Water resources planning under climate and economic changes in Skiathos island, Aegean

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INTRODUCTION

Greek islands are popular tourist destinations, as they combine unique beauty and multiple special characteristics (environment, coasts, societal, etc.). A specific managerial approach is required with respect to the above aspects. Small Aegean islands are called to fulfill many objectives (locals’ needs, productive and tourist objectives) with limited and deteriorating natural and financial resources (Kechagias & Katsifarakis 2004). Their semi-arid environment, hilly terrain, poor infrastructure in terms of water supply works and rainwater exploitation, and the unevenly distributed rainfall during the year (wet winters and dry summers – where the demand peaks) create serious water shortage problems (Kourtis et al. 2019). To overcome this issue, a common practice is the over-pumping of groundwater, which leads to aquifers’ drawdown, thus allowing sea water intrusion and salinization. Even in cases of physically available water of acceptable quality, residents may face water scarcity due to inadequate infrastructure, limited investments and human resources for proper management.

Moreover, there are factors that tend to increase water demand, e.g., climate change and increasing population (Kourtis et al. 2019). Modelling and quantifying these relations is considered a challenging task by the international literature, along with water price (House-Peters & Chang 2011). Regarding water price, the Water Framework Directive (WFD) (European Commission 2000) established the use of economic tools (costing and pricing) for water services, in order to reasonably manage and improve the quantitative and qualitative status of water bodies. Although these parameters have
been studied and modelled separately, there is still room for improvement regarding their joint consideration (Olmstead & Stavins 2009; Haque et al. 2015). Practically, it is challenging to quantify climate change’s effect on demand, and even more difficult to implement a new (increased) pricing scheme reflecting the full cost of water, regarding the difficulties of estimating the full cost of water objectively (Alamanos et al. 2020). Hence, no change has been observed to the pricing system, or to any of the above issues, according to Water Utility of Skiathos (WUS), continuing poor management practices. The tourist population increase creates water shortages for one or two months per year, and this short duration of the peak demand, with the limited investments, restricts the implementation of larger-scale solutions that require significant costs.

The present study examines the above factors in Skiathos island, a typical example that faces all the aforementioned challenges. Based on a water demand simulation, scenarios assuming future climate and pricing changes were developed to forecast the demand, while water quality issues are also discussed. Other pressures (i.e., the operation of new hotels) and measures (i.e., constructing a desalinization unit) already considered by the local authorities are discussed, assessing their potential. The case of Skiathos has attracted researchers to study mainly its water demand (Di Nardo et al. 2017) and water quality issues (Spyropoulou et al. 2018). However, to our knowledge, no study has addressed together hydrological, economic and engineering aspects, in the broader island’s area, aiming to inform the local society on climate change’s impacts, pricing effects, and evaluate future management plans and pressures in the island. The overall aim is to showcase possible future challenges, with simple analyses on some very topical parameters, indicating their magnitudes, thus raising attention regarding future management strategies.

STUDY AREA

Skiathos is located in the northern Sporades islands (Figure 1), in the Aegean Sea, covering an area of 47.13 km². The climate is characterized as dry Mediterranean (hot dry summer and mild rainy winter). According to the island’s meteorological station (Skiathos station), the average annual temperature is 18.03 °C and the average monthly precipitation is 901 mm. The hydrographic network includes three wetlands (serving mainly flora and fauna ecosystem services), several small streams (not directly exploitable) and four springs. Regarding hydrogeologic conditions, limestone, marble and cinnabar are dominant

Figure 1 | Skiathos island, the city and the main positions of water abstraction and supply: (1) reservoir of St. Fanourios (2,800 m³); (2) Ftelia’s water supply well (16 m depth) supplies St. Fanourios reservoir; (3) head of Ftelia’s network supplying the city; (4) St. Antonios pumping well supplies St. Fanourios reservoir; (5) reservoir (800 m³) of Pr. Elias network, supplying 20 public fountains across the city.
in the soil, while detailed knowledge of the aquifer’s hydrology is limited. The main land uses include random vegetation, forests, unorganized farming activities and small settlements. Subsequently, the main water uses are domestic and agricultural. The main settlement is the city of Skiathos (4,992 inhabitants), served by a pipeline network, suffering from losses and leakages (around 60% in total). The annual real losses are approximately 51%, the annual apparent losses 6%, and the annual water theft is at least 3.6% of the system input volume, according to Kofinas et al. (2020).

