

Water Demand Management in the Island of Crete, Greece

Vourdoubas John

Consultant Engineer, 107B El. Venizelou Str., 73132, Chania, Crete, Greece

ABSTRACT: The supply and demand management of water resources in Crete is necessary to avoid water shortages in the island predicted in the future due to climate change. Water demand management in Crete should aim not simply to reduce water consumption, but to ensure that available water is used efficiently, economically and sustainably. Several studies related to water resources in Crete have been reviewed and the water consumption in several sectors has been estimated. The island is sufficient in water resources under average meteorological conditions while climate change is foreseen to reduce water precipitation in the coming decades resulting in water shortages. Agriculture is by far the greatest water consumer in the island using around 80% of the total water use. Crete's tourism industry is growing fast while its share in total water demand is around 3%. Several technical and non-technical measures can be used to reduce the water demand in Crete. The efficient use of water in agriculture and tourism can reduce significantly the total water consumption which was estimated at 610.94 hm³ in 2016. A 10% reduction in water consumption in these two sectors can reduce the total annual water consumption in the island by 8.15 % or by 49.78 hm³/year. Appropriate water pricing, use of financial tools, awareness raising and education of several water-related stakeholders would contribute in the decrease of water demand in Crete. The results of the current study could be used from policy makers, local and regional authorities as well as from water-related organizations in the island.

KEYWORDS: climate change, Crete-Greece, public awareness, water demand, water resources

1. INTRODUCTION

The availability of the necessary water resources is a major problem in many countries particularly in regions characterized by water shortages such as eastern Mediterranean region [1], [2], [3]. The problem is exacerbated by climate change which is foreseen to increase the air temperature and reduce the precipitation in this area [2], [4]. The island of Crete, Greece has, under average meteorological conditions, sufficient water resources while climate change is predicted to reduce precipitation and increase the air temperature during the 21st century [5], [6], [7]. The share of agriculture in total water consumption is around 80% while the flourishing tourism industry requires more water resources every year [8], [3], [5]. Taking into account these circumstances the rational supply and demand management of water resources in the island is necessary to avoid future water shortages [9], [10], [11], [12], [13].

The aim of the present work is to examine the water resources in Crete, the impacts of climate change on them and the rational management of water demand in the island.

The text is structured as follows: After the literature survey the water resources in Crete and the impacts of climate change on them are presented. In the next two sections the management of water supply and demand is discussed. The water demand management (WDM) in agriculture and in tourism industry is analyzed. Additionally, the water pricing and the use of financial tools in WDM are mentioned as well as the necessity for awareness raising and education of water stakeholders and consumers. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The text is innovative since there are no similar studies related with the WDM in Crete while it covers the gap related to water resources management in the island. The results could be useful to all stakeholders of water resources in Crete.

2. LITERATURE SURVEY

The climate change adaptation in water resources in Mediterranean region has been explored [1]. It is stated that most countries on Mediterranean's southern and eastern shores are facing "chronic water scarcity" with water availability less than 1,000 m³ per capita per year while few of them have water availability less than 500 m³ per capita per year. It is mentioned that Mediterranean countries are vulnerable to the consequences of climate change on water resources availability. The current state of water resources in Mediterranean region and their future trends has been studied [2]. It is stated that due to climate change, by 2050, a decline in fresh

water resources by 30%-50% in the region is foreseen. An alternative water use scenario has been proposed stabilizing the total water withdrawals based on improvements in the efficiency of water distribution networks and in irrigated agriculture. The causes and the impacts of water scarcity in agriculture have been studied [3]. The authors stated that agriculture is responsible for nearly 70% of global water consumption and it is the most water-intensive sector. They mentioned that the improvement of irrigation technologies and practices is a good way to reduce water scarcity. The impacts of climate change on water resources in Crete during the 21st century have been analyzed [4]. The authors investigated 24 different scenarios stating that in all of them the future water scarcity was clear. They stated that climate change affects the water availability and use while improvements in water management are necessary to cope with future water shortages. The challenges and opportunities for sustainable management of water resources in Crete have been examined [5]. The authors stated that under average meteorological conditions the island is water sufficient. They mentioned that critical issues in water management in the island include: a) the overexploitation of groundwater, b) the low efficiency of water use in agriculture, c) the limited use of unconventional water resources, d) the lack of modern monitoring and control systems, and d) the lack of cooperation among stakeholders. The water resources in six major Mediterranean islands including Corsica, Crete, Cyprus, Mallorca, Malta and Sicily have been studied [6]. The authors stated that in Cyprus, Mallorca and Malta the water demand exceeds the renewable freshwater resources. They also stated that the water consumption per capita in agriculture in Crete is significantly higher than in the other five islands. They mentioned that in Mallorca around 50% of treated sewage effluents are reused in agriculture meeting around 25% of the agricultural water demand. The subsurface water potential in Crete has been studied [7]. The authors stated that the total annual water infiltration in Crete is $2.2 \times 10^9 \text{ m}^3$ while the annual runoff is $740 \times 10^6 \text{ m}^3$. They also estimated the annual water demand at $515 \times 10^6 \text{ m}^3$. The supply, the demand and the security of water use in tourism have been investigated [8]. The authors stated that direct tourism-related water use is considerably less than 1% of global consumption and it is not going to be significant even though the global tourism industry grows rapidly. They mentioned that indirect water use in tourism is likely to be significantly higher than direct water use. They also mentioned that in tourism destinations characterized by water scarcity this situation differs. The measures and policies used in WDM have been stated [9]. These measures include: water cost pricing, communication and education campaigns, universal customer metering, customer advisory services, use of appliances with low water consumption, water use restrictions et cetera. The WDM in the Mediterranean region has been studied [10]. It is stated that WDM requires a holistic approach that recognizes the complexity of the interrelationships among all factors affecting water demand. It is mentioned that policies and regulations though necessary are not sufficient while the WDM strategy requires the provision of investment capital for reducing the water losses. The psychological perspective of WDM has been explored [11]. The authors stated that there are five broad causes of residential water conservation behaviors including: attitudes, beliefs, habits or routines, personal capabilities and contextual factors. The WDM in Middle East North Africa countries has been studied [12]. The author stated that the supply management approach on its own used for many years in these countries has not bridged the water gap. He mentioned that WDM should be given first priority, particularly in agriculture, but it would not bridge alone the water gap and it should be combined with water supply management options. The supply of water resources in Crete has been explored [13]. The author stated that the island uses mainly subsurface water resources while around 80% of the total water consumption is used in agriculture. He mentioned that increase of water supply in Crete can be achieved with various ways including: the increase in the capacity of man-made water reservoirs, the increase of water in subsurface aquifers and the decrease in their pollution, the decrease of losses in water distribution networks, the increase in desalinated water production, the reuse of treated sewage effluents et cetera. The water losses in agriculture have been studied [14]. It is mentioned that 40-60% of water used in irrigation of open-field crops is lost. Several methods for reducing water losses in agriculture are also stated. The water resources management in Middle East countries has been examined [15]. It is stated that water scarcity exacerbated by population growth and political instability requires comprehensive strategies that encompass technological innovation, regional cooperation and robust policy frameworks. It is mentioned that the role of innovation and collaboration is critical in addressing water scarcity. The value of water pricing and the failure of markets have been studied [16]. The authors described the four principles of Dublin conference on water and environment in 1992 including: a) Water management in an integrated matter, b) Involvement of all the relevant stakeholders in water resources development, c) The central role of women in managing and safeguarding water, and d) Recognition of the economic value of water. The water demand management considering water as an economic good has been studied [17]. The authors stated that certain circles argue, based on Dublin principles, that water should be considered as an economic good and its pricing would result in desirable levels of demand. They proposed that a reasonable price of water should be defined achieving full cost

