TREATED WASTEWATER REUSE POTENTIAL: MITIGATING WATER SCARCITY PROBLEMS IN THE AEGEAN ISLANDS

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Abstract

Reuse of treated wastewater has been proven a reliable alternative water resource, which can constitute a significant component of integrated water resources management and provide an effective solution to cope with water scarcity conditions. In Greece, the recent introduction of the Joint Ministerial Decree (JMD) 145116/11, which specifies requirements concerning the reuse of treated effluents, gives rise to the investigation of reuse potential in water scarce regions. As most Aegean islands struggle with water scarcity, due to their specific geomorphology, climatic conditions, and increased water demand during summer, the implementation of wastewater reuse in this region could provide a key solution to address water stress. The aim of this paper is to propose a step-wise approach for the analysis of treated wastewater reuse potential in the islands of the Aegean Archipelago, and the assessment of its contribution in the mitigation of water scarcity problems. A Geographic Information System (GIS) was used for the classification of the islands according to certain criteria (e.g. operative WWTPs, vulnerability to water scarcity, population density, etc.) and their clustering according to wastewater reuse potential. For the cluster of high reuse potential, the quality of treated effluents was compared to the standards specified by the Greek wastewater reuse legislation, to identify potential reclaimed water uses. The contribution of reclaimed water in alleviating water deficits in the islands with high reuse potential was estimated to be significant, thus indicating that it could be an effective option towards water scarcity mitigation.

Keywords: Reuse potential, water scarcity, reclaimed water, integrated water resources management, Aegean islands.

Introduction

Water scarcity problems, caused by imbalances between supply and demand, increased pollution of water bodies and/or inadequate funds for the exploitation of available resources, render integrated water resources management a necessity. Treated wastewater has been proven a reliable alternative water resource, which can play a vital role in integrated water resources management addressing both water demand and supply, and wastewater disposal and environmental protection [1, 2].

European regions have been subject to growing water scarcity during the last two decades [3]. So far, however, the potential for treated wastewater reuse has not been widely exploited in Europe: by 2006 the total volume of reused treated wastewater represented only 2.4 % of treated effluent [4]. This is mostly due to the absence of a consolidated EU regulatory framework proposing common quality standards for all member states [5].

In Greece, although water shortage conditions have been exacerbated over recent years, reuse of treated wastewater is not a widespread practice [6]. The legal framework regarding the reuse of treated wastewater was developed very recently (in 2011) through the Joint Ministerial Decree (JMD) 145116/11, which defines measures, terms and processes concerning the reuse of treated effluents. The provided regulations and guidelines refer to agricultural, urban, and industrial reuse as well as aquifer recharge, while direct and indirect reuse to supplement potable water supply is not considered. The introduction of the JMD promotes the implementation of wastewater reuse in Greece and provides an opportunity to investigate the potential for using reclaimed water as an alternative resource in water scarce areas.

Most Aegean islands face severe water scarcity conditions due to their specific geomorphology, temporal and spatial variation of precipitation levels and increased water demand during summer periods. As a result, significant water deficits are often experienced affecting the local economies, which are mostly based on agriculture and tourism. Water resources availability in these areas is mainly dependent on groundwater, which is becoming depleted in most cases, and seawater desalination, which is a high cost and energy intensive option that may cause significant environmental impacts. Therefore, decentralized solutions such as reuse of treated wastewater can be suitable for implementation in the Aegean islands, taking into account their isolated location combined with the high cost of water transfers from the mainland. In addition to the enhancement of water availability, water reclamation and reuse can also provide social benefits in the islands of the Aegean Archipelago increasing the perception of self-sufficiency in the insular societies [7].

This paper aims to investigate the potential for wastewater reclamation and reuse in the Aegean islands and assess its anticipated contribution to water scarcity mitigation within the framework set by the Greek legislation on wastewater reuse.

Methodology

The study site area

The Aegean islands, with a total area of 9,104km^2 and resident population of 508,206 inhabitants (census 2011), are located in the eastern part of the Mediterranean Sea. The present analysis has been undertaken for 43 islands in total (Figure 1), which belong to the former administrative prefectures of Cyclades and Dodecanese (before the 2011 Kallikratis administrative reform). The islands vary in terms of size, population, water sources and socio-economic conditions as shown in Table 1.