The increasing population of the city and the peaks during the summer period due to tourists are the main pressures for water resources, leading to over-pumping. The island’s subsoil contains cinnabar rocks (HgS), which consist of mercury (Hg). It does not react when contacting freshwater; however, there is a reaction with seawater sodium chloride (NaCl), producing mercury chloride (HgCl₂). Since 1999 consumption from the city’s drinking fountains has been forbidden due to high concentrations of Hg. This implies seawater intrusion into the aquifer, indicating its drawdown due to overexploitation. According to the World Health Organization, the maximum allowable limit of Hg in freshwater is 0.001 mg/L, otherwise, people exposed (drinking, breathing, touching, etc.) are in danger of suffering chronic poisoning, reproductive, neurological, organic and even psychiatric problems (Spyropoulou et al. 2018). According to WUS samplings, the maximum concentrations were observed in 2014, and the peaks appear around August–September, i.e., after the summer period’s excessive pumping (Pouliaris et al. 2020). WUS is facing economic difficulties, as are the majority of small water agencies in the country, and has to face the above issues under changing climate, socio-economic pressures for tourist development’s benefits, and harmonization with WFD’s objectives. A project on the expansion of the main network has been underway during the last years; however, it cannot address all these challenges. Currently, investments are limited, and no other incentive is applied to face the above challenges.

**METHODS**

First, the water demand of the city is examined. Due to data limitations it was not possible to examine water availability (renewable surface and groundwater resources). Urban water demand is covered from groundwater stored in the reservoirs, and there are no data on the consumption of other uses or exact supply sources, since they are not organized.

Regarding urban water demand, a model was developed using the commercial software WEAP (Water Evaluation And Planning system) (Sieber 2005). The input data include a map-schematic (Figure 2(e)) with the locations of the supply sources (well and reservoir), their capacity, and the network’s structure (pipeline, i.e., transmission links) and demand nodes (water meters) and were retrieved from the WUS. The consumption per demand node was used from the WUS's records, too. The model attempts to show the possible evolution of water demand, so the demand-driven pressures were included in the simulation, i.e., billed authorized consumption (as metered from WUS) and apparent losses (theft and metering inaccuracies). The components of the IWA water balance table specifically for the case of Skiathos were recently described by Kofinas et al. (2020), so the respective seasonal estimations were used in the model per quarter (as percentage increment of consumption): 5.57% for January–March, 8.8% for April–June, 17.05% for July–September and 23.61% for October–December. The real losses are also very high, but since there were no available data on the physical water availability, in order to simulate the hydrological water balance (i.e., the actual needs and accuracy (Hagen et al. 2002; Donkor et al. 2012), its good performance in similar studies (Mentes 2001; Mylopoulos et al. 2017; Sfyris et al. 2019) and its broad application from water utilities (Billings & Jones 2008).

\[
Q_m = N \cdot q^* \cdot (X_1, m/X_1, b)^{\beta_1} \cdot (X_2, m/X_2, b)^{\beta_2} \cdots (X_i, m/X_i, b)^{\beta_i}
\]

(1)

where, \(Q_m\) is water demand for the month \(m\), \(N\) is number of water meters, \(q^*\) is specific consumption per water meter in the month of the base year, \(X_i\), \(m\) is value of parameter \(i\) in the month of prediction \(m\), \(X_i\), \(b\) is value of parameter \(i\) in the month of the base year \(b\) (2014), and \(\beta_i\) is elasticity of parameter \(i\) (a measure of how much each variable affects the demand).

