Towards Sustainable Water Use on Mediterranean Islands: Addressing Conflicting Demands and Varying Hydrological, Social and Economic Conditions

Report on Water Resouces of Crete

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Contents

Abstract

The area of Crete covers 8336 km^2; the mean altitude is 460 m and the total population is about 600,000 people. The climate is considered to be sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers. The average annual precipitation is estimated to be 750 mm; the potential renewable water resources 2650 $x10^6$ m^3 and the real water used about 384 Mm^3/a. Despite considerable precipitation, it is estimated that from the total precipitation in plains per year about 70% is lost to evapotranspiration, 10% as runoff to sea and only 20% goes to recharging the groundwater. Crete has high per capita water availability, which is slightly lower than that of the country. The major water use in Crete is irrigation for agriculture (83.3% of the total consumption) while domestic use including tourism is 15.6% and industrial use 1%. The demand for irrigation water is high, while at the same time only 31% of the available agricultural land is irrigated. The main vegetable crops grown in Crete are fresh tomatoes, cucumbers, potatoes, eggplants, onions, watermelons, melons, cabbages and peppers, while among fruit crops olive covers more than 89% followed by citrus 3.4%, almonds and avocados.

Crete shows significant regional variations in water availability, especially in coastal, eastern and southern regions due to tourism and agriculture. The rainfall is not uniformly distributed throughout the year, and it is mainly concentrated in the winter months while the drought period is extended to more than six months (May to October) with pan evaporation values ranging from 140 to more than 310 mm in the peak month. Long series rainfall data all over Crete does not show any significant change in precipitation. The temperature of the area shows a great variation. Crete lies between the isotherms 18.5-19^{o}C with an annual latitude of 14-15^{o}C. The annual temperature has increased in the last two decades by 0.3^{o}C. The southern part of the island is warmer than the northern part and it is the warmest part of Greece.

The geology of Crete can be described in terms of four pre Neogene major nappes and one autochthonous isopic zone with a cumulative thickness of 6.5 km. It is estimated that approximately 20% of the groundwater resources of the island, totaling approximately 1.5 billion m^3, are associated with Neogene-Quaternary aquifers while the remaining 80% are associated with their deep Karstic counterparts. There are no perennial streams on Crete and the total mean annual runoff is estimated to be in the region of 0.83 billion m^3. The contribution of the surface water to the potential water resources of Crete is about 40%. The real contribution though is about 13%, which means that almost all the water quantity used in Crete comes from subterranean sources (springs, wells and boreholes).

The main issue in water resources management on the island is focused on the uneven geographical distribution of water resources in relation to the water demand hotspots on the island. The key actions adopted by the Regional Governor of Crete for the implementation of the recommended strategic response to the water resource problems are the following: Protection of groundwater resources against over-exploitation; restrictions in issuing of groundwater abstraction license in areas under pressure; pollution control of surface and ground water; monitoring of water quality; protection of coastal aquifers from saline intrusion; exploitation of Un(der)Exploited Aquifers such as karstic aquifers; the establishment of a water plan on a watershed basis for detailed

water management; the investigation and implementation of artificial recharge of aquifers; feasibility studies for further introduction of surface reservoirs; the improvement of the information services in rural scale; the application of modern effective irrigation methods; improved freshwater storage and transport; groundwater recharge promotion; reuse of water after treatment; utilization of untapped surface water sources; interbasin transfer; agricultural, industrial and domestic demand reduction.

It should be noted that water availability in average terms is not the limiting factor. Much more important are the significant regional and seasonal variations in water availability and demand. To overcome the water shortage, especially in the future, several measures should be taken for conservation of water resources and protection of the environment.