recovery while safeguarding ecological requirements and providing safe water for the low-income families. The water and crop management strategies enhancing agricultural sustainability in Iran have been studied [18]. The authors studied three water saving methods including: mulching, transitioning from traditional to drip irrigation and combining mulching with drip irrigation. They mentioned that the blue water footprint was reduced by 3.3% - 10.2% using the abovementioned water saving methods in traditional crops. They also stated that adjusting the cropping pattern based on unit blue water footprint is a crucial method for eliminating unsustainability in the region. The trends, opportunities, barriers and solutions in agricultural water management have been examined [19]. The authors proposed several solutions to promote sustainable water management in agriculture including: development of innovative agricultural practices, collaboration among water stakeholders, promotion of climate-smart agriculture, integration of water, energy and food systems, increase in technological innovations and use of digital technologies. The role of tourist water literacy in hotel management with reference Cape Town, South Africa has been explored [20]. The authors stated that Cape Town's tourism industry contributed to unprecedented water conservation across the city after the day zero water crisis in 2018. They mentioned that the majority of tourists positively responded to water conservation campaigns in the city. The water-tourism nexus in Mediterranean region in the past two decades has been reviewed [21]. The authors stated that the majority of the published research was related with water systems in tourism regions and to water consumption in tourism accommodations and destinations. They also mentioned that the main body of research was related to Spanish universities, the data availability on water consumption was limited while the involvement of stakeholders was also limited. The water saving potential in tourism destinations using smart water meters has been studied [22]. The authors analyzed 213 high water-consumption tourism establishments in Canary Islands, Spain. They stated that while smart water meters significantly improved consumption tracking and enabled early leak detection they increased water consumption instead of water saving. The water management in tourism has been investigated [23]. It is stated that according to the World Travel and Tourism Organization tourism accounts for between 3.5% and 5.8% of global water consumption. Around 80% of this water consumption is indirect, meaning that direct water use by tourism contributes to approximately 1% of the global water consumption which is much less than water consumption in agriculture that account for 69%. The report proposed three indicators for assessing sustainable development of tourism in destinations such as: a) water saving, b) % wastewater recycled, and c) number of tourism entities participating in water conservation measures. The community water literacy in improving sustainable WDM has been studied in Colorado, USA [24]. The authors stated that after the severe drought in Colorado in 2002 the local authorities developed WDM and water literacy programs. They mentioned that their experience revealed structures that both help and hinder community water literacy. The principles of WDM have been examined [25]. The authors stated that WDM depends on the socio-economic features of a region and it has site specific character. They mentioned that WDM is based on five core principles including: a) enforcement of water conservation, b) encouragement of water saving, c) investments on water saving, d) application of economic instruments, and e) capacity building of water users. The lessons learned from water conservation policies in Singapore have been presented [26]. The authors stated that Singapore is a water-stressed country because of its limited catchment and the high population density. They mentioned that the application of water non-pricing and pricing strategies was successful resulting in decline of water consumption. The non-pricing strategies involved consistent and sustained public education campaigns creating a culture of water conservation. The pricing strategies included charging full costs and tariffs reflecting water's real value and scarcity. The tourism data in Greek regions including the number of overnight staying in Crete have been reported [27]. The strategies to promote urban WDM in south east Queensland have been explored [28]. The authors conducted three different interventions in 221 households including: a) water saving information alone, b) information plus a descriptive norm manipulation, and c) information plus tailored end user feedback. They stated that the three intervention groups reduced the level of water consumption. However, after twelve months their water consumption returned to pre-intervention levels. The water-tourism nexus in the island of Crete, Greece has been studied [29]. The author stated that tourism affects the water resources in Crete while water is a basic resource to tourism industry. He also mentioned that the share of direct water demand in tourism to total water consumption in the island is 3.06% which is above the global average at around 1%. A report related to water-agriculture nexus for climate change adaptation has been published [30]. It is proposed three easy steps promoting climate proof agriculture including: a) acceleration of farm-level adaptation to absorb the imminent water stress, b) updating the infrastructure to new weather patterns and water availability, and c) scaling-up innovative water technologies. The management of water resources in agriculture in Crete has been studied [31]. The authors stated that the water availability per capita is relatively high in Crete while over 80% of total water consumption is used in agriculture. They mentioned that although only 31% of the agricultural land is irrigated the demand for

