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The Supply of Water Resources in The Island of Crete, Greece

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Abstract: Eastern Mediterranean region is characterized by water resources scarcity while climate change is expected to has adverse impact on them. Shortage of water resources requires their rational management to meet the water needs. The water resources in the island of Crete, Greece are studied in light of climate change analyzing their supply and the use of nonconventional water resources. The increase in tourism industry and the decrease in precipitation due to climate change in the future is going to affect the water supply and demand in the island. The study has been conducted reviewing the existing literature. It is indicated that Crete under normal meteorological conditions is water sufficient while water consumption per capita is significantly higher compared to other Mediterranean islands. The island uses mainly subsurface water resources while around 80% of total water consumption is used in agriculture. The water consumption in agriculture per capita in Crete is significantly higher than in other Mediterranean islands indicating the low efficiency in water use in agriculture. Increase in water supply in Crete can be achieved with several ways including the increase in the volume of man-made reservoirs, the increase of water in subsurface aquifers and the decrease of their pollution, the reduction of losses in water distribution networks, the increase of desalinated water production, the reuse of treated sewage effluents et cetera. The results could be useful to policy makers and to stakeholders of the water resources in Crete.

KEYWORDS: Agriculture, Climate Change, Crete-Greece, Subsurface Water, Supply, Water Resources.

1. INTRODUCTION

The rational management of water resources in the island of Crete as well as in other Mediterranean islands is important because of their scarcity in this geographical region. Climate change is expected to reduce the precipitation, to increase the temperature, the droughts, the floods and the evapotranspiration in Mediterranean region including the island of Crete [1], [2], [3]. Therefore, climate change is foreseen to increase the shortage of water resources in Mediterranean islands in the near future [4], [5], [6], [7]. Crete hosts an increasing number of tourists every year while agriculture has a high share in total water consumption [8], [9], [10], [11], [12]. The island uses mainly subsurface water resources meeting their needs while around 80% of water is used in agriculture. The use of nonconventional water resources, such as desalinated water and treated sewage effluents, although undeveloped in Crete is going to reduce the pressure on fresh water resources [13], [14], [15]. The increase in water supply and the decrease in water demand in Crete is necessary for coping with the expected water shortages in the near future.

The aim of the present work is to examine the water resources in Crete, the impacts of climate change on them and the increase in their supply with various ways 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 examined. Next, the supply of water with various ways in the island is analyzed. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The work is innovative since there are no many studies focusing on the increase of the supply of water resources in Crete while it covers a gap regarding the rational management in the supply of water resources in the island. The results could be useful to all stakeholders involved in water resources utilization in Crete and in other Mediterranean islands.