Introduction

The island of Crete may be characterised as having marginal water resources, which, although still adequate at present, will decline over the period to 2025. Irrigation and tourism create peak demands resulting in a seasonal pattern of water demand with an annual volume of waters abstracted exceeding 50% of the average annual runoff or 35% of the groundwater potential. It is therefore considered essential that the water problems the island faces can be effectively encountered only by strategic policies based on integrated water management systems. The climate is considered to be sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers. The average annual precipitation is estimated to be 750 mm; the potential renewable water resources 2650 x10^6 m^3 and the real water used about 384Mm^3/a.

Chapter I
Overview of the island

The area of Crete covers 8336 km^2, the mean altitude is 460 m and the total population is about 600,000 people. Crete consists of four prefectures, namely from west to east these are: Chania prefecture, Rethymnon prefecture, Iraklion prefecture and Lasithi prefecture. The climate is considered to be sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers (Chartzoulakis et al., 2001). The average annual precipitation is estimated to be 750 mm; the potential renewable water resources 2650 x10^6 m^3 and the real water used about 384Mm^3/a. The major water use in Crete is irrigation for agriculture (83.3% of the total consumption) while domestic use, including tourism, is 15.6% and industrial use 1%. Crete shows significant regional variations in water availability, especially in coastal, eastern and southern regions due to tourism and agriculture. It has high per capita water availability, which is slightly lower than that of the country. The demand for irrigation water is high, while at the same time only 31% of the available agricultural land is irrigated. The growing water requirements make the rational management of water resources extremely important for development to be sustainable and for the environment to be served (Chartzoulakis et al., 2001).

Figure 1.1: Geophysical map of Crete. Source: Regional Governor of Crete

1.1 Physical characteristics

1.1.1 Climate

The present climate of Crete is sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers. The annual rainfall ranges from 300 to 700 mm in the low areas and along the coast (Lerapetra 312 mm, Iraklio 512 mm and Chania 665 mm) and from 700 to 1000 mm in the plains of the mainland, while in the mountainous areas it reaches up to 2000 mm (Chartzoulakis et al., 2001). During winter that starts in November, the weather is instabilised due to frequent changes from low to high pressures. Precipitation decreased significantly during the last 20 years in the Messara valley. However, long series of rainfall data all over Crete does not show any significant change in precipitation (Markou-Iakovaki, 1979; Macheras & Koliva-Machera, 1990).

The rainfall is not uniformly distributed throughout the year, and it is mainly concentrated on the winter months while the drought period is extended to more than six months (May to October with pan evaporation values ranging from 140 to more than 310 mm in the peak month (Chartzoulakis et al., 2001).

As noticed, more than one-third of the total precipitation occurs along the northern coast of the island in the three main mountainous terrains (White Mountain, Idi and Dikti).

Spring is short because of the cold fronts often affecting the region in March, whereas May is rather warm, especially due to the appearance of the first south winds and the disappearance of the action of low pressures. North winds are dominant in the island. In summer, the north winds predominate, creating very dry conditions, which are also enhanced by the diminishing of low pressures in the Eastern Mediterranean and are only interrupted by some local rainfall of tropical origin (Chartzoulakis et al., 2001).

The temperature of the area shows a great variation. Crete lies between the isotherms 18.5-19^{o}C with an annual latitude of 14-15^{o}C. The southern part of the island is warmer than the northern part and it is the warmest area of Greece. During the cold period, temperature increases with decreasing latitude, whereas in the warm period and especially in the period from May to August, temperature increases from the coast to the mainland and particularly in the plains. In winter the lowest temperatures scarcely fall below 0^{o}C in the plains. During the summer temperatures greater than 40^{o}C may occur in the lowlands of Crete. The annual temperature has increased by 0.3^{o}C over the last two decades (Chartzoulakis et al., 2001).

1.1.2 Geology

The geology of Crete can be described in terms of four pre Neogene major nappes and one autochthonous isopic zone with a cumulative thickness of 6.5 km. The nappes were transported from the north along E-W trending thrusts and were emplaced between Late Eocene and early Miocene times. Shortly after nappe emplacement during the Middle Miocene an N-S extensional regime was established in the region due to the initiation of subduction in the Hellenic trench. The extensional tectonics has resulted in the development of numerous E-W grabens with offsets of up to 5 km. This period was associated with the deposition within the grabens of Miocene to Quaternary sediments, which consist mainly of red beds, sandstones, marls, limestones and evaporites (Source: Regional Governor of Crete).