Figure 1: The Aegean islands included in the analysis

The significant tourist influx, particularly during the summer period, has resulted in the economic development of the region in general. However, each island has its own special character and development rate. Agriculture, stock raising and fishing are also significant economic activities, while industry is limited in the region [8].

Traditionally, the inhabitants of the islands used groundwater, limited available surface water resources and rainwater harvesting to meet water demand [7]. Nowadays, desalination is also used to increase water supply and eliminate water scarcity problems, particularly during the summer peak season. However, significant water deficits are still experienced in most islands and additional measures and management options are required for mitigating water scarcity. Wastewater reclamation and reuse is acknowledged as a viable, low cost and energy efficient option [7-11].

Table 1: Main characteristics of the study region [12]

Parameter	Minimum value	Maximum value
Size (km^2)	9.1 (Megisti)	1,635.1 (Lesvos)
Population (inhabitants – census 2011)	185 (Agathonisi)	115,490 (Rhodes)
Total water demand (m^3)	17,085 (Agathonisi)	44,398,658 (Lesvos)
Percentage contribution of agriculture in demand (%)	4 (Symi)	83 (Naxos)
Percentage contribution of domestic sector in demand (%)	17 (Naxos)	96 (Symi)
Coverage of domestic demand with desalination (%)	0 (34 islands)	49.42 (Syros)
Coverage of irrigation demand with groundwater (%)	2.93 (Megisti)	100 (4 islands)

Step-wise approach for the analysis of wastewater reuse potential

The approach followed for the analysis of wastewater reuse potential in the Aegean islands comprises 3 steps, as illustrated in Figure 2. A *Geographic Information System (GIS)* was developed to support the classification and clustering steps of the analysis through the integration of regional information concerning existing Wastewater Treatment Plants (WWTPs), quantity and quality of generated wastewater, water uses, demographic data, and local characteristics in a GIS-based database. The steps of the approach followed are described in detail below.

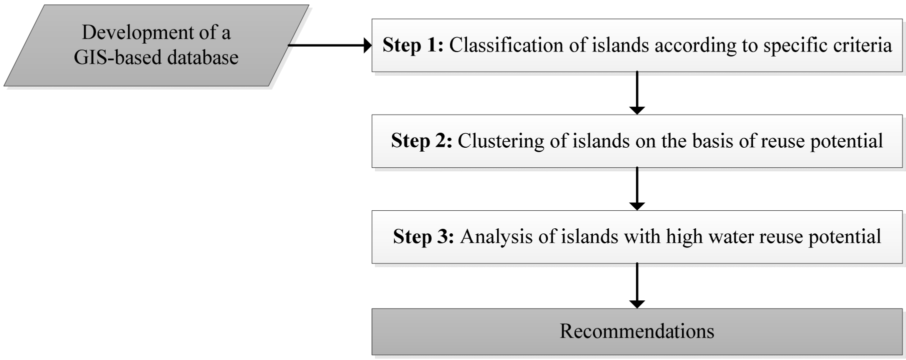


Figure 2: Step-wise approach for the analysis of wastewater reuse potential

Step 1: Classification of islands according to specific criteria

The classification of islands was supported by a GIS-based database which provided information on the selected classification criteria. The criteria used for the classification of the examined islands, in order of importance, are:

- *Operation of wastewater treatment plants (WWTPs)*: the operational status of existing WWTPs was considered.
- *Vulnerability to water scarcity*: vulnerability was expressed as the mean annual water deficits in agricultural and domestic sectors. Water demand of agricultural and domestic (demand of resident population and tourists) sectors, which are the main consumptive water uses in the region, often exceeds the available supplies especially during summer periods. Four vulnerability classes were distinguished according to the percentage of uncovered demand: a) greater than 30% - high, b) greater than 10% and smaller than 30% - medium, c) greater than 5% and smaller than 10% - low, and d) smaller than 5% - very low.
- *Population and population density*: population size determines water demand and generation of wastewater, while population density indicates density of infrastructure and level of development. Both criteria were examined to allow for a more comprehensive consideration of demands. Islands were separated into four classes according to their population: a) more than 10,000 – high, b) more than 2,000 and less than 10,000 – medium, c) more than 1,000 and less than 2,000 – low, and d) less than 1,000 – very low. They were also divided to three classes according to their population density (inhabitants/m^2): a) more than 90 – high, b) more than 40 and less than 90 – medium, and c) less than 40 – low.
- *Environmentally protected areas:* the existence of protected areas is usually accompanied by restrictive measures for their protection which can influence wastewater treatment requirements, e.g. compulsory tertiary treatment (N and P removal) of discharged effluents. In addition, limited water availability may endanger the preservation of water dependent environmentally protected areas (e.g. coastal marine habitats, surface and groundwater dependent habitats). Islands were separated into three classes according to the existence and water dependence of protected areas.