irrigation water is high. The 1st revision plan of river basin management plan Crete has been published [32]. It is stated that effective water saving measures include: a) provision of proper information, b) development of water saving systems, and c) creation of proper pricing policies. It is also mentioned that the main priorities for confronting the important water management issues include: a) saving water resources with infrastructure improvements, b) water pricing according to “the polluter pays”, and c) reduction of pollution on the subsurface water bodies. The water resources in Mires basin located in central Crete have been analyzed [33]. The authors stated that the basin’s water resources have been significantly reduced by unregulated subsurface water pumping and irrigation. They mentioned that during the last 30 years the groundwater level has been reduced by 35 meters. The characteristics of water resources availability and use in Crete are presented in Table 1.

Table 1. Characteristics of water resources availability and use in Crete

1	Crete is water sufficient under average meteorological conditions. However, water is unevenly distributed in the western and eastern part of the island [5]
2	The annual precipitation in Crete is estimated around 967 mm [5]
3	Only 31% of the agricultural land in Crete is irrigated. Around 80% of the total water resources in the island are used in agriculture. This value is above the global average at around 70% [31], [30]
4	Subsurface water resources are mainly used in the island [5]
5	The share of direct water demand in tourism to total water consumption in the island is 3.06% compared to the global average at around 1% [13], [23]
6	The water consumption per capita in agriculture in Crete is significantly higher than in other Mediterranean islands [6], [13]
7	The use of unconventional water resources in Crete is limited [5], [6]
8	Climate change is foreseen to reduce the availability of water resources in Crete [4]
9	The actual water consumption per capita in Crete is 978.43 m ³ /year [13]
10	The capacity of man-made water reservoirs in Crete is around 100 mil. m ³ [13]

Source: various authors

3. THE WATER RESOURCES IN CRETE

Crete, the largest island of Greece, has a Mediterranean climate characterized by hot, dry summers and relatively mild, wet winters. Although the island receives considerable rainfall during the winter months, water resources are unevenly distributed in both space and time. This seasonal and spatial imbalance, combined with increasing demand and the effects of climate change, makes water management one of the most important environmental challenges facing the island. Crete's water resources come mainly from rainfall, groundwater, springs, rivers, and reservoirs. The island has extensive mountainous areas and a complex geological structure that allows substantial amounts of rainwater to infiltrate the ground and recharge underground aquifers. Groundwater is therefore particularly important for water supply and agriculture. However, most rainfall occurs between autumn and spring, while demand is greatest during the dry summer months. Irrigation is essential for the cultivation of olives, vegetables, grapes, citrus fruits, and other crops. Tourism also creates significant seasonal demand, particularly in coastal areas where hotels, restaurants, swimming pools, and other facilities require large quantities of water during the summer. Domestic consumption and industrial activities represent additional demands. However, the water consumption in cattle breeding and in industry in Crete is relatively low (table 3). In some areas, intensive groundwater abstraction has contributed to declining water tables and, particularly near the coast, to seawater intrusion into aquifers. The future of water resources in Crete will depend increasingly on efficient and sustainable management. Climate change is expected to increase temperatures, intensify droughts, and potentially reduce or alter the seasonal distribution of rainfall. At the same time, population growth, tourism, and agricultural activity may continue to increase water demand. These pressures could make existing water shortages more frequent. Therefore, Crete possesses important but vulnerable water resources. Climate change, groundwater depletion, rising water costs and higher frequency of droughts threaten the availability and use of water resources in Crete. A combination of conservation, technological innovation, infrastructure investment, and integrated water-resource management will be essential to ensure that Crete can meet the needs of its population, agriculture, and

tourism while protecting its water resources for future generations. Table 2 indicates the general hydrological data in the island of Crete while Table 3 the water uses in Crete in 2016.

Table 2. General hydrological data in the island of Crete

Parameter	Value
Area	8,336 km ²
Annual precipitation	967 mm
Water volume	8,060.91 hm ³
Evapotranspiration	4,635.02 hm ³
Percolation	2,216.75 hm ³
Surface runoff	1,209.14 hm ³
Theoretical water potential	3,425.89 hm ³
Population (census 2021)	624,408 inhabitants
Total water demand	610.94 hm ³
Theoretical water potential per inhabitant	5,486.62 m ³ /year
Actual water consumption per inhabitant	978.43 m ³ /year
Water exploitation index (total water demand divided by the percolated water resources)	0.28
Water exploitation index (total water demand divided by the theoretical water potential)	0.18

Source: [13]

Table 3. Water uses in Crete in 2016 (hm³)

	Domestic	Agriculture	Livestock	Industry	Total	%, total
Surface	39.40	34.60	2.10	0.27	76.37	12.50
Subsurface	88.21	443.81	2.08	0.48	534.58	87.50
Total	127.65	478.39	4.16	0.75	610.94	100
%	20.89	78.30	0.68	0.12		

Source: [5]