2. LITERATURE SURVEY

The 1st revision of the river basin management plan for the Cretan river basin district has been approved in 2017 [1]. The plan provided a detailed analysis of the status and the pressures of water bodies, the water abstraction as well as an economic analysis of the water uses. The water supply management in Cyprus under climate uncertainty has been examined [2]. The authors stated that numerous water dams have been constructed in Cyprus, with total water capacity at 331.86 mil. M^3 in 2010, as well as several desalination plants. They mentioned that another technology that has been developed is the purification of used water through microfiltration, reverse osmosis and ultra-violent disinfection. The climate-induced water shortage in Crete has been studied [3]. The authors stated that the Intergovernmental Panel on Climate Change predicts that Mediterranean region is on the climate change hot spots characterized by lower precipitation, higher temperatures and intense floods and droughts. They mentioned that according to climate models, precipitation in Crete is going to decrease by around 26 mm per decade while the temperature is going to increase by 0.5°C per decade. They added that Crete is classified as a water district under high water stress due to the fact that most of runoff ends untapped into the sea. The water scarcity challenges in Malta have been investigated [4]. The authors stated that in recent years the over-extraction of the groundwater resulted in salt water intrusion in the subsurface aquifers worsening the groundwater quality. The authors proposed several alternatives for the future regarding water resources management including wastewater reuse, increased awareness, use of renewable energies, rainwater harvesting and the implementation of national strategic water policies. The impact of climate change on water resources in the island of Crete, Greece has been investigated using different scenarios and global climate models [5]. The authors stated that water deficit is foreseen in the future ranging from 10% to 74%. They mentioned that the development of water resources infrastructure is necessary in Crete combined with improved water management and climate change adaptation measures. The nexus among energy, water and climate change in Crete has been examined [6]. The author stated that the island faces water shortages which are exacerbated by climate change. He mentioned that water, energy and climate change are interdependent while the sustainable management of water resources in Crete should take into account their interlinkages. The management of water resources in light of climate change in Cyprus has been examined [7]. The authors stated that climate change factors which affect the water resources in Cyprus are the increase in temperature, the decrease in precipitation and the increase of droughts and the heavy rainfalls. They mentioned that the water exploitation index in Cyprus is 64% indicating severe water stress while the use of desalinated water and treated wastewater effluents reduce the pressures of fresh water resources in the island. The water-tourism nexus in the island of Crete, Greece has been explored [8]. The author stated that Crete hosts more than 6 million tourists each year who consume large quantities of water during their vacations. He mentioned that the share of direct water demand in tourism to total water consumption in the island is 3.06% compared to the global average at 0.65%. The management of water resources in Crete, Greece emphasizing the agricultural use has been studied [9]. The authors stated that the average annual precipitation in Crete is around 900 mm, the potential annual renewable water resources are 2,650 mil. M^3 and the real annual water use is 485 mil. M^3. They mentioned that the main water use in Crete is crops' irrigation with a share at 84.5% in total use, followed by domestic use with share at 12% and other uses at 3.5% while only 31% of the agricultural crops in the island are irrigated. The impacts of climate change on water resources in Crete have been studied using simulation of several climate change scenario [10]. The authors stated that a significant water deficit is foreseen in Crete in the near future while they proposed several measures to cope with the future water deficit such as reduction of water losses from water supply and irrigation networks, the rational use of irrigation water and better exploitation of the water storage facilities. The sustainable management of water resources in Crete, Greece has been explored [11]. The authors stated that under average meteorological conditions the island is water sufficient with 967 mm annual precipitation, theoretical annual water potential 3,425.89 mil. M^3 and total annual water use 610 mil. M^3. They mentioned that agriculture is by far the greatest water user with share at 78% in total water use, followed by domestic use at 21%. They added that groundwater is overexploited accounting for 93% of the water used in agriculture while the water management in the island should be improved. The water-agriculture nexus in the context of climate adaptation has been investigated [12]. It is stated that three trends in adaptation solutions have been identified including: a) The use of all available technologies that reduce the water stress in crops, b) The promotion of low-risk measures preventing leaks, preserving water and recharging groundwater aquifers, and c) The creation and retrofitting of water storage and transport infrastructure systems. The water management in Mediterranean islands focusing on Majorca, Corsica, Sicily, Crete and Cyprus has been explored [13]. The authors stated that in Crete groundwater is the main water source used while the available annual water resources are 4,767 M^3 per capita and the annual exploitable water resources are 1,428 M^3 per capita. The state of water resources in major Mediterranean islands including Corsica, Crete, Cyprus, Mallorca, Malta and Sicily has been studied [14]. The authors stated that the fresh water exploitation index in Crete is below 1 indicating that the available water resources are sufficient to meet the island's water demand. On the contrary in Cyprus, Malta and Mallorca this index is above 1. They mentioned that different strategies have been developed in these islands to face water scarcity in the context of climate change. The potential of wastewater reuse for irrigation in Italy has been studied [15]. The authors stated that in Mediterranean countries water shortage is becoming a major problem and water management should include the treated wastewater reclamation and reuse. They mentioned that the potential useable treated wastewater in Sicily was about 87 mil. M^3 per year while the annual water deficit was 65 mil. M^3. The carbon footprint on water full cycle in Balearic Islands has been estimated [16]. The authors stated that in Mallorca Island groundwater is mainly used while Formentera Island is based on desalinated water. They mentioned that the largest footprint was from seawater desalination plants followed from water extraction from subsurface water aquifers and from the drinking water distribution networks. The water policy in Balearic Islands has been investigated [17]. The authors stated that maintaining the ecological quality of water ecosystems and covering the increasing water demand are competing objectives while improving the water efficiency is not enough. For Balearic Islands they proposed a 10% savings on current water consumption in the tourism sector with moderate price increases which could result in sizable reduction of the pressures on water resources. A case study regarding the water resources management for smart farming in Cyprus has been conducted [18]. The authors stated that remote sensing has been used for estimating evapotranspiration which is essential for calculating the irrigation needs of crops. They mentioned that three crop types are using more water than the total annual inflow of reservoirs in 2023. The total annual irrigation needs of citrus, olives and potatoes amount at 153.65 mil. M^3 in 2023 while over the past 35 years the average annual inflow in all the water dams was around 83.63 mil. M^3. The integrated water management in the Maltese islands has been studied [19]. The author stated that natural freshwater resources are not sufficient to meet the national water demand while the islands' semi-arid conditions preclude the formation of surface water bodies. He mentioned that the 2nd river basin management plan in Malta foresees that in 2021 the water supply will be distributed as follows: a) groundwater, 48%, b) rainwater harvesting, 11%, c) desalinated water, 32%, d) treated sewage effluent, 8%, and e) alternative resources, 1%. The impacts of climate change on the water needs of crops in three Mediterranean basins in Catalonia, Spain have been explored [20]. The authors stated that the net water needs will be increased by 3.9%-6.7% until 2040. They mentioned that the increased net water requirements in these basins combined with lower water availability will reduce crops' productivity in both rainfed and irrigated crops concluding that adaptation measures are needed. The groundwater footprint methodology balancing the water needs in Crete, Greece has been studied [21]. The authors stated that the concept of the groundwater footprint can help in sustainable management of water resources taken into account that in Crete the main water supply is groundwater. They mentioned that the average value of 11 groundwater systems in Crete is characterized as very good. The water resources in Greece have been critically reviewed [22]. The author stated that groundwater resources consist the main sources of water in Greece with a percentage close to 70%. He mentioned that the eastern part of Crete is among the Greek areas which are going to be seriously affected by climate change with reduced crops' yields, a greater risk of floods and droughts, loss of agricultural land and declining water availability. He added that the agricultural sector in Greece will be adversely affected by climate change. The sustainable water resources management to combat desertification in Nurra Region, Sardinia, Italy has been explored [23]. The authors stated that the high concentration of the population in the coastal zone and the intense agricultural activity have increased the water demand. They mentioned that water demand in the region is satisfied by surface water but in some dry periods, groundwater is used. Therefore, the quality of groundwater resources should be protected avoiding contamination or salination. The water demand in several crops under climate change in Sardinia region, Italy has been studied [24]. The authors estimated that water demand in crops such as wheat and barley will increase by 12-14% while in other crops such as almond, wine grapes and pasture will increase by 4-7%. They stated that the increasing water demand in agriculture represents a considerable challenge in water management taking into account the increasing competition from other sectors. The water footprint on Crete has been assessed considering climate change effects on future agricultural production in the Mediterranean region [25]. The authors stated that climate change will result in lower annual precipitation and in higher air temperatures in Crete. They mentioned that in the future several crops in the island will require more blue water – received from surface and subsurface water resources - taken into account that the availability of green water – received from rainfalls - will be decreased. The impacts of climate change on the performance of the water supply system in a Sicilian reservoir have been assessed [26]. The authors stated that climate change is going to decrease the water inflow into the reservoir. They mentioned that climate change adaptation measures should be implemented decreasing significantly the water demand avoiding the declined performance of the reservoir. The impacts of climate crisis on water distribution systems focusing on Messina, Sicily have been assessed [27]. The authors stated that Sicily experiences a severe water crisis due to droughts and climate change. They mentioned that reduction of losses in Messina's water distribution system is the most-effective long-term strategy against water scarcity. The leakages in water distribution networks and their mitigation have been explored [28]. The authors stated that leakages in water distribution networks result in significant economic losses and environmental risks. The causes of leakages along the pipelines of water distribution networks can be attributed to a variety of structural, external, internal (hydraulic) and maintenance-related factors. They mentioned that robust legislative measures must be implemented to address this issue. The monitoring of water leakages in water supply networks has been studied [29]. The authors stated that a significant amount of water is lost in the water supply system while water leakages are a major problem for many regions around the world which in some cases could exceed 40%. They mentioned that water leakages in several EU countries vary in the range of 50% in Bulgaria to less than 10% in Germany and Denmark. The solar electricity generation from floating solar photovoltaics installed in water dams in Crete has been estimated [30]. The author stated that the water capacity of the major water dams in Crete is around 100 mil. M^3. The dynamics of the water-agriculture nexus for the next three decades has been studied [31]. The authors stated that the current patterns of water use and agricultural practices, if continued, are projected to cause severe water shortages in the coming three decades. They proposed to halt the cultivation of water-intensive crops, to reduce groundwater withdrawal and to transfer large quantities of water. The sustainable management of water resources in small Greek islands in the era of climate change has been studied [32]. The authors examined several scenarios in eight small Greek islands in Aegean Sea including current water supply practices via ship transfer, domestic rainwater harvesting and desalinated water supply with wind power. They mentioned that combination of various water supply alternatives is essential while additional technological solutions such as grey water recycling should be promoted.