The developed classification scheme is presented in Table 2.

Table 2: Classification scheme

Criteria	WWTP in use	Population (inh.)	Population density (inh./m^2)	Vulnerability to water scarcity (deficit %)	Protected areas
Classes	C1: Yes C2: No	C1-very low: <1,000 C2-low: 1,000-2,000 C3-medium: 2,000-10,000 C4-high: >10,000	C1-low: < 40 C2-medium: 40-90 C3-high: >90	C1-very low: <5% C2-low: 5-10% C3-medium: 10-30% C4-high: >30%	C1: No C2: Yes – no water dependent C3: Yes – water dependent

Step 2: Clustering of islands on the basis of reuse potential

Based on the classification process, the following clusters of wastewater reuse potential were distinguished:

- Cluster 1 "*No reuse potential*": islands with inoperative WWTPs belong in this cluster.
- Cluster 2 "*Low reuse potential*": islands with low water deficits, i.e. low vulnerability to water scarcity, which cannot justify the need for water reuse implementation.
- Cluster 3 "*Medium reuse potential*": it includes islands with significant water deficits but relatively small population and/or low population density. Implementation of wastewater reclamation and reuse may not be economically feasible in these islands as the size of potentially supplied population cannot justify such an investment.
- Cluster 4 "*High reuse potential*": it comprises islands with significant/high water deficits (particularly for the agricultural and secondarily for the domestic sector), high population and/or population density, in which the implementation of treated wastewater reuse could provide an essential measure to address water scarcity and should be further investigated.

The developed clusters and their description are presented in Table 3.

Table 3: Clusters of wastewater reuse potential

Cluster	Description
"*No potential*"	• WWTP in operation: no (C1)
"*Low potential*"	• WWTP in operation: yes (C2) • Vulnerability to water scarcity – both deficits: very low/low (C1/C2) • Remaining criteria: any class
"*Medium potential*"	• WWTP in operation: yes (C2) • Vulnerability to water scarcity - agricultural deficit: medium/high (C3/C4) • Vulnerability to water scarcity - domestic deficit: very low - medium (C1/C2/C3) • Population: very low/low (C1/C2) • Population density: low/medium(C1/C2) • Environmentally protected areas: yes – no water dependent (C2)
"*High potential*"	• WWTP in operation: yes (C2) • Vulnerability to water scarcity – agricultural deficit: high (C4) • Vulnerability to water scarcity – domestic deficit: very low - high (C1/C2/C3/C4) • Population: medium/high (C3/C4) • Population density: medium/high (C2/C3) • Environmentally protected areas: yes – water dependent (C3)

Step 3: Analysis of islands with high reuse potential

For the islands with high reuse potential, data on location, treatment stage (secondary, tertiary), and operational capacity of the existing WWTPs were analyzed. Treated effluent quality characteristics were compared to the standards specified by the Greek wastewater reuse legislation (Table 4) to identify potential reclaimed water uses. The contribution of reclaimed water in alleviating current water scarcity conditions was also assessed, through the estimation of the proportion of water deficits that could be covered through treated wastewater.

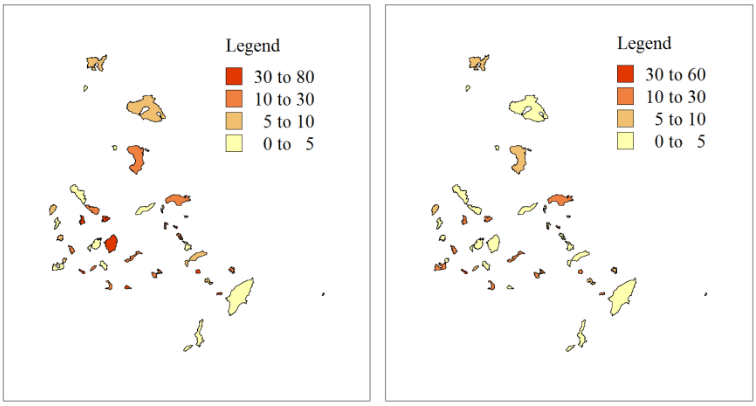
Table 4: Provisions of the Joint Ministerial Decree 145116/11 for wastewater reuse [13]