4. THE IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN CRETE

Climate change is increasingly affecting water resources around the world and the island of Crete is particularly vulnerable because of its Mediterranean climate, limited freshwater supplies and high demand for water. Rising temperatures, changing rainfall patterns and more frequent droughts are creating significant challenges for the sustainable management of water resources across the island. One of the most important effects of climate change in Crete is the reduction and irregularity of rainfall. Higher temperatures also increase evaporation from soil, reservoirs and agricultural land, further reducing the amount of water available for human and environmental needs. Agriculture is particularly vulnerable to these changes. Greater reliance on groundwater can lead to the over-exploitation of aquifers. In coastal areas, excessive groundwater extraction can contribute to seawater intrusion, which increases salinity and makes groundwater less suitable for agriculture and drinking. Climate change can also affect the quality of water resources. Lower water availability can increase the concentration of pollutants, while extreme rainfall events may cause flooding and soil erosion, carrying sediments and contaminants into rivers, reservoirs, and groundwater systems. These problems can place additional pressure on local communities and ecosystems. Crete can reduce its vulnerability by improving irrigation efficiency, repairing water infrastructure, reducing water losses, increasing the use of treated wastewater and protecting groundwater resources. Therefore, climate change poses a serious threat to Crete's water resources by increasing drought, reducing water availability and placing greater pressure on agriculture, ecosystems and communities. Adapting water-management practices and using freshwater resources more efficiently will be essential for ensuring that Crete can meet its future water needs.

5. THE MANAGEMENT OF WATER SUPPLY IN CRETE

Water supply management is a major challenge for Crete because the island has highly seasonal rainfall, increasing water demand and significant differences in water availability between regions. Demand is particularly high during the summer, when agricultural irrigation and tourism coincide with limited natural recharge. Consequently, sustainable water supply in Crete requires a combination of traditional water sources, infrastructure development, groundwater protection and alternative water-supply technologies. The River Basin Management Plan for Crete provides the overall framework for the rational management and protection of the island's water resources. One of the most important methods is the management and storage of surface water. Dams and reservoirs allow winter rainfall and runoff to be stored and used during the dry summer period. The development of additional storage capacity, together with appropriate management of existing reservoirs, can improve the reliability of water supplies for agriculture and other uses. A second major component is the sustainable management of groundwater. Groundwater from wells and springs is an important source of water for both agricultural and domestic uses. However, excessive abstraction can reduce groundwater levels and contribute to deterioration of aquifers. Crete has several major groundwater systems and research has demonstrated the importance of monitoring abstraction, recharge and water quality when determining sustainable levels of groundwater use. Pollution of groundwater from various urban or industrial wastes and agrochemicals as well as from salination due to intrusion of seawater to aquifers should be avoided. Improving pipelines, pumping stations and distribution networks can increase the reliability of supply and reduce losses caused by leakage. Better interconnection of local water systems can also allow available water to be transferred from areas with greater availability to areas experiencing shortages. However, infrastructure development needs to be carefully planned so that it does not encourage unsustainable increases in water consumption. An increasingly important alternative is desalination. Desalination has already been used in Crete and can provide an additional source of water in areas where conventional resources are insufficient. Rainwater harvesting in small or larger scale can increase the availability of water resources in Crete. Finally, wastewater treatment and reuse can contribute to water-supply security. This approach is particularly relevant to Crete because it can connect water supply management with the principles of a circular economy. Therefore, sustainable water supply management in Crete requires a diversified and integrated approach. Dams and reservoirs, groundwater management, improved distribution networks, desalination and wastewater reuse can all contribute to greater water security. Under increasing climate variability and water scarcity, the objective should not simply be to find more water, but to manage existing and alternative resources in a way that is economically, socially and environmentally sustainable and acceptable. The methods of increasing the supply of water resources in Crete are indicated in Table 4.

Table 4. Methods of increasing the supply of water resources in Crete

1	Increasing the capacity of man-made water reservoirs
2	Increasing the subsurface water resources
3	Reducing the leakages in urban and agricultural water distribution networks
4	Developing water desalination plants
5	Improving the quality of subsurface water resources
6	Reusing treated sewage effluents for irrigation
7	Increasing rainwater harvesting

Source: [13]

6. THE MANAGEMENT OF WATER DEMAND IN CRETE

Water demand management in Crete should aim not simply to reduce water consumption, but to ensure that available water is used efficiently, economically and sustainably. One of the most important areas for water demand management is agriculture, which represents a major component of water use on the island. A second important sector is tourism. Hotels, resorts, restaurants and tourist facilities can therefore place considerable pressure on local water systems. Economic instruments and water pricing can also influence consumption. A pricing structure that reflects the cost and scarcity of water can encourage users to avoid unnecessary consumption. At the same time, essential domestic water needs should remain affordable. Incentives, subsidies and grants can encourage households, farmers and businesses to install water-saving equipment and adopt efficient technologies. Finally, public awareness and education are essential. Households, farmers, businesses and tourists should understand the value and scarcity of

water in Crete. Information campaigns can promote simple measures such as repairing leaks, avoiding unnecessary washing, using appliances efficiently and limiting outdoor irrigation during periods of high-water stress. Therefore, effective WDM in Crete requires a combination of technological, economic, environmental and behavioral measures.