It is the nappe emplacement and post emplacement tectonic and depositional history of the island, which formulated its present day hydrogeological structure. The Neogene-Quaternary sediment filled grabens host shallow aquifers whereas the carbonates of the pre Neogene nappes host the deep Karstic aquifers. Furthermore, the major fault systems play a central role in the ground water flow regime and spring discharge by imbedding or facilitating flow, depending on their relative structural positions. It is estimated that approximately 20% of the groundwater resources of the island (totaling approx. 1.5 billion m^3) are associated with the Neogene-Quaternary aquifers, whereas the remaining 80% represent the groundwater potential of deep Karstic counterparts (Source: Regional Governor of Crete).

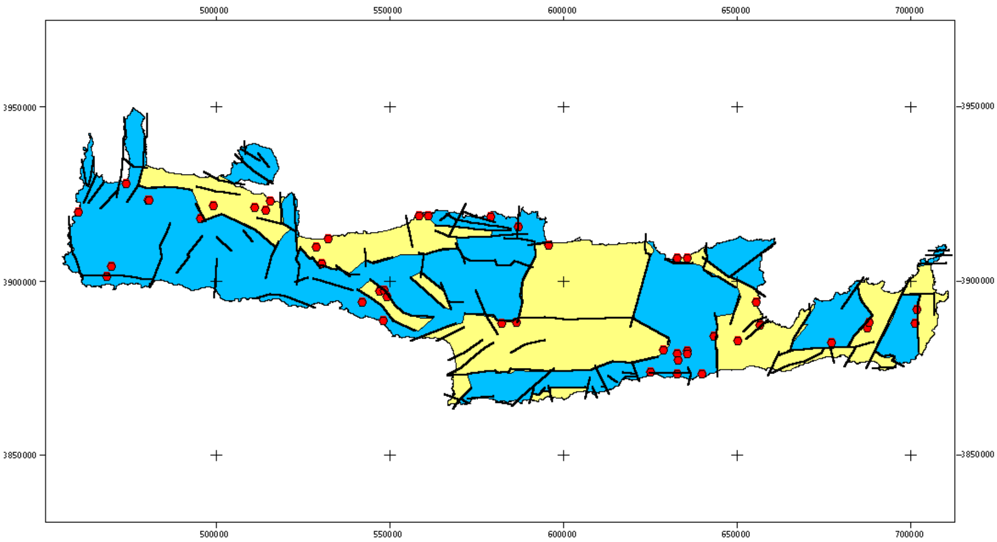


Figure 1.1.2.1: Spatial distribution of Neogene – Quaternary sediment
Filled grabens hosting shallow, mainly alluvial aquifers (yellow) and pre Neogene formations hosting deep Karstic aquifers (blue). Also depicted are the major fault systems (black lines) and the most important karstic springs (red dots) (Source: Regional Governor of Crete.)

Karstic aquifers occupy an area of 3,200 sq. Km (39% of the total area of the island) and are characterised by negligible runoff and high infiltration rates. It is estimated that 40 to 55% of the mean annual precipitation infiltrates into the ground, in these formations, creating a renewable annual groundwater potential of approximately 1.25 billion m^3, 80% of which is discharged from karstic springs the majority of which are unfortunately disposed along the coast, thus contaminated by intruding seawater (Source: Regional Governor of Crete).

The Neogene and Quaternary sediment filled grabens occupy an area of 3000 km^2 (36% of the total area of the island), include the major plains and are commonly characterised by a rich network of streams due to the presence of surface marly deposits and shallow aquifers hosted by quaternary alluvial and/or older sandstone-conglomeratic deposits with a renewable annual groundwater potential of approximately 0.25 billion m^3. These plains are the focus of intense agricultural activity with cultivation of olives, grapes, fruits and vegetables. The alluvial aquifers, which are among the most productive on the island, have undergone severe overexploitation (Source: Regional Governor of Crete).