Potential use	Minimum required treatment level	Effluent quality standards
Agricultural use (restricted irrigation)	Secondary biological treatment & disinfection	• EC/100ml: ≤200 • BOD5(mg/l): ≤25 • SS (mg/l): ≤35 • NTU:-
Agricultural use (unrestricted irrigation)	Tertiary biological treatment & disinfection	• EC/100ml: ≤5 for 80% of samples & ≤50 for 95% of samples • BOD5(mg/l):≤10 for 80% of samples • SS (mg/l): ≤10 for 80% of samples • NTU: ≤2
Urban use (landscape irrigation and non-irrigation applications)	Advanced treatment & disinfection	• TC/100ml: ≤2 for 80% of samples & ≤20 for 95% of samples • BOD5(mg/l):≤10 for 80% of samples • SS (mg/l): ≤2 for 80% of samples • NTU: ≤2
Groundwater recharge – infiltration – surface spreading (non-potable purposes)	Secondary biological treatment & disinfection	• EC/100ml: ≤200 • BOD5(mg/l): ≤25 • SS (mg/l): ≤35 • NTU:-
Groundwater recharge – injection wells (non-potable purposes)	Advanced biological treatment & disinfection	• TC/100ml: ≤2 for 80% of samples • BOD5(mg/l):≤10 for 80% of samples • SS (mg/l): ≤2 for 80% of samples • NTU: ≤2
Industrial use (once-through, non-contact cooling water)	Secondary biological treatment & disinfection	• EC/100ml: ≤200 • BOD5(mg/l): ≤25 • SS (mg/l): ≤35 • NTU:-
Industrial use (recirculating cooling water, boiler make up water, process water)	Tertiary biological treatment & disinfection	• EC/100ml: ≤5 for 80% of samples • BOD5(mg/l):≤10 for 80% of samples • SS (mg/l): ≤10 for 80% of samples • NTU: ≤2

Results and discussion

Classification and clustering of the Aegean islands

Almost half of the examined Aegean islands (49%) have WWTPs in operation [12, 16]. The islands with the greatest mean annual water deficits in the agricultural sector are Anafi (78.3%), Leipsoi (75.9%) and Chalki (69.9%), and those with the greatest mean annual water deficits in the domestic sector (tourist demand included) are Folegandros (51.6%), Syros (29.1%), and Samos (21.9%) [12]. The classification of islands according to their mean annual water deficit, which expresses their vulnerability to water scarcity, is portrayed in Figure 3. Islands with combination of significant mean annual deficits (greater than 20%) in both agricultural and domestic sectors are Leipsoi (75.9% and 20.7% respectively), Folegandros (49.7% and 51.6% respectively) and Syros (45.9% and 25.1% respectively). More than half of the islands under consideration (51%) have more than 2,000 inhabitants, while half of those have resident population of more than 10,000 (census 2011, Figure 4). The population density of each island was estimated using the GIS, based on the population data provided (census, 2011). Most of the islands considered (58%) have low population density (< 40 inhabitants/km^2), while 12% have high population density (> 90 inhabitants/km^2). Furthermore, most of the considered islands (86%) are associated with environmentally protected areas, the majority of which (94%) are water dependent [14, 15].



(a) (b)

Figure 3: Classification of Aegean islands according to water deficit (%) in (a) agricultural and (b) domestic sectors

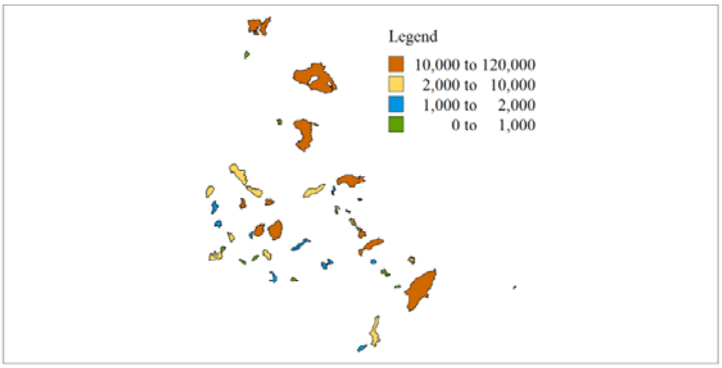


Figure 4: Classification of Aegean islands according to population size (No. of inhabitants)

