs of salinization. In one of the areas (Kampos) agriculture is the main consumer, but in the other (Messokampos), the consumption of drinking water is higher.

[21] The sharp difference in the daily consumption per tourist between Rhodes and Samos is explained by the fact that while in Rhodes 70% of the tourist beds belong to 4 and 5 star hotels, in Samos only 20% of the beds belong to these categories.

Cubic meters (10^6 m^3) Aquifers of Samos	Average annual supply	Average annual consumption	Irrigation	Water Supply	Animal husbandry	Status
Kerketea (A and B)	15,66	0,34	0,2	0,15	0	Good locally bad
Idrousa - Marathokampos	5,09	1,73	1,36	0,37	0,01	Good
Karvouni	11,62	0,79	0,77	0,02	0	Good
Imvressou	4,08	0,65	0,54	0,1	0	Good
Vourlioton - Milon	4,53	0,8	0,29	0,51	0	Good
Mytilinion	8,14	2,06	1,43	0,63	0,01	Good
Kampos (A)	1,15	0,99	0,87	0,12	0	Good
Kampos (B)	0,34	0,34	0,34	0	0	Bad
Vathi	15,26	1,42	0,4	1,01	0	Good
Mesokampos	0,29	0,64	0,07	0,58	0	Bad
TOTAL (m^3)	66,19	9,76	6,27	3,49	0,02	
TOTAL (%)	100	14,7	9,5	5,3	0,035	

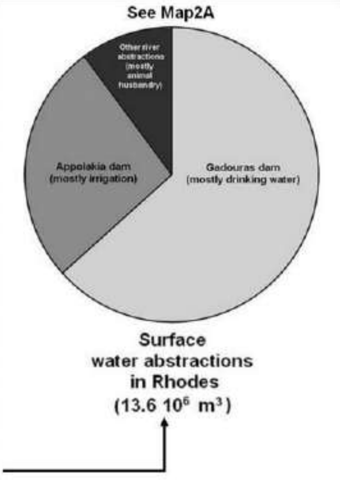
Cubic meters (10^6 m^3) Aquifers of Rhodes	Average annual supply	Average annual consumption	Irrigation	Water Supply	Animal husbandry	Status
North section of Rhodes (A)	34,98	15,18	6,37	8,73	0,08	Good
North section of Rhodes (B)	4,44	2,13	0,66	1,46	0,01	Good
Prophet Elia	3,91	0,01	0,01	0	0	Good
Epta pigon	6,06	2,32	1,22	1,1	0,01	Good
Kalathou – Gadoura	3,4	3,07	1,15	1,91	0	Good
Central Rhodes	63,09	6,51	5,16	1,32	0,02	Good
Attavirou	6,72	0,22	0,22	0	0	Good
Apolakkia	4,48	1,87	0,8	1,06	0	Good
Gennadiou	8,19	2,99	0,7	2,29	0,01	Good
TOTAL (10^6 m^3)	135,27	34,3	16,29	17,87	0,12	
TOTAL (%)	100	25,4	12	13,2	0,091	

Table 6 - *Annual infiltration and consumption in the aquifers of Rhodes (A) and Samos (B).*

Source A and B: First revision of the water basin management plan of the water department of the Aegean Islands (2017).

Data refers to various years and periods between 2012 and 2015 depending of the island and the aquifer.

A RHODES Water system name	Type of water system	Annual consumption (10^6 m3)	Uses		
			Drinking water	Animal husbandry	Irrigation
Gadoura dam	Dam	8,621	*	*	
Apolakkia dam	Dam	3,601		*	*
Platis	River	0,489	*	*	
Kolonitis	River	0,451		*	*
Argiros	River	0,273		*	
Gadouras	River	0,1192	*	*	
Loutanis	River	0,009		*	
Pelemonis	River	0,007		*	
Sianitis	River	0,006	*	*	
Karavas	River	0,006		*	
Kremasteikos	River	0,006		*	
Makaris	River	0,004		*	
Kolovrechtis	River	0,003		*	
Fonias	River	0,003		*	
Petaloudes	River	0,002		*	
Kipirionas	River	0,0015		*	
Asklipinos	River	0,001		*	
Lahania	River	0,001		*	
Hohlakas	River	0,001		*	
TOTAL RHODES	**Mostly dams**	**13.60**	[4]	[19]	[2]