The remaining 25% of the island comprises aquitards of impermeable geological formations such as phyllites and flysch, characterised by a rich network of streams. It should be noted that there are no perennial streams on Crete and the total mean annual runoff is estimated to be in the region of 0.83 billion m^3 (Source: Regional Governor of Crete). There are three main mountainous terrains in Crete (White mountain, Idi and Dikti). These three mountains extend over an area of 1900 km^2 and consist mainly of limestone masses intensely karstic.

1.1.3 Hydrology

1.1.3.1 Precipitation

The average annual precipitation in Crete is estimated to be 750 mm. Rainfall decreases from west to east and from north to south and is higher at high elevation areas than at the lowlands. As mentioned, the annual rainfall ranges from 300 to 700 mm in the low areas and along the coast (Ierapetra 312 mm, Iraklio 512 mm and Chania 665 mm), and from 700 to 1000 mm in the plains of the mainland, while in the mountainous areas it reaches up to 2000 mm (Chartzoulakis et al., 2001). More than one third of the total precipitation occurs along the northern coast of the island in the three mountainous terrains (White Mountains, Idi, Dikti). Figure 1.1.3.1 shows the monthly variation of rainfall at the Askifou rainfall station (White Mountains), which has an elevation of 740 m and a mean annual rainfall of 2085 mm.

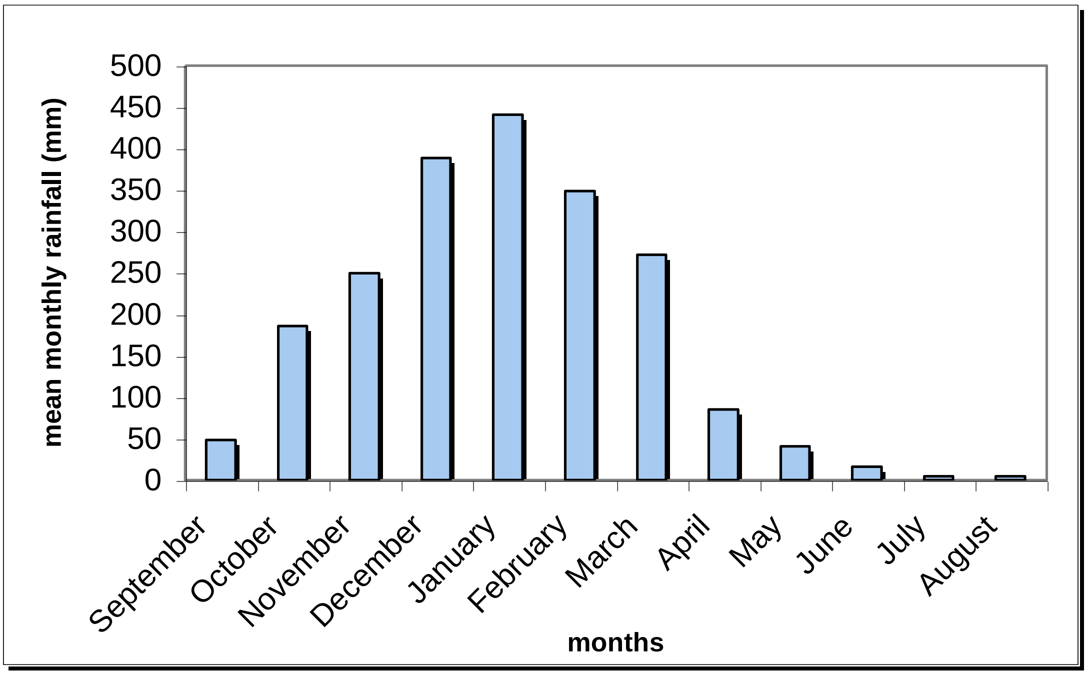


Figure 1.1.3.1: Monthly variation of rainfall at the Askifou rainfall station (White Mountains)