The water resources planning in Skiathos island, Greece has been studied [33]. The author stated that the limited water resources in the island should meet the increasing water demand of the local population and the tourists. He mentioned the currently the overexploitation of aquifers results in seawater intrusion deteriorating the water quality while he suggested to improve the water infrastructure in the island as well as the management of water resources. The integrated approach to water resources sustainability in Aegean islands has been explored [34]. The authors analyzed the main water supply and demand characteristics of the Greek islands. They also presented several water sustainability indexes including the water poverty index and the water exploitation index which is the ratio of the mean annual total demand of freshwater to the long-term average freshwater resources. The sustainable water resources management and the energy production in small Mediterranean islands have been explored [35]. The authors proposed a hybrid renewable energy system integrating wind turbines, pumped-hydro storage, hydrogen production and storage and water desalination. They stated that the hybrid renewable energy system offers in small islands globally a replicable model for addressing the water-energy nexus. The community-led actions in water management in Crete have been studied [36]. The author stated that water was not always treated as a commodity while community-led activities have emphasized the need for local mobilization and collaboration around the issue of water scarcity in the island. She mentioned that technical training and capacity building programs in water management are required for the local non-profit water management organizations (TOEB) in the island. The use of rainwater harvesting systems in two small Greek islands has been evaluated [37]. The authors stated that Greek islands are characterized by poor water potential while they host a large number of tourists. They mentioned that rainwater harvesting systems is a cost-effective “green” solution achieving additional water resources particularly in regions with water scarcity.