6.1 Management of water demand in agriculture in Crete

Agriculture is the largest consumer of water in Crete and therefore represents the most important sector for implementing water demand management measures. The island's Mediterranean climate, characterized by hot and dry summers and considerable spatial and seasonal variations in rainfall, creates significant pressure on water resources. Agriculture accounts for approximately 80% of total water consumption in Crete, while irrigation demand is concentrated during the period when natural water availability is lowest. This imbalance makes the efficient management of agricultural water demand essential for protecting the island's water resources and maintaining the long-term viability of its agricultural sector. Excessive water abstraction for irrigation has contributed to groundwater depletion and, in some areas, increased the risk of seawater intrusion and degradation of aquifers. These problems are particularly significant in parts of southern and eastern Crete, including areas such as the Messara Valley. Studies in this valley indicated that unregulated irrigation has reduced the level of subsurface aquifers by 35 meters in 30 years [33]. Climate change is going to adversely affect both irrigated and rainfed crops. The decrease of precipitation and the increase of air temperatures in the future will require more blue water for meeting crops' demand. Several rainfed crops that currently use green water might need blue water in the future increasing the water consumption in irrigation. One of the most important measures for reducing agricultural water demand is the improvement of irrigation efficiency. Traditional irrigation practices can result in water losses through evaporation, leakage, runoff and excessive application. Modern systems such as drip irrigation and micro-sprinklers can deliver water more directly to the crop root zone and therefore reduce losses. However, installing efficient irrigation equipment alone is not sufficient. Farmers must also apply the correct quantity of water at the appropriate time according to crop requirements, soil conditions and weather conditions. For this reason, irrigation scheduling and precision agriculture have an increasingly important role. Technologies such as soil-moisture sensors, weather stations, remote sensing and digital decision-support systems can help farmers determine when irrigation is actually necessary. Such systems can help reduce water consumption while maintaining agricultural productivity. Another important approach is the better allocation of water between crops, locations and seasons. Different crops have different water requirements and economic values. Research examining irrigation strategies in Crete has found that optimization of irrigation allocation could potentially reduce irrigation volumes substantially while maintaining agricultural benefits. This demonstrates that WDM can involve not only using less water, but also using available water where it generates the greatest agricultural and economic value. WDM should also include crop selection and agricultural practices adapted to local climatic conditions. Promoting drought-tolerant crops and varieties, improving soil organic matter, using mulching and maintaining appropriate soil management can reduce crop water requirements. Water pricing based partly on the volume of water used can encourage conservation, while subsidies or financial support can help farmers invest in efficient irrigation systems and monitoring technologies. Nevertheless, these measures should be combined with farmer education, technical assistance and reliable water monitoring, rather than relying on pricing alone. Since agriculture is the island's largest water user, even relatively small improvements in efficiency can produce significant benefits at the basin level. Moving from a traditional approach based on increasing water supply towards a demand-management approach that prioritizes efficiency, productivity and conservation will be increasingly important for ensuring both agricultural resilience and long-term water security in Crete. It is estimated that 40-60% of the water used in open-field irrigation is lost. Strategies to reduce water losses include: soil amendment, hydroponic solutions and greenhouse water management. Table 5 indicates the distribution of water losses in agriculture.

Table 5. Distribution of water losses in agriculture

Sector	Losses (%)
Evaporation	25-40%
Surface run-off	10-20%
Deep percolation	15-25%
Inefficient irrigation systems	10-30%

Source: [14]

6.2 Management of water demand in tourism in Crete

Tourism is one of the most important economic activities in Crete and makes a major contribution to employment, income and regional development. However, the rapid growth of tourism also creates additional pressure on the island's water resources, particularly because tourist demand is highly concentrated during the hot and dry summer months. This creates a significant challenge for water management: the period of greatest tourism activity coincides with the period of lowest natural water availability. Research on Crete indicates that domestic water demand increases significantly during the summer because of tourism, while water scarcity is particularly evident in some eastern and southern parts of the island. Assuming that the overnight stays of tourists in 2025 in Crete were 48,622,000 [27] and the average water consumption per tourist per night is 400 lit [8] the total water consumption of visitors in Crete in 2025 was 19.45 mil. m³. This corresponds at 3.18% of the total water consumption in 2016 in the island and at 15.24% of the water consumption in the domestic sector in 2016 in Crete [Table 3]. WDM in tourism should therefore focus on reducing unnecessary consumption while maintaining the quality of the experience of visitors. This is important because tourism does not necessarily have to be associated with high water consumption. Hotels, resorts, restaurants and other tourism businesses can reduce their demand through technological improvements, better management practices and greater awareness among employees and visitors. One of the most effective measures is the installation of water-efficient technologies. Hotels can install low-flow showerheads and taps, dual-flush toilets, efficient washing machines and water-efficient kitchen equipment. Smart water meters can also be installed to monitor consumption in different areas of a hotel and identify unusual increases that may indicate leaks. Regular inspection and maintenance of plumbing systems are particularly important because water losses can otherwise remain unnoticed. Another important area is the management of swimming pools and hotel landscaping. Landscaping can also be redesigned to use drought-resistant and native Mediterranean plants rather than water-intensive species. Wastewater and grey-water reuse represent another important opportunity for Crete. Treated wastewater can potentially be reused for non-potable purposes such as toilet flushing, landscape irrigation and, where appropriate, other applications. The behavior of tourists and employees is equally important. Hotels can encourage guests to reduce shower times, reuse towels and linen, avoid unnecessary water consumption and participate in water-saving programs. Economic instruments can also support WDM. Hotels could face water charges that better reflect the volume and scarcity of water used, creating incentives for investment in efficiency. At the same time, financial incentives, certification schemes and technical support could encourage tourism businesses to adopt water-saving technologies. WDM in tourism is essential for the long-term sustainability of Crete's tourism industry. A combination of efficient technologies, leak reduction, sustainable landscaping, wastewater reuse, smart monitoring, guest education and appropriate economic incentives can substantially reduce water consumption. As climate change increases the likelihood of drought and water scarcity, improving water efficiency in hotels and other tourism businesses will be essential for protecting Crete's water resources while maintaining the island's attractiveness as a leading Mediterranean destination. Table 6 indicates the impact of reduced water consumption in agriculture and tourism on total water use in Crete.