There are 56 stations in Crete measuring rainfall. Of those stations 28 are situated in Iraklion prefecture, 10 in Rethymnon prefecture, 12 in Lasithi prefecture and 6 in Chania prefecture. The spatial distribution of the rainfall stations in Iraklion prefecture is shown in figure 5. There is a fairly even spatial distribution of stations in the prefecture. Figure 1.1.3.3 shows the distribution of rainfall stations and their height for Iraklion prefecture. Most stations fall into heights between 200 and 500 m while there are only three stations between 500 and 800 m and five stations in heights lower than 200 m. There is no direct relationship between rainfall and height in the prefecture (figure 1.1.3.4) due to the complex vertical and horizontal distribution of the area. The highest precipitation is observed at Borizia station with an elevation of 520 m and a mean annual rainfall of around 1100 mm, while the lowest precipitation is observed at Kapsaloi station with an elevation of 10 m only and a mean annual rainfall of 410 mm. The station with the highest elevation in the prefecture (Kapetaniana station at an elevation of 800 m) has a mean annual precipitation of 680 mm. Borizia station lies in the mainland in West

Messara Valley and shows higher precipitation than Kapetaniana station, which has a higher elevation but lies closer to the south coast in the same valley. Figure 1.1.3.5 shows the mean annual rainfall distribution for the different stations in Iraklion.