Of the 21 islands with WWTPs in operation, nine are of low reuse potential (Ikaria, Ios, Kalymnos, Kos, Lesvos, Limnos, Paros, Rhodes, and Serifos) mainly due to low water deficits, and nine have medium reuse potential (Astypalaia, Thira, Leipsoi, Leros, Patmos, Samos, Sifnos, Tinos, and Chios) because of low population and/or population density. The islands with high wastewater reuse potential are Syros, Naxos and Mykonos. These islands combine significant water deficits with high population and population density, as shown in Table 5. Leipsoi and Folegandros, which are among the islands most vulnerable to water scarcity, are not included in the cluster of high reuse potential, because of low resident population and the absence of operative WWTPs in the case of Folegandros. The results of the clustering process are shown in Figure 5.

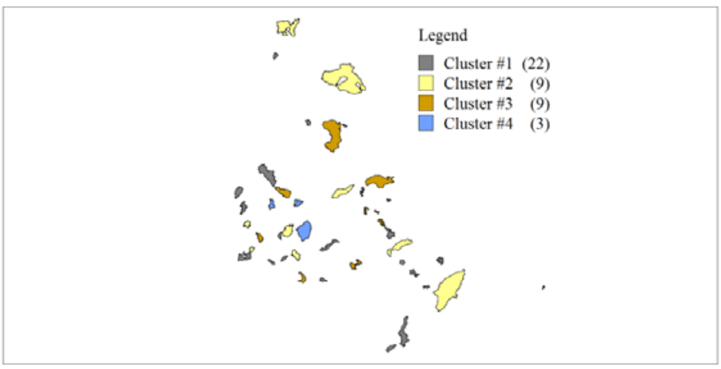


Figure 5: Clustering of the Aegean islands according to wastewater reuse potential (Cluster #1: no reuse potential, Cluster#4: high reuse potential)

Table 5: The islands with high wastewater reuse potential

Island	Population class	Population Density class	Agricultural deficit class	Domestic deficit class	Environmentally protected areas class
Mykonos	C4 (10,134 inh.)	C3 (118.1 inh/km^2)	C4 (30.5%)	C3 (18.7%)	C3: Yes – water dependent
Naxos	C4 (18,864 inh.)	C2 (43.8 inh/km^2)	C4 (54.5%)	C1 (1.1%)	
Syros	C4 (21,507 inh.)	C3 (256.6 inh/km^2)	C4 (45.9%)	C3 (29.1%)	

Analysis of islands with high wastewater reuse potential

The location of the WWTPs and the main land uses (CORINE 2000) in the islands with high treated wastewater reuse potential, i.e. Mykonos, Naxos, and Syros, are presented in Figure 6. The volume of treated wastewater available for reuse was estimated considering a typical reduction of 5% in the influent volume due to sludge removal. The analysis of the potential for each island is provided in detail below.

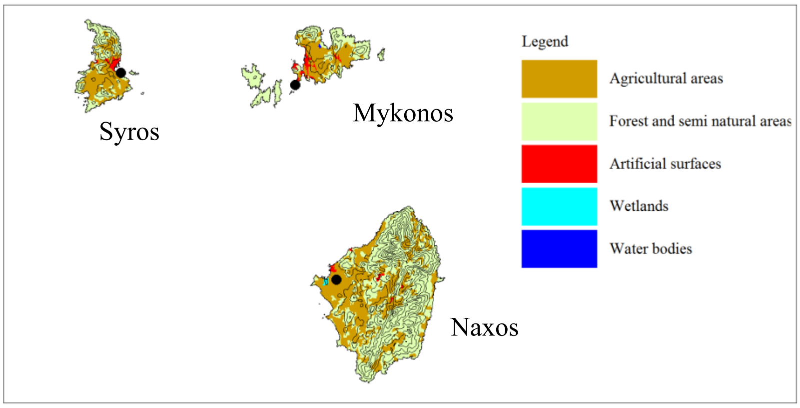


Figure 6: Land uses and location of WWTPs in the islands with high reuse potential

Reuse potential in Mykonos island

The WWTP which serves the island of Mykonos provides tertiary wastewater treatment (rotating drum screens), biological nutrient removal, and disinfection (chlorination). It is located in Alogomandra cape and has a design capacity of 32,000 population equivalent (p.e.). The mean annual volume of wastewater entering the plant is 4,180 m^3/d, ranging from 1,500 m^3/d in the winter to 7,500 m^3/d in the summer, while the design capacity of the facility is 4,300 m^3/d. As the influent load exceeds the design capacity of the WWTP during summer period, wastewater is not treated properly and thus the quality of the plant effluents is low. Treated effluents from the WWTP are discharged into the sea, via a subsea pipeline, within 450m away from shore [12, 16].