The specific consumption was estimated by dividing the monthly consumption to the water meters and was considered constant through the future years, as it is not changing significantly (Figure 2(d)). The forecasting period was 2019–2028. The Xi variables examined were temperature, rainfall and water pricing. In the survey of Mylopoulos (2015), the elasticity of each variable was estimated as the proportionate difference in the purchased quantity divided by the proportionate difference.
in price paid, as described from a logarithmic equation, and were found to be 0.109 for temperature, −0.026 for rainfall and −0.524 for water pricing.

The forecasting was examined under climate change and water pricing scenarios, depicting changes in temperature (T), rainfall (P) and water price (WP). Three climate change scenarios were developed assuming T and P variations according to the representative concentration pathways (RCPs) proposed by the IPCC (5th Assessment Report AR5–IPCC 2014). The results of the program CORDEX (WCRP 2017) were used for RCP2.6, RCP4.5 and RCP8.5 (Moss et al. 2008) in order to consider a wide range of possible changes in future anthropogenic greenhouse gas (GHG) emissions. Changes of T and P are based on the ensemble mean of ten simulations of regional circulation models (RCMs) based on five different global circulation models (GCMs). The results’ statistical adjustment (correction) was done using the Delta-test, thus downscaling T and P by truncating their historical time series by the monthly change of the RCMs’ results between base and future periods, as presented in Alamanos et al. (2018, 2019). Hence, mild, intermediate and extreme GHG emissions’ mitigation scenarios were developed for the short-term period’s (until 2030) downscaled results of Skiathos island (resulting changes as in scenarios’ description).

WP changes illustrate the recommendations of WFD. From January 2018 the price of urban water was expected to include its full cost, but is still stable, to our knowledge. The numbers assumed in the two scenarios refer to the minimum and maximum suggested price levels (YPEKA 2012). Summarizing, the forecast was examined under the following situations:

Figure 2 | (a) Temperature; (b) rainfall; (c) number of water meters installed for the period 2012–2018 and their forecast until 2028; (d) water consumption; (e) WEAP’s model of Skiathos city, with its water meters (demand sites) and water supply network (transmission links).
• BS: baseline scenario: Stable climate and pricing conditions.
• Scenario 1 (mild climate change): Increased T by 1.21% and decreased P by 1.07%.
• Scenario 2 (intermediate climate change): Increased T by 2.47% and decreased P by 2.95%.
• Scenario 3 (worst climate change): Increased T by 4.11% and decreased P by 4.36%.
• Scenario 4: Increased WP by 2% per four years.
• Scenario 5: Increased WP by 5% per four years.
• Scenario 6: Increased T by 2.47% and decreased P by 2.95%, until 2030, and increased WP by 2.5% per four years.

Of course, these changes are multi-parametric and affect the system in many direct and indirect ways, but here, the focus is on investigating simple but realistic future conditions. For example, Scenarios 1, 2 and 3 represent the possible climatic futures in the region, assuming stable water price as it continues to apply today (no price changes for the last two years). To show the potential of water pricing as a tool and its impact on water demand, Scenarios 4 and 5 were developed, while Scenario 6 is the ‘middle-way’ combination: intermediate climate and price changes, indicating a more realistic prediction.

The scenarios were inserted in Equation (1) as inputs (variables Xi), thus finding the future water demand (Q). The monthly water consumption distribution (Figure 2(d)) was followed during the forecasting period, thus considering the seasonal variances. The detailed simulation of the city’s network allowed a ‘hot-spot’ analysis, indicating stressed nodes in certain periods. As mentioned in the Introduction section, the aim of this study is to raise the awareness regarding future challenges in the broader area. In line with this, and in addition to the above scenarios, two more possible future situations for Skiathos are discussed. The first refers to another common pressure for small islands, the operation of new hotels. The second one refers to the installation of a desalination unit for more potable water, following the example of other Aegean islands, as a measure to cover demand peaks. These refer to a broader discussion of the island’s water management, since they will not necessarily be connected or supply the same network, but as scenarios, are being discussed by the local authorities over time.