Table 6. Impact of reduced water consumption in agriculture and tourism in total water demand in Crete

Total water use in Crete (2016)	610.94 hm ³
Water use in agriculture in Crete (2016)	478.39 hm ³
Water use in tourism in Crete (2025)	19.45 hm ³
Annual water saving with 10% less water use in agriculture	47.84 hm ³
Annual water saving with 20% less water use in agriculture	95.68 hm ³
Annual water saving with 10% less water use in tourism	1.94 hm ³
Annual water saving with 20% less water use in tourism	3.89 hm ³
Annual water saving with 10% less water use in agriculture and tourism	49.78 hm ³
Annual water saving with 20% less water use in agriculture and tourism	99.57 hm ³
%, Total water saving with 10% less water use in agriculture and tourism	8.15 %
%, Total water saving with 20% less water use in agriculture and tourism	16.30 %
Total annual water consumption in Crete with 10% less water use in agriculture and tourism	561.16 hm ³
Total annual water consumption in Crete with 20% less water use in agriculture and tourism	511.37 hm ³

Source: own estimations

6.3 Water pricing and use of economic instruments in water management in Crete

Water is a strategically important resource for Crete, an island where agriculture, tourism and domestic consumption place significant pressure on limited freshwater resources. Increasing drought frequency, climate change, groundwater depletion and seasonal variations in demand make efficient water management particularly important. In this context, water pricing and other economic instruments can play an important role in encouraging efficient water use, recovering infrastructure costs and protecting water resources. Water pricing is not simply a mechanism for financing water services; it can also influence users' behavior. At national level, agriculture accounts for around 80% of Greece's water use, while drought and increasing climate variability are placing additional pressure on available resources. In Crete, an effective pricing system should therefore distinguish between different categories of users and reflect the scarcity of water in individual river basins and aquifers. However, pricing alone is unlikely to solve Crete's water-management challenges. Economic instruments can include volumetric tariffs, progressive pricing, abstraction charges, subsidies, environmental charges and financial incentives for water-saving technologies. Subsidies could also support investments in drip irrigation, smart metering, soil-moisture monitoring and other technologies that reduce water consumption. Economic instruments should also support water reuse and circular water management. Nevertheless, water pricing must be designed carefully. Excessively high prices may disproportionately affect small farmers and low-income households. Therefore, policies should combine cost recovery with social protection, transparent pricing and targeted subsidies. Accurate metering is also essential because users cannot respond effectively to volumetric pricing if their consumption is not measured. Water pricing and economic instruments should become an integral part of sustainable water management in Crete. A combination of realistic water tariffs, resource-cost charges, incentives for efficient irrigation, subsidies for water-saving technologies and support for wastewater reuse could reduce unnecessary consumption while generating funds for maintaining water infrastructure. Pricing should not be viewed as simply making water more expensive; rather, it should communicate the economic and environmental value of a scarce resource and encourage users to manage it more efficiently. For Crete, where water scarcity is likely to intensify under climate change, well-designed economic instruments can therefore complement regulation and infrastructure investment in achieving long-term water security.

6.4 The need for education and public awareness raising for effective water management in Crete

Water is one of the most important natural resources for the economic, social and environmental development of Crete. Therefore, effective water management requires not only infrastructure and regulatory measures but also education and public awareness. Education is essential because sustainable water management ultimately depends on the behavior of individuals, households, farmers, businesses and institutions. People need to understand that water is a limited resource and that its availability cannot be taken for granted. However, policies and regulations are more effective when citizens understand their purpose and actively participate in their implementation. Schools should therefore have an important role in developing a water-conscious culture from an early age. Educational programs can introduce students to the water cycle, local water resources, drought, climate change and practical water-saving measures. Students can also become effective communicators by transferring knowledge and environmentally responsible practices to their families and communities. Public awareness campaigns should extend beyond schools to farmers, tourism businesses, households and local communities. Farmers should receive practical information about efficient irrigation, soil-moisture monitoring, irrigation scheduling and technologies that reduce water losses. Tourism businesses should also be encouraged to adopt water-efficient technologies, reduce unnecessary consumption and communicate sustainable water-use practices to visitors. Public awareness is also important for building social acceptance of water-management policies. Transparent communication about water availability, drought conditions and consumption can encourage cooperation and strengthen trust between citizens and water-management authorities. Finally, education and awareness should be continuous rather than limited to periods of severe drought. Therefore, education and public awareness should be considered fundamental components of sustainable water management in Crete. Infrastructure, legislation and economic instruments are necessary, but they cannot achieve long-term water security without changes in behavior and public participation. By educating young people, supporting farmers and businesses, informing residents and involving local communities in decision-making, Crete can develop a stronger culture of water conservation.

7. DISCUSSION

The WDM in the island of Crete, Greece has been studied. Our results indicate that Crete has sufficient water resources which are unevenly distributed along the island while climate change threatens their sufficiency in the coming decades. Agriculture is by far

the main consumer of water resources in the island while tourism industry requires an increasing amount of water every year. Although the rational supply of water resources in Crete is necessary, specific focus should be given in optimizing their demand increasing water efficiency in all sectors. Improvements in WDM can be achieved with technical and non-technical measures. Agriculture and tourism in Crete consume a large share of water, around 80% and 3% correspondingly. Increasing water efficiency in agriculture and tourism with several interventions can result in significant water savings. Using appropriate water pricing policies taking into account the value of water as a scarce resource, accounting for its environmental value and protecting the low-income households would result in additional water savings. Increasing awareness raising and educating people about water as a valuable natural resource and the necessity to use it efficiently would also save water resources. Therefore, WDM in Crete can be improved with technical and non-technical interventions which are necessary for coping with the undesired impacts of climate change. The accuracy of our results depends on the accuracy of the data in the references used. It should be mentioned that the data used in table 6 are reported in different years. Future research should be focused on the combined supply and demand management of water resources in the island taking into account the adverse impacts of climate change.