3. WATER RESOURCES IN CRETE

Recent studies indicate that Crete is water sufficient under average meteorological conditions with 967 mm annual precipitation [11]. Water is used in several sectors in Crete while agriculture has the highest share at 78.30% in total water consumption in the island (table 2). However, underground water is mainly used in the island (87%) compared to surface water (13%) [9]. The general hydrological data of Crete are presented in table 1, the water consumption and the distribution of water use in the island in table 2 while the water demand and the water production from unconventional sources in table 3. Small differences in water demand in Crete are reported from different authors (tables 2 and 3).

Table 1. General annual 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: [1], own estimations

Table 2. Water use in Crete in 2016 (hm^3)

	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: [1]

Table 3. Water demand and water production from nonconventional water resources in six Mediterranean islands

	Corsica	Crete	Cyprus	Mallorca	Malta	Sicily
Population	325,000	601,000	794,000	846,000	425,000	6,226,000
Domestic water use (mil. M^3 per year)	39	65	66	126	23	323
Domestic water use per inhabitant (M^3 per inhabitant per year)	120.00	108.15	83.12	148.94	54.12	51.88
Water use in agriculture (mil. M^3 per year)	47	446	161	98	29	780
Water use in agriculture per inhabitant (M^3 per inhabitant per year)	144.62	742.10	202.77	115.84	68.24	125.28
Other water uses (mil. M^3 per year)	n/a	4	25	7	12	164
Total water use (mil. M^3 per year)	86	515	252	231	64	1,267
Total water use per inhabitant (M^3 per inhabitant per year)	264.62	856.91	317.38	273.05	150.59	203.50
Desalinated water production (mil. M^3 per year)	0	8.8	32	42.3	19	31
Reused treated sewage effluent (mil. M^3 per year)	n/a	0.4	n/a	29	2	n/a

Source: [14]

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

Climate change is becoming one of the most serious environmental challenges facing Crete, particularly because the island already has limited water resources. Rising temperatures, changing rainfall patterns and more frequent droughts are putting increasing pressure on reservoirs, groundwater and agricultural water supplies. One of the main impacts is the reduction and irregularity of rainfall. Crete has a Mediterranean climate, with most precipitation occurring during the winter months and long, dry summers. Climate change is expected to make rainfall less predictable and increase the frequency of prolonged dry periods. At the same time, higher temperatures, increase evaporation from soil, reservoirs, and other water sources are predicted. This means that even when rainfall occurs, less water may remain available for human consumption, agriculture and ecosystems. Agriculture is particularly vulnerable because it is one of the largest users of water in Crete. Olive cultivation, vineyards, vegetables and other crops depend heavily on irrigation, especially during the hot summer months. Water shortages can reduce crop yields and increase production costs as farmers are forced to use more irrigation or invest in more efficient technologies. In some areas, excessive groundwater extraction may also lead to declining groundwater levels and, near the coast, seawater intrusion into freshwater aquifers. Climate change can also affect tourism, which is an important part of Crete's economy. The island receives millions of visitors, especially during the summer, when water demand is already at its highest. Hotels, restaurants, swimming pools and other tourist facilities require substantial amounts of water. If droughts become more frequent, water competition among tourism, agriculture, local communities and natural ecosystems could become more intense. To address these challenges, Crete needs effective and sustainable water management. Measures such as modern irrigation systems, rainwater harvesting, wastewater treatment and reuse, reduction of water losses in distribution networks and protection of groundwater resources can help. Public awareness and responsible water consumption are also essential. Therefore, climate change is increasing pressure on Crete's water resources. Although the challenges are considerable, careful planning, improved technology and sustainable water management can reduce the risks and help ensure that sufficient water remains available for the island's people, economy, agriculture and ecosystems in the future.