RESULTS
To our knowledge, climate change projections and water pricing changes have not previously been combined to forecast domestic water demand in Skiathos, together with a spatial analysis. The work shows future demand variation under extreme possible conditions (Figure 3). According to WUS, an increasing trend in the number of water meters is an expected situation for the coming years. T and P changes of Scenarios 1, 2 and 3 were assumed for the end of the forecast period (i.e., overall, not for each year). Water pricing changes were assumed based on the actual water price (not prices charged), considering inflation over the years. This was achieved through the Consumer Price Index (CPI). The actual water price is the price referred to on the water bills divided by the CPI.

Due to lack of data on pressure, pump characteristics, junction elevation, pipe length, diameter and roughness coefficients (not available from the water utility), only the nodal demand and its allocation was simulated, as mentioned. The model describes satisfactorily the demand’s behaviour (Figure 3(c) and 3(d)) (Li et al. 2021) and the difference is attributed to measurement errors, model errors on ‘unknown parameters’, e.g., theft, losses in the junctions and elevation effects.

All scenarios result in higher future demand. Climate change stresses this trend, while increasing water price reduces the augmenting consumption rate. The mild climate change Sc. 1 is responsible for an overall 12.7% increment, Sc. 2 for a 12.97%, and Sc. 3 for a 13.51% increment in the total consumption over eight years, compared to the current levels. Scenarios 4 and 5 result in an overall 3.36% and 1.27% increment of the total demand over eight years, respectively, with a reducing rate. This shows the importance of water pricing as an economic demand-management tool and its bigger impact on final consumption compared to climate change. The results agree with previous findings (Bithas & Stoforos 2006; Ghiassi et al. 2008; Slyris et al. 2019) on water pricing and climate scenarios for long-term forecasts, highlighting the higher impact of WP compared to climate, and the increasing trends of the demand regardless of the followed pricing policy.

The hot-spot analysis of the city’s network, as resulting from the WEAP model, follows the same peak pattern over the forecast, and (although the software provides only the total demand value – not per node size) the most ‘pressured’ nodes are as shown in Figure 3(c). The increased demand is found at the sea promenade zone, where taverns, motels and restaurants are concentrated. The nodes of the southern part of the centre have a higher population density, while there are nodes across the whole city showing some (few) random peaks.

Overall, the forecasted demand’s magnitude indicates the necessity of action, as the measure of charging the full cost of water (even if implemented) cannot save the situation; network maintenance could help significantly, and the consideration...
of a new reservoir or the expansion of Pr. Elias reservoir could relieve the network nodes from seasonal stress. Of course, for each measure more data and extensive hydrological-hydrogeological studies are required, but the purpose of this analysis was to highlight the future challenges.

DISCUSSION

From the analysis, it is clear that a number of factors will increase future water demand, and this implies the need for infrastructure and rational development. The increasing number of water meters affects the total consumption, so a good starting point could be the improvement of the current infrastructure.

Emphasis should be placed on the continuation and the proper completion of the ongoing WUS projects aiming to cover the demand, the most efficient water use, and the flexibility of the supply in case of network failures. The control of network losses and leakages is also essential. Storage (reservoir capacity, need for new reservoirs and rational operation) must also be

Figure 3 | (a) Future water demand of the city; (b) percentages of demand changes compared to the previous year (Sc. = Scenario); (c) and (d) model’s goodness-of-fit performance; (e) consumption per demand node (indicatively for August 2022).
considered by WUS in order to ensure the ability to cover the future increased needs. A project initiated in 2015 aims to connect the drilling well of the Plagia area (St. Antonios) with Skiathos reservoirs through a closed pipeline. The reservoirs are located in St. Fanourious area and their storage capacity is 2,800 m³. The project is not yet completed, and the final connection has yet to be made. The project is expected to upgrade the existing infrastructure and will enable the connection with other wells later through the pipeline.

However, the continuing pumping from the aquifer cannot be a sustainable practice, given the mentioned water quality issues (Spyropoulou et al. 2018). In order to cover future water requirements across the island, the consideration of individual, locally placed reservoirs is an alternative that the local authorities must examine. Then, more surface water resources could be stored and used, rather than overexploiting the aquifer.