8. CONCLUSIONS

The water resources in Crete, the impacts of climate change on them and the management of water demand in the island have been examined. The main findings can be summarized as follows:

- a) The island of Crete has sufficient water resources under average meteorological conditions.
- b) Agriculture is the main water consumer having a share at around 80% in total water consumption, while the share of tourism industry is around 3%.
- c) Crete's water needs are mainly met by subsurface water resources while the use of unconventional water resources is limited.
- d) Climate change is predicted to have adverse impact to water resources in Crete in the coming decades.
- e) Water demand in several sectors can be reduced with technical and non-technical interventions.
- f) The high consumption of water resources in agriculture and tourism can be reduced with appropriate technical measures and policies.
- g) Water pricing combined with financial instruments are important tools affecting the water demand in the island.
- h) Education and awareness raising among the stakeholders of water resources in Crete can improve the water use efficiency in several sectors.
- i) The impact of water reduction in agriculture on total water demand in Crete is significantly higher than the reduction in tourism industry.
- j) A 10% reduction in water consumption in both agriculture and tourism can reduce the total annual water consumption in the island by 8.15 % or by 49.78 hm³/year.

The main take away of our study is that the rational WDM in Crete can reduce the overall water consumption avoiding water shortages in the near future.

REFERENCES

1. Simonet, S. Adapting to climate change in the water sector in the Mediterranean: situation and prospects, Blue Plan Papers 10, UNEP, 2011. Available from: https://planbleu.org/sites/default/files/publications/cahier10_eau_cc_en.pdf
2. Milano, M., Ruelland, D., Fernandez, S., Dezetter, A., Fabre, J., Servat, E., Fritsch, J-M., Ardoin-Bardin, S. & Thivet, G. Current state of Mediterranean water resources and future trends under climatic and anthropogenic changes. Hydrological Sciences Journal, 58(3), 2013, pp. 498-518. DOI: 10.1080/02626667.2013.774458
3. Ingrao, C., Stroppoli, R., Lagioia, G. & Huisinigh, D. Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. Heliyon, 9, 2023, e18507. <https://doi.org/10.1016/j.heliyon.2023.e18507>
4. Koutroulis, A.G., Tsanis, I.K., Daliakopoulos, I.N. & Jacob, D. Impact of climate change on water resources status: case study for Crete, Greece. Journal of Hydrology, 479, 2013, pp. 146-158. <http://dx.doi.org/10.1016/j.jhydrol.2012.11.055>
5. Tzanakakis, V.A., Angelakis, A.N., Paranychianakis, N.V., Dialynas, Y.G. & Tchobanoglous, G. Challenges and opportunities for sustainable management of water resources in the island of Crete, Greece. Water, 12, 2000, 1538. <http://dx.doi.org/10.3390/w12061538>