When the amount of influent does not exceed the plant's design capacity, the WWTP operates in compliance with the standards and requirements set by the European Council Directive 91/271/EEC on urban waste-water treatment, and the JMD 5673/400/1997 for the collection, treatment and discharge of urban waste water and treatment of residual sludge [16]. Hence, treated wastewater can be used for the irrigation of food and non-food crops (agricultural reuse - restricted and unrestricted irrigation), groundwater recharge (infiltration – non potable purposes) and industrial uses, as the treatment requirements specified by the Greek wastewater reuse legislation (JMD 145116/11) are satisfied.

Industrial activity in the island is limited compared to agriculture and tourism. The percentage contribution of the industrial sector in the total water consumption is 4.2%, and the sector is not anticipated to significantly develop in the coming years, whereas irrigation accounts for 46.2% of total water consumption [12]. Thus, irrigation of non-food crops is the most suitable water use to supply with reclaimed water. Furthermore, as shown in Figure 6, the location of the WWTP is relatively close to agricultural areas facilitating the distribution of reclaimed water for irrigation purposes.

The mean annual volume of potentially reusable treated wastewater is about 1,450,000 m^3 y^{-1}, while the mean annual agricultural water deficit of the island is 439,520 m^3 y^{-1} [12]. As a result, the deficit of the agricultural sector could be covered completely and a significant surplus of water resources could be gained through the use of treated wastewater (Figure 7). This surplus could be used for groundwater recharge to control overexploitation and saltwater intrusion. Therefore, reuse of treated wastewater can significantly contribute in the mitigation of the island's vulnerability to water scarcity.

Reuse potential in Naxos island

For the purposes of the current analysis, only the main WWTP of Naxos island, which has the greatest design capacity was considered, as listed in the database of the Hellenic Ministry of Environment, Energy and Climate Change [16].

The examined WWTP provides tertiary wastewater treatment (microfiltration membranes), with biological nutrient removal and disinfection (chlorination). It has a design capacity of 40,917 population equivalent (p.e.) and the volume of wastewater entering the plant ranges from 2,500 m^3/d in the winter to 4,500 m^3/d in the summer. During the peak tourist season the volume of influents is beyond the maximum capacity of the plant resulting into improper operation and insufficient treatment of wastewater. The effluents of the plant are discharged into the sea through a subsea pipeline which is located in the Stelida district [12&16].

For most of the year the plant operates below its design capacity and the quality characteristics of the treated effluents satisfy the standards specified by the JMD 145116/11 (BOD5: ≤10 mg/l and SS: ≤10 mg/l for 80% of samples, sampling 2012 – [16]) for reuse in agriculture (irrigation of food and non-food crops) and industry (recirculating cooling water, boiler make up water, process water) or for groundwater recharge (infiltration and injection wells – no abstraction for potable use).

The most suitable potential use of reclaimed water in the island is agricultural irrigation, as it accounts for 80% of the total water consumption [12]. In addition, the proximity of the WWTP to cultivated areas (Figure 6) facilitates the distribution of potentially reusable wastewater. The reuse of the effluents for irrigation purposes could reduce the mean annual agricultural deficit of the island up to 21% (Figure 7).

Reuse potential in Syros island

The WWTP which serves the island of Syros is an extended aeration activated sludge system which provides secondary wastewater treatment, with nitrogen removal and disinfection (chlorination). It has a design capacity of 28,067 population equivalent (p.e.); the mean annual volume of influents is 3,000 m^3/d while the maximum capacity of the plant is 4,148 m^3/d. The stream of treated wastewater is discharged into the sea [12&16].

The WWTP operates in compliance with the standards and requirements specified by the European Council Directive 91/271/EEC on urban waste-water treatment, and the JMD 5673/400/1997 for the collection, treatment and discharge of urban waste water and treatment of residual sludge [16]. Treated effluents can be used for the irrigation of non-food crops (restricted agricultural irrigation), the discharge of groundwater aquifers (filtration – no abstraction for potable reuse) and the supply of industrial water uses (once-through, non-contact cooling water), as their quality characteristics satisfy the effluent quality standards of the respective Greek legislation (JMD 145116/11).