Every form of development must also follow the environmental, ecosystem and archaeological standards, as set by the Greek Ministry (water quantity, water, soil, air, noise pollution, flora and fauna protection, and areas’ reservation). For each planned, proposed, or mentioned solution-scenario, the pros and cons will be listed in our future work, as for most of these strategies more and more detailed data are necessary. At this primary stage, our intention is to encourage monitoring and systematic assessment for each plan (thus covering the current data limitations), and consider the long-run impacts.

Other pressures and measures
To justify the last paragraph’s statement, this sub-section presents common pressure (hotels’ increment) and measure (desalinization) for most Greek islands, using Skiathos island (broad area, not only the city) as an example. According to the Hellenic Chamber of Hotels (HCH) databases, Skiathos has the most hotels in the Sporades islands (85 units, 3,380 rooms, 6,673 beds) (HCH 2018). Many of these units are not connected to the public network and use their own drillings. Tourist development has been a priority for local policymakers so far, due to its economic, social and administrative benefits. The old abandoned building of Xenia Hotel in Skiathos (in the very east side of the island), was restored and started operating as a new five-star hotel. Initially, the water supply came from two existing wells, but recently the hotel has been connected to Skiathos’ main network. According to the Greek Tourism Organization, tourists consume around 300 L/pe/day (using baths, swimming pools, spas, etc.). Hence, the connection of this hotel to the main network will demand approximately 93 m³/day (just for residents, not for the additional operational needs and staff).

Some of the most common measures for tackling water scarcity in the Aegean islands in the last decades are desalinization units and water transfer. Drinking water transferred by vessels has a cost of approximately 6–10 €/m³. Desalinization units are gaining ground in the Aegean, as their cost is lower. Depending on the desalinization method (multi-stage flashing (MSF), multiple effect distillation (MED), vacuum compression (VC), reverse osmosis (RO), etc.), different installation, labour, energy, administration, and operation and maintenance (O&M) costs occur. Indicatively, the total cost, as a sum of the above, for a RO unit of 5,000 m³/day is around 1.5 €/m³ of produced water on average. For 20,000 m³/day, this cost is estimated to be around 0.75 €/m³ (Bourouni et al. 2011). When referring to desalinization, the environmental issues must be considered, too, especially in the aquatic ecosystems (Younos 2009), combined with the potential risks (not only environmental) of mercury disposal (Palmer et al. 2009). However, the use of renewable energy can reduce the energy and O&M expenses. Bad water quality is a major issue, so a desalinization unit producing 1,000 m³/day is considered, according to the WUS administration board. In any case, a careful and rational design, planning and operation process should be followed, in order to achieve the maximum economic, productive and environmental benefits.

CONCLUSIONS
Small Aegean islands are facing complicated pressures of different natures. In order to answer the research questions set, integrated modelling is required. This needs integrated monitoring and data which are still impossible to know in most cases. This paper has attempted to examine multiple factors up to the point that data limitations allow. Factors such as water availability, demand from every water use (no matter its magnitude) and continuous water quality monitoring need to be known for future integrated planning at catchment level. Only the demand-driven consumption was considered in order to incorporate it in the forecast model, so the real losses (and their spatial distribution) must be included in our future research. A limitation of the study was that the possible future demand evolution was based mainly on water meters, climate and water price changes, while more variables affect the demand (e.g., water quality, specific uses, education, income, information, etc.); however, and given the data limitations, the goal of this study was to sensitize and raise awareness on future water management. Our results and data limitations could motivate local policymakers to construct databases, start monitoring and include
more factors in the decision-making process. Focusing on the coverage of tourist and other productive objectives often narrows policymakers’ judgement. Overexploitation for the sake of non-sustainable development leads to non-sustainable measures, too. The rich and lively nature of these areas often is distracting, hiding their problems. Studies enlightening similar issues (unavoidably with their limitations), and mainly, cooperation of experts and decision-makers should become starting points for the poorly managed small islands, which have not gained the necessary attention until now.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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