5. THE SUPPLY OF WATER IN CRETE

The supply of water in the island is mainly based on subsurface water and surface water resources while small water quantities are produced from desalination plants. Additionally, small quantities of treated wastewater effluents are used in agriculture for irrigation. Several studies foresee decrease in water availability in the future, due to climate change, in Crete as well as increase in water demand in tourism and agriculture. Therefore, the rational management of water resources in Crete should increase the water supply and reduce the water demand. Increase in water supply can be achieved with various ways including:

a) Increase in the capacity of man-made water reservoirs,
b) Increase of the subsurface water resources,
c) Reduction of leakages in urban and agricultural water distribution networks,
d) Development of water desalination plants,
e) Improvement of the quality of subsurface water resources,
f) Reuse of treated sewage effluents, and
g) Increase in rainwater harvesting.

6. INCREASE OF THE CAPACITY OF MAN-MADE WATER RESERVOIRS

Increasing the capacity of man-made water dams represents an important strategy for improving water security and ensuring a more reliable supply of freshwater throughout the year. Man-made water dams and reservoirs can store large quantities of winter rainfall that would otherwise flow directly into the sea. The stored water can then be used during the dry summer months for irrigation, drinking-water supply and other purposes. Increasing the capacity of existing dams, as well as constructing new reservoirs where environmentally and economically appropriate, could therefore help reduce seasonal water shortages. Larger storage capacity would also allow Crete to make better use of periods of heavy rainfall, which are becoming increasingly important under changing climatic conditions. Agriculture is one of the main sectors that could benefit from increased water dam capacity. Crete has extensive agricultural production, including olives, grapes, vegetables, and citrus fruits, all of which require water, particularly during the summer. Reliable reservoir supplies could reduce dependence on groundwater and help prevent the over-exploitation of aquifers. Tourism is another important reason for strengthening water-storage infrastructure. During the summer, when rainfall is limited, the island experiences a substantial increase in water demand because of the large number of visitors. Adequate reservoir capacity can provide additional security for urban areas and tourist destinations, helping communities cope with periods of high consumption. However, increasing dam capacity must be carefully planned. Large infrastructure projects can affect rivers, ecosystems, agricultural land and local communities. Environmental impact assessments are therefore essential before construction or expansion. Sedimentation, evaporation, leakage and the effects of climate change must also be considered. Therefore, increasing the capacity of man-made water dams can play a major role in addressing Crete's growing water needs. By storing more winter rainfall and making it available during dry periods, dams can strengthen agricultural production, support tourism, reduce pressure on groundwater and improve overall water security. Nevertheless, dam expansion should be part of an integrated and sustainable water-management strategy that balances human needs with the protection of Crete's valuable natural environment. Table 4 indicates the existing large water dams in Crete.

Table 4. Large water dams in Crete

Name of water dam	Location-prefecture	Capacity
Potamon	Rethymno	22.50 mil. M^3
Aposelemi	Heraklion	36.20 mil. M^3
Valsamioti	Chania	is not completed
Ini-Machera	Heraklion	1.79 mil. M^3
Mpramianon	Lasithi	16.40 mil. M^3
Faneromeni	Heraklion	19.70 mil. M^3
Total capacity		96.59 mil. M^3
Total capacity per inhabitant		154.69 M^3 per inhabitant

Source: [30],

7. INCREASING THE SUBSURFACE WATER RESOURCES

Crete has a complex geological structure consisting mainly of limestone and other permeable rocks. These formations allow rainwater to infiltrate into the ground and recharge underground aquifers. During the winter months, rainfall can therefore replenish groundwater reserves, particularly in mountainous areas. Karstic aquifers, which are common in Crete, can store and transport considerable quantities of water through underground fractures, caves, and channels. This makes groundwater one of the most important sources of freshwater on the island. Several factors can contribute to increasing subsurface water resources. One important measure is the construction and maintenance of small dams, reservoirs, and artificial recharge systems. These structures can slow down surface runoff and allow more water to infiltrate into the ground. However, increasing groundwater resources is not simply a matter of extracting more water.

Excessive pumping, particularly for agriculture and tourism, can lower groundwater levels and cause seawater intrusion into coastal aquifers. Climate change may further increase the problem by producing longer droughts, higher temperatures, and changes in rainfall patterns. Consequently, sustainable groundwater management requires continuous monitoring of aquifer levels, careful regulation of pumping, and cooperation between local authorities, farmers, scientists, and water users. Therefore, subsurface water resources are essential for Crete's future. Increasing groundwater recharge, reducing unnecessary consumption, improving irrigation efficiency, and protecting aquifers from pollution and seawater intrusion can strengthen the island's water supply.