6. Viola, F., Sapiano, M., Schembri, M., Brincat, C. et al. The state of water resources in major Mediterranean islands. *Water Resources*, 41(6), 2014, pp. 639-648. DOI: 10.1134/S0097807814060207
7. Perleros, V., Papamastorakis, D., Kritsotakis, M., Drakopoulou, E. & Panagopoulos, A. Subsurface water potential in Crete. Problems and prospects. *Bulletin of the Geological Society of Greece*, 36(4), 2004, pp. 2048-2056, (in Greek). <https://doi.org/10.12681/bgsg.16704>
8. Gossling, S., Peeters, P., Hall, C.M., Ceron, J-P., Dubois, G., Lehman, L.V. & Scott, D. Tourism and water use: supply, demand and security: An international review. *Tourism Management*, 33, 2012, pp. 1-15. <http://dx.doi.org/10.1016/j.tourman.2011.03.015>
9. What is water demand management? Available from: <https://www.pacificwater.org/pages.cfm/water-services/water-demand-management/what-water-demand-management/>
10. Water Demand Management: The Mediterranean experience, Technical Focus Paper, 2012. Available from: <https://gwp-gwp.org/wp-content/uploads/2026/04/01-water-demand-management-the-mediterranean-experience-2012-english.pdf>
11. Russel, S. & Fielding, K. Water demand management research: A psychological perspective. *Water Resources Research*, 46, 2010, W05302. <https://doi.org/10.1029/2009WR008408>
12. Mualla, W. Water demand management is a must in MENA countries... But is it enough? *Journal of Geological Research and Engineering*, 6, 2018, pp. 59-64. doi:10.17265/2328-2193/2018.02.002
13. Vourdoubas, J. The supply of water resources in the island of Crete, Greece. *Engineering and Technology Journal*, 11(9), 2026, pp. 11479-11490. <https://doi.org/10.47191/etj/v11i09.10>
14. Water retention in Mediterranean agriculture. Available from: <https://nordiaagro.gr/guides/water-retention-mediterranean/>
15. Wang, G., Kumar, S., Huang, Z. & Liu, R. Water resource management and policy evaluation in Middle east countries: Achieving Sustainable Development Goal 6. *Desalination and Water Treatment*, 320, 2024, 100829. <https://doi.org/10.1016/j.dwt.2024.100829>
16. van der Zaag, P. & Savenije, H.H.G. (2006). Water as an economic good: The value of pricing and the failure of markets, Research Report Series, UNESCO-IHE, Institute for Water Education. Available from: https://waterfootprint.org/resources/Report_19_Water_as_an_Econ_Good.pdf
17. Savenije, H. & van der Zaag, P. Water as an economic good and demand management, Paradigms with pitfalls. *Water International*, 27(1), 2002, pp. 98-104. <https://doi.org/10.1080/02508060208686982>
18. Hashemi, S-Z., Darzi-Naftchali, A., Karandish, F., Ritzema, H. & Solaimani, F. Enhancing agricultural sustainability with water and crop management strategies in modern irrigation and drainage networks. *Agricultural Water Management*, 305, 2024, 109110. <https://doi.org/10.1016/j.agwat.2024.109110>
19. Nhamo, L., Taguta, C., Mpandeli, S., Dirwasi, T., Liphadgi, S. & Mabhaudhi, T. Transforming agricultural water management through the water-energy-food nexus: Trends, Opportunities, Barriers and Solutions. *Irrigation and Drainage*, 2025, pp. 1-12. <https://doi.org/10.1002/ird.70032>
20. McCarroll, M.J., La Vanchy, G.T. & Kerwin, M.W. Tourism resilience to drought and climate shocks: The role of tourism water literacy in hotel management. *Annals of Tourism Research Empirical Insights*, 5, 2024, 100147. <https://doi.org/10.1016/j.annale.2024.100147>
21. Sandra Ricart, S., Villar-Navascués, R., Reyes, M., Rico-Amorós, A.M., Hernández-Hernández, M., Toth, E., Bragalli, Cr., Neri, M. & Amelung, B. Water-tourism nexus research in the Mediterranean in the past two decades: a systematic literature review. *International Journal of Water Resources Development*, 40(1), 2024, pp. 57-83. DOI: 10.1080/07900627.2023.2207686
22. Padrón-Fumero, N., Bauluz, A., Díaz-Hernández, J.J., Díaz-Farina, E. & Hernández-Yumar, A. Unlocking water saving potential in tourism destinations using Smart Water Meters. *Current Issues in Tourism*, 2025, pp. 1-27. DOI:10.1080/13683500.2025.2519662
23. Water Management in Tourism, Boku University, Department of Water, Atmosphere and Environment, Malaga, 2024. Available from: https://pre-webunwto.s3.eu-west-1.amazonaws.com/s3fs-public/2024-09/WaterManagementInTourism_Malaga_compressed.pdf?VersionId=v9YVU4RVib2P3sJ43s2STnNNLKSQ6Wvj

24. McCarroll, M.J., Hamann, H.B., LaVanchy, G.T. & Kerwin, M.W. Promoting sustainable water demand management through community water literacy: A case study from Aurora, Colorado, USA. *Journal of American Water Resources Association*, 62, 2024, e70122. <https://doi.org/10.1111/1752-1688.70122>
25. Kampragou, E., Lekkas, D.F. & Assimakopoulos, D. Water demand management: implementation principles and indicative case studies. *Water and Environment Journal*, 25(4), 2010, pp. 466-476. doi:10.1111/j.1747-6593.2010.00240.x
26. Sanlath, C. & Masila, N.M. Water demand management: what lessons can be learned from Singapore's water conservation policy? *Water Utility Journal*, 26, 2020, pp. 1-8. Available from: https://www.researchgate.net/publication/346588912_Water_Demand_ManagementWhat_lessons_can_be_learned_from_Singapore%27s_water_conservation_policy
27. Inbound Tourism, Data per Region, Institute of Greek Tourism Enterprises-INSETI. Available from: <https://inseti.gr/bi/inbound-tourism-data-per-region/?lang=en>
28. Fielding, K.S., Spinks, A., Russel, S., McCrea, R., Stewart, R. & Gardner, J. An experimental test of voluntary strategies to promote urban water demand management. *Journal of Environmental Management*, 114, 2013, pp. 343-351. <http://dx.doi.org/10.1016/j.jenvman.2012.10.027>
29. Vourdoubas, J. The water-tourism nexus in the island of Crete, Greece. *International Journal of Current Science Research and Review*, 8(12), 2025, pp. 5986-5995. <https://doi.org/10.47191/ijcsrr/V8-i12-11>
30. Water-agriculture nexus: Forefront of climate adaptation, Playbook for volatile future, Project Mizu, 2023. Available from: <https://uploads.water-energy-food.org/resources/Full-Report-Water-Agriculture-Nexus-231126.pdf>
31. Chartzoulakis, K.S., Paranychianakis, N.V. & Angelakis, A.N. Water resources management in the island of Crete, Greece with emphasis on the agricultural use. *Water Policy*, 3, 2001, pp. 193-205. [https://doi.org/10.1016/S1366-7017\(01\)00012-5](https://doi.org/10.1016/S1366-7017(01)00012-5)
32. 1st revision of River Basin Management Plan Crete River Basin District, EU, NSRF 2014-2020, Ministry of Environment and Energy, Hellenic Republic. Available from: https://wfdver.ypeka.gr/wp-content/uploads/2021/02/EL13_1REV_P22b_Perilipsi_EN.pdf
33. Varouchakis, E.A. Integrated Water Resources Analysis at Basin Scale: A Case Study in Greece. *Journal of Irrigation and Drainage Engineering*, 142(3), 2026, 05015012. DOI: 10.1061/(ASCE)IR.1943-4774.0000966

Cite this Article: John, V. (2026). Water Demand Management in the Island of Crete, Greece. International Journal of Current Science Research and Review, 9(9), pp. 5180-5191. DOI: <https://doi.org/10.47191/ijcsrr/V9-i9-34>