As intense industrial activity is not observed in the island, the most relevant potential reclaimed water use is the irrigation of non-food crops, considering also the proximity of the WWTP to agricultural areas, as shown in Figure 6.

The mean annual volume of potentially reusable treated wastewater is about 1,040,250 m^3 y^{-1}, while the mean annual agricultural water deficit of the island is 870,517 m^3 y^{-1} [12]. Hence, the reuse of treated wastewater for irrigation purposes could completely cover the agricultural water deficit (Figure 7), also providing a surplus water resource which could be used for groundwater recharge, as in the case of Mykonos island. As a result, reuse of treated wastewater could significantly contribute in the mitigation of the island's vulnerability to water scarcity by alleviating the water deficit of agricultural sector.

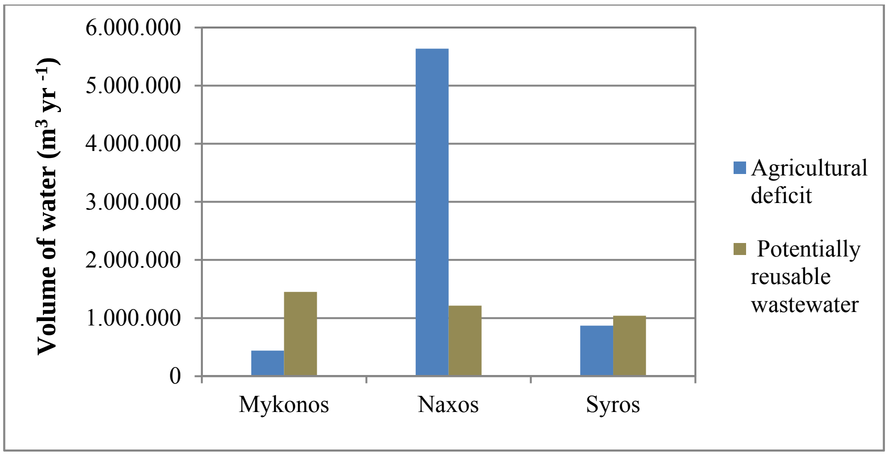


Figure 7: Potential contribution of treated wastewater reuse in the alleviation of agricultural water deficits

Conclusions

The present study provides a broad estimation of the treated wastewater reuse potential in the Aegean islands. On the basis of the selected classification criteria, Mykonos, Naxos and Syros were determined to be the islands with the highest reuse potential. The treatment stage and quality of treated effluents generated by the operating WWTPs determined the potential reclaimed water uses in these islands. Overall, the most suitable potential reclaimed water use is crop irrigation.

A significant factor which should be considered is that peak irrigation water demand in these islands occurs during summer period, when the volume of influents exceed the maximum treatment capacity of the WWTPs due to the high influx of tourists. As a result, wastewater is treated insufficiently and direct irrigation with reclaimed water cannot take place during this period. Hence, additional measures should be considered in order to ensure the supply of agricultural areas with wastewater of suitable quality, such as upgrading of facilities or construction of storage reservoirs to enable the release of properly treated effluents at the desired time. Indirect irrigation through groundwater recharge can also provide a solution in this case, as wastewater of suitable quality can be stored and abstracted from the groundwater aquifers for irrigation.

As shown in the present study, the reuse of treated effluents in the islands with high potential can completely eliminate or partially reduce the agricultural water deficits and even provide a surplus water resource, thus reserving high quality water for other uses or avoiding aquifer overexploitation. Therefore, wastewater reuse can significantly contribute to the mitigation of current water scarcity problems in the region. In addition, in islands without WWTPs where great water deficits were observed, such as Anafi and Folegandros, the installation of a treatment facility could provide, in addition to environmental benefits, an effective solution towards water scarcity mitigation.

The present study provides a methodological approach for the investigation of the reuse potential in the Aegean islands. The results of the analysis rely on the quality of available data and the classification criteria considered. In order to estimate in detail the reuse potential of the region and assess its actual contribution in water scarcity mitigation, further analysis would be needed. Additional site-specific characteristics and techno-economic criteria, such as infrastructure requirements and investment costs, environmental aspects and social considerations should be taken into account to identify the reclaimed water uses with the greatest potential for success.

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