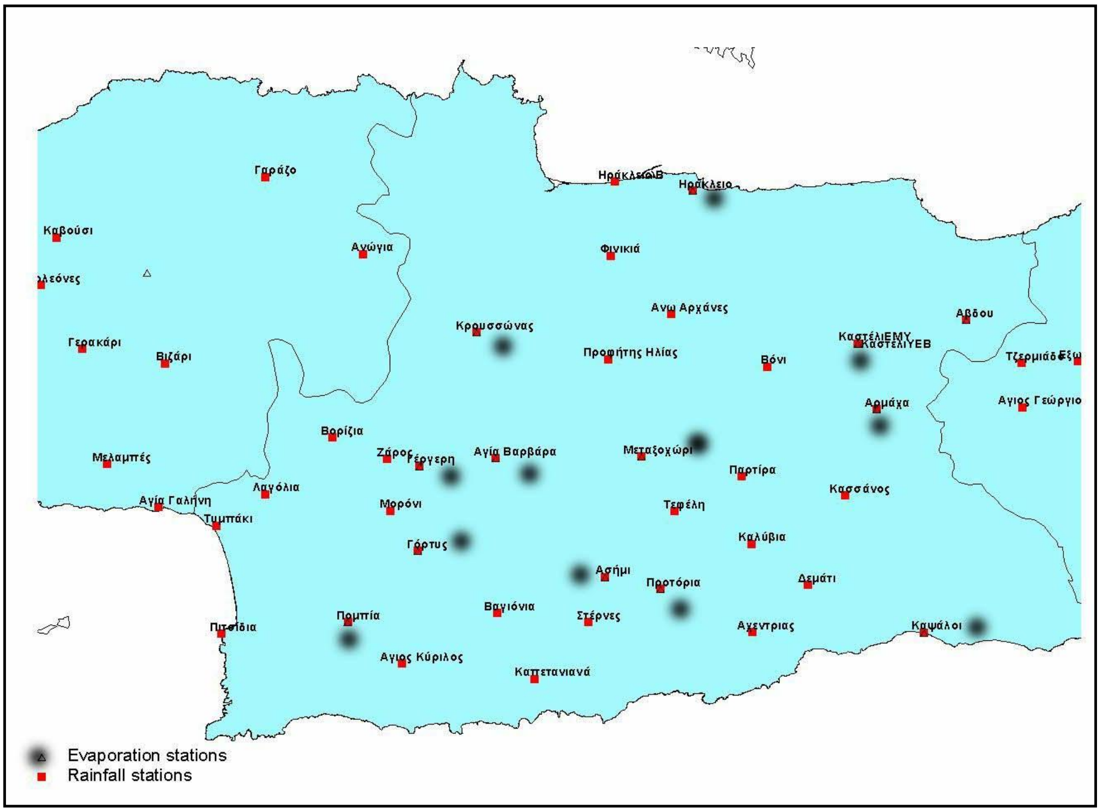


Figure 1.1.3.2: Rainfall and evaporation stations in the prefecture of Iraklion. (Source: RGC)

During the period 1909-1987, the annual average rainfall in the prefecture of Iraklion was 489 mm while the seasonal precipitation for winter was 252 mm, for spring 95 mm, for summer 5.3 mm and for autumn 138.2 mm (Macheras and Koliva-Machera, 1990). During this time there were observed two moist periods, the first lasting for 16 years (1917-1932) and the second for 8 years (1961-1969), and one dry period lasting 23 years (1938-1960). During the first moist period there was an increase in precipitation of 13% while for the second period the increase was around 28%. It was concluded that the dry season in Iraklion lasts for five months (November to March) and the moist for seven. The dry period was accompanied by a 13% decrease in rainfall (Macheras and Koliva-Machera, 1990).

The profile for mean annual and monthly rainfall for the years 1969 to 1999 of the existing stations in the prefecture of Iraklion is shown in figures 1.1.3.6 and 1.1.3.7. The wettest year for Iraklion prefecture was 1977-1978, while the driest year appears to have been the hydrological year 1989-1990.