B SAMOS Water system name	Type of water system	Annual consumption (10^6 m3)	Uses		
			Drinking water	Animal husbandry	Irrigation
River R.	River	0,76	*	*	
Imvresos	River	0,62	*	*	*
Fourniotikos	River	0,24	*	*	
Amfilyssos	River	0,14	*	*	*
TOTAL SAMOS	**Rivers**	**1,76**	[4]	[4]	[2]

Source A and B: First revision of the water basin management plan of the water departement of the Aegean islands (2017)
Data refers to the various year between 2012 and 2015 depending of the island and the water system

Figure 12 - *Consumption of surface water resources of Rhodes (A) and Samos (B).*

Even though not related with tourism, the refugee crisis which peaked in 2015 with nearly a million asylum seekers passing through Greece had a strong impact on those Aegean islands that received huge amounts of people. Samos was and still is one of those islands (Figure 13). After the EU-Turkey agreement on March 2016, the number of new arrivals dropped substantially but the average stay of the asylum seekers on the islands increased from a few days/weeks to many months or even more than a year. As a result, the inhabitant equivalent of Samos in 2019 was increased approximately by 5,000 compared to pre-refugee crisis levels. The average daily water consumption of the people living on the Vathi Hotspot is estimated at approximately 0.064 m^3 per person. For the beneficiaries of the ESTIA Accommodation Scheme[22] the average daily water consumption is approximately 0.17 m^3 per person. For 2019 the total estimated water consumption of refugees and asylum seekers was about 128,885 m^3. Assuming 8,000 refugees with equivalent

[22] UNHCR's Accommodation Scheme is part of the ESTIA programme (Emergency Support to Integration and Accommodation), co-funded by the Asylum, Migration and Integration Fund of the European Union. The scheme provides rented housing to vulnerable asylum-seekers and refugees in Greece.

consumption of local people, the amount of water abstraction should have been 730,000 m^3.

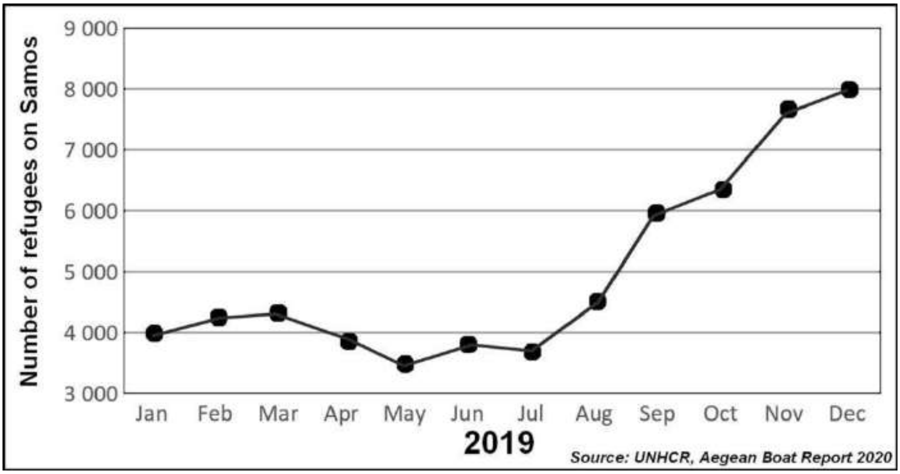


Figure 13 - *Number of asylum seekers and refugees on Samos in 2019.*

3.2. Tourist abstractions versus resources on Rhodes and Samos at present and in the future

Table 7 gives estimations on few elements of the water balance and abstractions compiled from the various previous data and methods. In the case of Samos, the pressure on water due to tourism is moderate: 0.33% of total resources and 4.7% of total abstractions. For Rhodes, the same figures 1.76% and 13.19% indicates a much noticeable use of water resources and supplies (Table 7A). Assuming in Rhodes a 9.34% depletion of rainfall and a 32.6% diminution of surface and ground water in 2050 (Table 7C), the same tourist abstraction would become 2.61 % of total water resource (Table 7B). For Samos, the projection for 2050 remains moderate. It is worth mentioning that for this island there are possibilities to build several hydropower stations on small catchments (Soulis & al., 2016, p. 230).