8. REDUCING THE LEAKAGES IN WATER DISTRIBUTION NETWORKS

A significant amount of water is lost through leakages in water distribution systems. These losses increase operating costs, waste energy and place additional pressure on limited water resources. Therefore, reducing leakage should be a major priority for water utilities. Leakages can occur because of aging and damaged pipes, poor-quality materials, excessive water pressure, faulty connections, and inadequate maintenance. To reduce these losses, water distribution networks should be regularly inspected and maintained. Modern technologies, such as acoustic sensors, pressure-monitoring devices, and smart meters, can help detect leaks quickly, even when they are not visible at the surface. Early detection allows repairs to be carried out before small leaks become major failures. Another important measure is effective pressure management. Excessive pressure can increase the frequency and severity of pipe failures. Installing pressure-control valves and monitoring pressure levels can therefore significantly reduce leakage. In addition, old and deteriorated pipelines should be replaced with durable materials, while proper installation standards should be followed for new networks. Public awareness also has an important role. Consumers should be encouraged to report visible leaks and use water responsibly. Water utilities can further improve efficiency by collecting accurate data on water consumption and comparing the amount of water supplied with the amount actually delivered to customers. Therefore, reducing leakages in water distribution systems requires a combination of regular maintenance, modern monitoring technology, pressure management, infrastructure renewal, and public cooperation. By implementing these measures, communities can conserve valuable water resources, reduce costs and create more reliable and sustainable water distribution systems for the future.

9. INCREASING THE WATER DESALINATION SYSTEMS IN THE ISLAND

In coastal and island regions, where freshwater supplies may be particularly restricted, desalination of seawater and brackish water can provide an important additional source of water. This technology has significant potential to increase water availability and improve the security of water supplies. Desalination is the process of removing dissolved salts and other impurities from seawater or brackish water to produce freshwater suitable for human consumption, agriculture, or industrial applications. The most widely used modern technology is reverse osmosis, in which water is forced through semi-permeable membranes under high pressure. The membranes allow water molecules to pass through while retaining most salts and other dissolved substances. Other desalination technologies use thermal processes, in which water is evaporated and subsequently condensed. The choice of technology depends on factors such as water quality, energy availability, plant capacity, and economic conditions. One of the main advantages of desalination is that it provides a relatively reliable source of water that is not directly dependent on rainfall. This is particularly valuable in arid and semi-arid regions and during prolonged periods of drought. Desalination plants can supply drinking water to cities, support tourism and industry, and reduce pressure on rivers, reservoirs, and groundwater. By diversifying water sources, desalination can also increase the resilience of communities to climate change and future variations in rainfall. Despite these benefits, desalination has several challenges. The process requires considerable amounts of energy, particularly reverse osmosis systems operating at large scale. If this energy comes from fossil fuels, desalination can contribute to greenhouse gas emissions. For this reason, combining desalination with renewable energy sources such as solar and wind power can help reduce its environmental impact. Improvements in membrane technology and energy-recovery systems can also reduce electricity consumption and operating costs. Another important environmental issue is the management of concentrated brine produced during desalination. Brine contains high concentrations of salts and may also contain treatment chemicals. If discharged improperly, it can affect marine ecosystems. Appropriate discharge design, dilution, monitoring, and advanced brine-management techniques are therefore necessary to minimize environmental impacts. Desalination is most effective when it forms part of an integrated water resources management strategy that combines several complementary sources and measures. Therefore, water desalination can play an important role in increasing water availability, particularly in coastal regions experiencing water scarcity. It offers a dependable source of freshwater and can reduce pressure on traditional water resources. However, its energy requirements, cost, and potential effects on marine ecosystems must be carefully addressed. Fortunately the abundance of solar and wind power in Crete favors their use in water desalination systems for fresh water production in the island. The use of renewable energy, improved technologies, responsible brine management, and integration with water conservation can make desalination a more sustainable solution. When properly planned and managed, desalination can contribute significantly to long-term water security and climate resilience.

10. IMPROVEMENT OF THE QUALITY OF SUBSURFACE WATER RESOURCES

Groundwater is increasingly threatened by pollution and overuse. Studies have shown that agricultural activities can increase nitrate concentrations in groundwater, while excessive pumping in coastal areas can contribute to seawater intrusion. Therefore, protecting groundwater requires action from farmers, local authorities, businesses and residents. One of the most important ways to reduce groundwater pollution is to improve agricultural practices. Farmers should use fertilizers and pesticides carefully and only in the quantities that crops actually need. Excess fertilizer can be carried through the soil by rain or irrigation and eventually reach underground water. Farmers can also use organic fertilizers, soil testing and precision irrigation to reduce the amount of chemicals entering the environment. Another important solution is better management of wastewater. Domestic and industrial wastewater must be properly collected and treated before it is released into the environment. Treated wastewater can also be reused for irrigation, reducing pressure on groundwater resources. For example, treated and disinfected wastewater is already being reused for irrigating olive trees in parts of Crete. However, wastewater intended for agricultural reuse needs appropriate treatment and regular monitoring. Olive oil production is also important to Crete's economy, but olive-mill wastewater can create environmental problems if it is poorly managed. Modern treatment and safe disposal systems should be used to prevent this waste from reaching soil and groundwater. Recent research in the Messara area has highlighted the need for improved management of olive-mill wastewater. Seawater intrusion is a serious problem in Crete because excessive pumping of groundwater can lower underground water levels and allow seawater to move into coastal aquifers. This is especially important in areas where agriculture and tourism create high water demand. To prevent this problem, groundwater pumping should be carefully controlled, especially during the dry summer months. Finally, wells should be regularly monitored for changes in water levels and salinity. With responsible water use, better irrigation and careful groundwater management, Crete can protect its freshwater resources from seawater intrusion. Crete needs stronger monitoring and better control of groundwater extraction. Authorities should regularly test wells, monitor nitrate and salinity levels, control illegal or excessive pumping, and encourage water-saving irrigation methods. Therefore, reducing groundwater pollution in Crete requires a combination of responsible farming, effective wastewater treatment, safe olive-mill waste management, monitor of salinity and careful control of groundwater use. Protecting underground water today will help ensure that Crete has a safe and reliable water supply for future generations. The sources of pollution of water resources in Crete are presented in table 5.