A	Water balance	Data and	Rhodes (610 mm)		Samos (700 mm)	
2000	**and abstraction**	**methods**	**10^6 m^3**	**%**	**10^6 m^3**	**%**
Pma	Precipitation	WC0 and ARIMA	858,7		335,1	
Gwr+R	Aquifer+Runoff	ARIMA, MEDOR	358,5	41,8	164,9	49,2
A	Total abstraction 2018	Cf. previous tables	47,9	13,4 (A/(Gwr+R))	11,5	7,0 (A/(Gwr+R))
At	Tourist abstraction 2018	Nb. Tourists x Nb. Days x 0.4 m^3/day	6,32	1,76 (At/(Gwr+R))	0,54	0,33 (At/(Gwr+R))
At	Tourist abstraction 2018	Nb. Tourists x Nb. Days x 0.4 m^3/day	6,32	13,19 (At/T)	0,54	4,7 (At/A)
B	**Water balance**	**Data and**	**Rhodes (553 mm)**		**Samos (635 mm)**	
2050	**and abstraction**	**methods**	**10^6 m^3**	**%**	**10^6 m^3**	**%**
Pma	Precipitation	WC123 and ARIMA	778,5		304	
Gwr+R	Aquifer+Runoff	ARIMA, MEDOR	241,7	31	129,6	42,6
At	Tourist abstraction 2050*	Nb. Tourists x Nb Days x 0.4 m^3/day	6,3	2,61 (At/(Gwr+R))	0,5	0,42 (At/(Gwr+R))
** Hypothesis: same At as 2018*						
C	**Evolution of**	**Data and**	**Rhodes**		**Samos**	
2000-2050	**water balance**	**methods**	**10^6 m^3**	**%**	**10^6 m^3**	**%**
Pma	Precipitation	Mean (Kostas and WC0)	-80	-9,34	-31	-9,29
Gwr+R	Aquifer+Runoff	Kostas, Ioannis, MEDOR	-117	-32,6	-35	-21,4

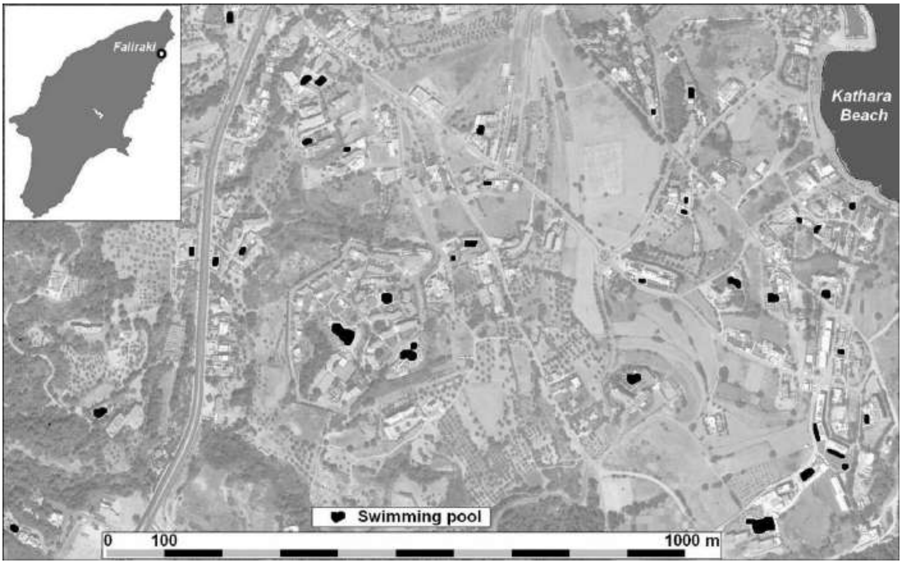
Table 7 - Synthetic water balance from various data and methods.
A./ Up to 2000 or nowadays. B./ Scenario for 2050. C./ Evolution between the two periods.

Even though the annual tourist consumption in Rhodes seems to be marginal, decision makers have to take into account three elements concerning tourism and water resources: the inter annual variability of precipitations, groundwater recharges and streamflow and the fact that most of the tourist abstraction takes place during the hot and dry period of July and August. All these factors jeopardize the water resource supply of the main economical activity of the island. This is what economist call a risk of "water stress" on the supplies (Skrimizea & Parra, 2019) and consequently urges for more intensive exploitation of aquifers as well as surface streamflow with somehow provisional solution as illustrated by the construction of the Gadouras dam.

Taking it as an example, the mean annual abstraction from this reservoir (2012-2015, 8.6 10^6 m^3) is almost equivalent to the annual consumption of tourists (2018, 6.3 10^6 m^3). If the direct evaporation loss from the lake is taken into account (1950-2000, 2 10^6 m^3), this means that more than 10 10^6 m^3 are diverted from the natural cycle every year with impacts on the ecology of the river and the coast downstream. About one third of the mean annual stream flow of the catchment is thus put to contribution.