Table 5. Pollution of water resources in Crete

1	Waste water treatment plants
2	Large hotels
3	Industrial units
4	Livestock facilities
5	Aquaculture
6	Leaks from sewage networks
7	Leaks from dumping and landfill sites

Source: [1]

11. REUSE OF TREATED SEWAGE EFFLUENTS

Large quantities of wastewater are produced by households, industries, and urban areas every day. After appropriate treatment, this wastewater can become a valuable resource rather than simply being discharged into rivers or the sea. The reuse of treated water effluents in agriculture is therefore an important strategy for sustainable water management. Treated wastewater can be used for irrigation of crops, orchards, vineyards, fodder plants, and landscaping. Its use can reduce the demand for freshwater and provide farmers with a reliable alternative source of irrigation water, especially during periods of drought. In addition, treated effluents may contain nutrients such as nitrogen and phosphorus. When present at appropriate concentrations, these nutrients can contribute to plant growth and reduce the need for chemical fertilizers. Consequently, wastewater reuse can provide both environmental and economic benefits. However, the safe reuse of treated effluents requires appropriate treatment and careful management. Wastewater may contain pathogens, heavy metals, salts, organic pollutants, pharmaceutical residues, or other contaminants. If inadequately treated water is applied to agricultural land, these substances may affect soil quality, groundwater, crops, animals, and human health. For this reason, wastewater should undergo treatment processes that are suitable for its intended agricultural use. Depending on the quality required, treatment may include biological processes, filtration, disinfection, and advanced treatment technologies. Monitoring is also essential. The quality of treated effluents should be regularly tested for microbiological and chemical parameters. Another important consideration is the effect of long-term wastewater irrigation on soil and groundwater. High concentrations of salts or certain elements can accumulate in agricultural soils and negatively affect crop productivity. Proper irrigation management, soil monitoring, drainage, and, where necessary, periodic leaching can help control these problems. The reuse of treated water effluents can contribute significantly to the principles of a circular economy. Instead of viewing wastewater as a waste product, it can be considered a resource containing water and, in some cases, recoverable nutrients. This approach can reduce freshwater abstraction, decrease pressure on water supplies, and improve the resilience of agricultural communities in Crete to climate change and prolonged drought. Crete has four large sewage treatment plants and several smaller plants which currently dispose the treated effluents into the sea. These effluents can be additionally treated and used for irrigation of various crops. Therefore, the reuse of treated water effluents in agriculture offers considerable environmental, economic, and social benefits. It can provide an alternative source of irrigation water, conserve freshwater resources, and potentially supply nutrients to crops. Nevertheless, its success depends on adequate wastewater treatment, continuous monitoring, appropriate irrigation practices, and compliance with health and environmental standards.

12. INCREASE IN RAINWATER HARVESTING

Rainwater harvesting can provide an effective and sustainable method of increasing available water resources and reducing pressure on existing water supplies. Rainwater harvesting involves collecting and storing rainwater from rooftops, roads, agricultural areas, and other suitable surfaces. The collected water can be stored in tanks, cisterns, reservoirs, or underground systems and used later during periods of low rainfall. In Crete, where rainfall is highly seasonal, capturing water during the winter months can be particularly valuable. Instead of allowing large quantities of rainwater to run off into the sea, part of this water can be retained and used during the dry summer period. Agriculture is one of the most important sectors that could benefit from wider rainwater harvesting. Crete has extensive olive groves, vineyards, and other agricultural activities that require substantial amounts of water. Farmers could collect rainwater from farm buildings and other surfaces and use it for irrigation. When combined with efficient irrigation technologies, such as drip irrigation, rainwater harvesting could reduce dependence on groundwater and improve the efficiency of agricultural water use. Rainwater harvesting can also be implemented in urban and residential areas. Houses, hotels, schools, public buildings and businesses can install collection systems that direct rainwater from roofs into storage tanks. Depending on the quality of the collected water and the treatment system available, it can be used for garden irrigation, toilet flushing, cleaning and other non-potable purposes. This could be especially useful in tourist areas, where seasonal water consumption is high. However, rainwater harvesting also has limitations. Rainfall in Crete is irregular, and prolonged droughts may reduce the amount of water that can be collected. Storage facilities must also be properly designed and maintained to prevent contamination and losses through evaporation. Furthermore, rainwater harvesting should complement rather than replace other water-management measures. Therefore, rainwater harvesting offers Crete an important opportunity to make better use of its natural water resources. By collecting and storing winter rainfall, households, farmers, businesses, and public authorities can reduce water waste and strengthen water availability during the dry season. With appropriate investment, maintenance and regulation, rainwater harvesting can become an important component of a sustainable water-management strategy for Crete, helping the island respond to increasing water demand and future climate challenges.

13. DISCUSSION

The water resources and their supply in Crete have been studied. Our findings indicate that Crete has sufficient water resources under normal meteorological conditions to meet its needs while climate change is predicted to reduce precipitation and increase air temperature, evapotranspiration, floods and droughts in the island in the coming years. However, there is an uneven distribution of water resources between the eastern and western part of the island. The urgent need to adapt to climate change requires the improvement of water resources management, both in supply and demand side, in Crete. The estimated low water exploitation index, in the range 0.18-0.28, indicates the sufficiency of water resources in the island. However, the water exploitation index in Crete in another study has been reported higher but below one [14]. In Mallorca, Cyprus and Malta the water exploitation indexes have been estimated higher than one characterized by water shortages [14]. Agriculture is the main user of water resources in the island having a share in the total water consumption around 80%. Underground water is the main water source used in Crete to meet the island's requirements followed by surface water resources. Therefore, protection of subsurface aquifers from pollution and salination is important. The recharging of underground aquifers with rainwater is also essential. Use of nonconventional water resources is limited nowadays in Crete. Production of desalinated water in Crete in the future could reduce the pressures on surface and underground water resources. The abundant solar and wind energy in Crete could power the energy intensive desalination plants. It should be noted that the estimated total water demand in Crete is slightly different in two studies (tables 1, 2 and 3).

Our work implies that the management of water resources in Crete is not optimal and new policies regarding water supply and demand should be developed. Specific focus should be given to agricultural sector that consumes a large amount of water resources in Crete taking into account that climate change is going to reduce precipitation and increase evapotranspiration affecting the rainfed as well as the irrigated crops. The amount of water used in agriculture per capita in Crete is significantly higher compared to other Mediterranean islands. Current work indicates that the supply of water resources in Crete can be improved with several ways including the construction of new water dams, the reduction of pollution in subsurface reservoirs, the reduction of losses in water distribution networks, the use of nonconventional water resources et cetera. However, the improvement of the necessary infrastructure, increasing the supply of water resources in the island, is costly.

The accuracy of our results depends on the accuracy of the data in the sources used. The predictions regarding the future availability of water resources in Crete under the light of climate change depend on the accuracy of the climate models used.

Future work should be focused on the exploration of the demand side of water resources in Crete indicating the areas which can be improved achieving the rational management of water resources in the island.

14. CONCLUSIONS

The water resources in Crete, the impacts of climate change on them and the increase in their supply with various ways in the island have been investigated. The main findings of the current study can be summarized as follows:

a) Crete is nowadays sufficient in water resources under normal meteorological conditions,

b) The demand of water in agriculture per inhabitant is significantly higher in Crete compared to other Mediterranean islands,

c) The domestic water use per inhabitant in Crete does not have significant differences with other Mediterranean islands,

d) The total water demand per inhabitant in Crete is significantly higher in Crete compared to other Mediterranean islands,

e) The water production from nonconventional water resources, including desalinated water and treated sewage effluent, in Crete is lower compared to other Mediterranean islands,

f) Climate change is foreseen to reduce precipitation and increase air temperatures, evapotranspiration, floods and droughts in the island,

g) Increase in water supply in Crete can be achieved with various ways including:

1. Increase in the capacity of man-made water reservoirs
2. Increase of the subsurface water resources
3. Reduction of leakages in water distribution networks
4. Development of water desalination plants
5. Improvement of the quality of subsurface water resources reducing pollution and salination
6. Reuse of treated sewage effluents
7. Increase in rainwater harvesting

The key takeaway from the current study is the fact that the island should adapt to climate change improving the management of water resources including their supply and demand. Crete's agricultural sector should improve its efficiency in using water resources. The increase of the supply of water resources with various ways is necessary combined with decrease in water demand. Therefore, the island under the light of climate change should increase its resilience to water resources taking into account their predicted shortages in the near future.

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