In most cases, only direct uses of water by the tourist are taken into account. On top of that, several other supplies are also needed and must be considered as indirect pressure on the resources. This is the "invisible burden" as suggested in this sentence: "*Tourists] take showers more often, use pools,* *and frequent beautiful gardens, which are irrigated to retain perfect image for the guest.*" (Epler Wood & al., 2019, p. 13). The fact that the water from the Gadouras reservoir on Rhodes (photo 1) is used to fill the pools in the region of Falikari is also illustrating emblematically the under estimation of the water needs of the tourist sector (Map 3).

Photo 1 : the Gadouras Lake with the Atavyros Mountains in the background (C. Depraetere, September 2015)



Map 3: swimming pools in the southern part of Faliraki, one of main touristic spots of the north east coast of Rhodes. The density is about 35 pools over 1.5 km² (image 2019 from Google Earth).

Conclusion

For decision-makers and planners in the tourism sector, questions of resources are often considered secondary when compared to other key economic variables. In Mediterranean islands with economies relying strongly on tourism, the management of water resources could be seen as unimportant; just by looking at figures for Rhodes, direct water consumption from tourists accounts for less than 1% of total rainfall, about 2% of surface and groundwater, and 13% of total water supplies . A hasty and slipshod conclusion might be "much ado about nothing"; this could be like throwing the baby out with the bathwater.

The pressure on local water resources is, however, much worst on Mediterranean islands, particularly in the Aegean Sea for instance Mikonos, Delos, Kos or Patmos islands. Patmos, for instance, obtained most of its drinking water from Rhodes until recently but depends now on desalinization plants. The ongoing climate change and its consequences on water balance, as discussed in this article, could overburden the regional capacities to cope with growing needs, leading to overexploitation of a partly renewable local resource with outsourcing solution being costly and most often provisional.

To make the point clearer using a simple example taken on Rhodes, the construction of the Gadouras dam in 2001 had become a necessity as stated in the document project:

"*The overuse and excessive exploitation of water resources has resulted in a severe drop of groundwater levels and very soon led to brackish water inflow in several areas of the island* [Rhodes]. *The construction of the dam managed to solve the important and crucial water supply problems of the wider Rhodes urban area, of all the coastal settlements on the east and northwest side of the island as well as the neighboring arid islands*"[23].

In the context of Mediterranean islands with large tourist influxes, an Integrated Water Resources Management (IWRM) policy is necessary to prevent water stress or shortage[24] that may directly jeopardize local

[23] Project objective of the "water supply for Rhodes from Gadouras dam" (2001). Ministry of Infrastructure, Transport and Networks and then Region of South Aegean (https://www.een-gadoura.gr/en/objective/).

[24] From the ratio between population (including visitors) and water resources,(Engelman & Leroy, 1993) define two states: "water stress alert" below 1700 m^3/inh./year and "chronic

economies, especially those based on tourism. The water resource issue stands like a sword of Damocles hanging over societal and ecological conditions. The threat of climate change is just underpinning the problem with uncertainties on the future of water resources. Last but not least, sustainable tourism goes hand in hand with environmental quality. The specific context of touristic Mediterranean islands could become the bellwether of a local but not closed sustainable "ecolomy"[25] that our contemporaries are calling for. The IWRM is an example of ecolomical practice that could be relevant to overcome the multi sectorial, ecological and ethical Gordian knot challenging the future of the Mediterranean islands, its inhabitants and for sure their touristic alluringness.

water shortage" below 1000 m^3/inh./year (cited in (Azonsi & Depraetere, 2002). Supposing the same number of inhabitants and tourists for Rhodes in 2050, this ratio would be 1400 m^3/inh./year. A period of dry years could then create the conditions for a chronic water shortage especially during summer.

[25] Ecolomy: from the Greek *οἶκος*, house, heritage, … *λόγος* "logos", rationality, speech, knowledge... and from "*νομία*" nomos, management. Ecolomy means optimizing the synergy between ecological and economical issues. This term is freely inspired by the book of Arthur Lyon Dahl « The ECO principle : ecology and economics in symbiosis »(1996) with the agreement of the author. An equivalent in Greek would be *Οικοδιαχείριση*.

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