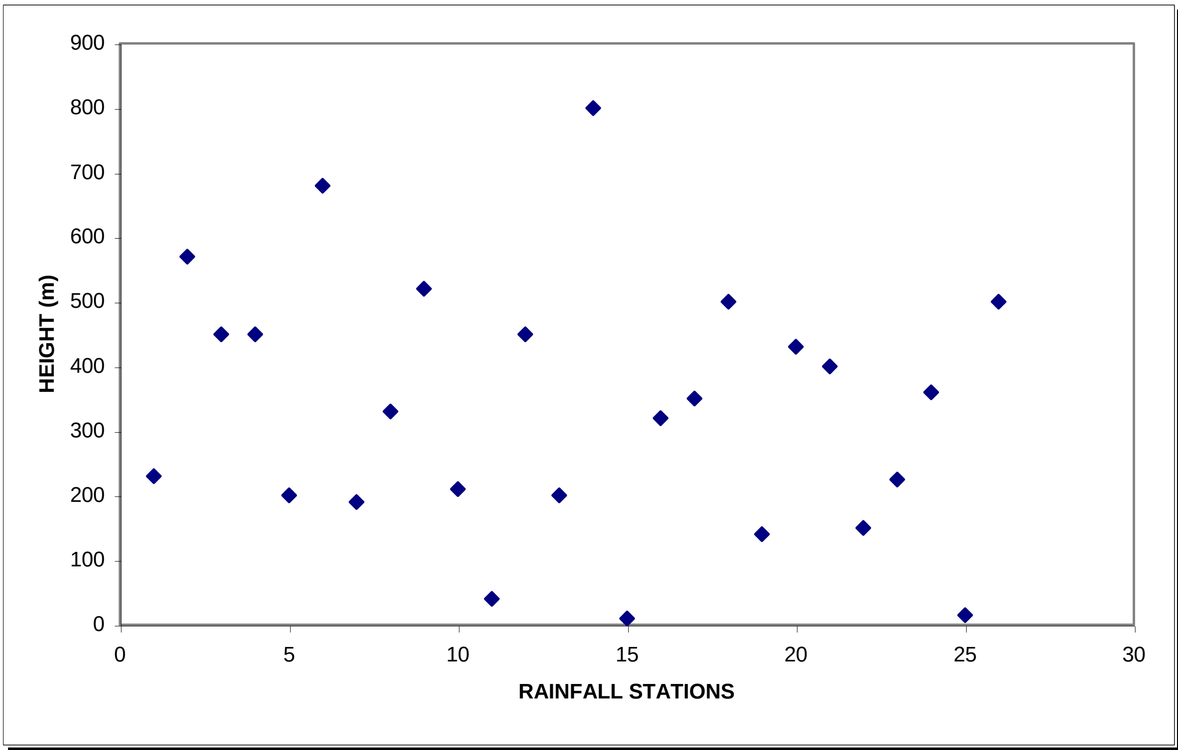


Figure 1.1.3.3: Rainfall stations height distribution in the prefecture of Iraklion

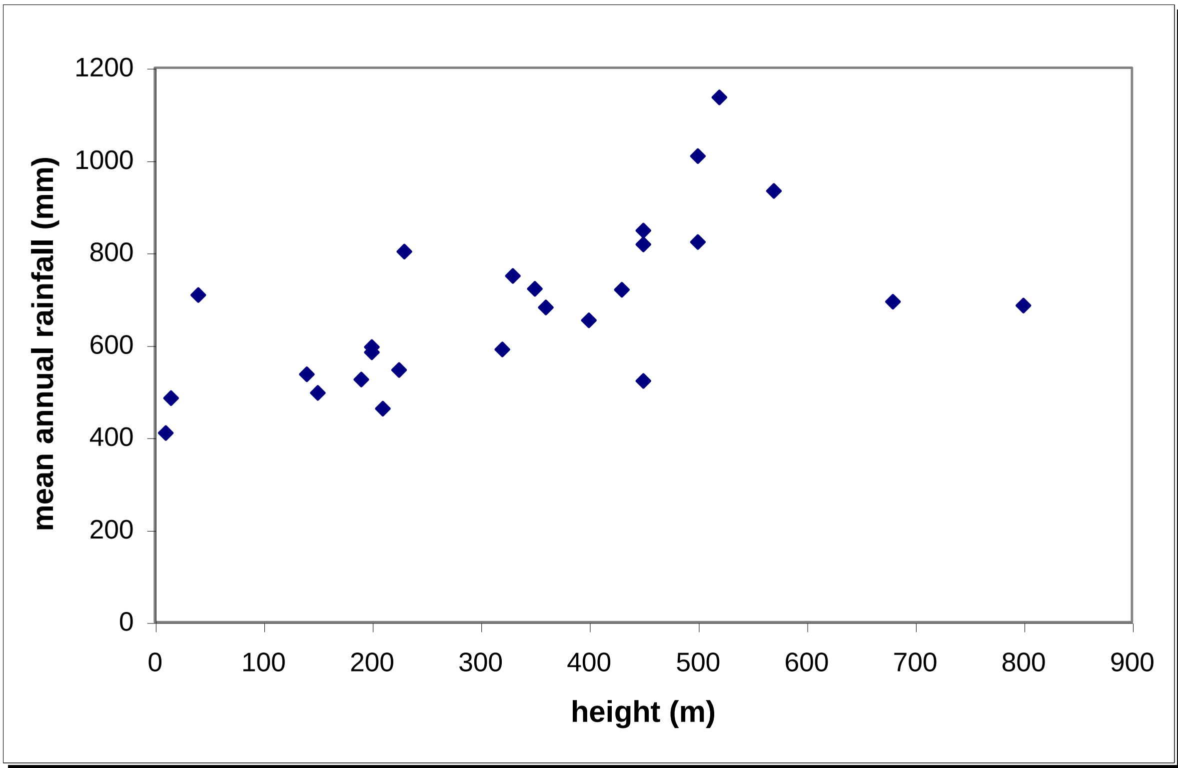


Figure 1.1.3.4: Rainfall – height distribution in the prefecture of Iraklion

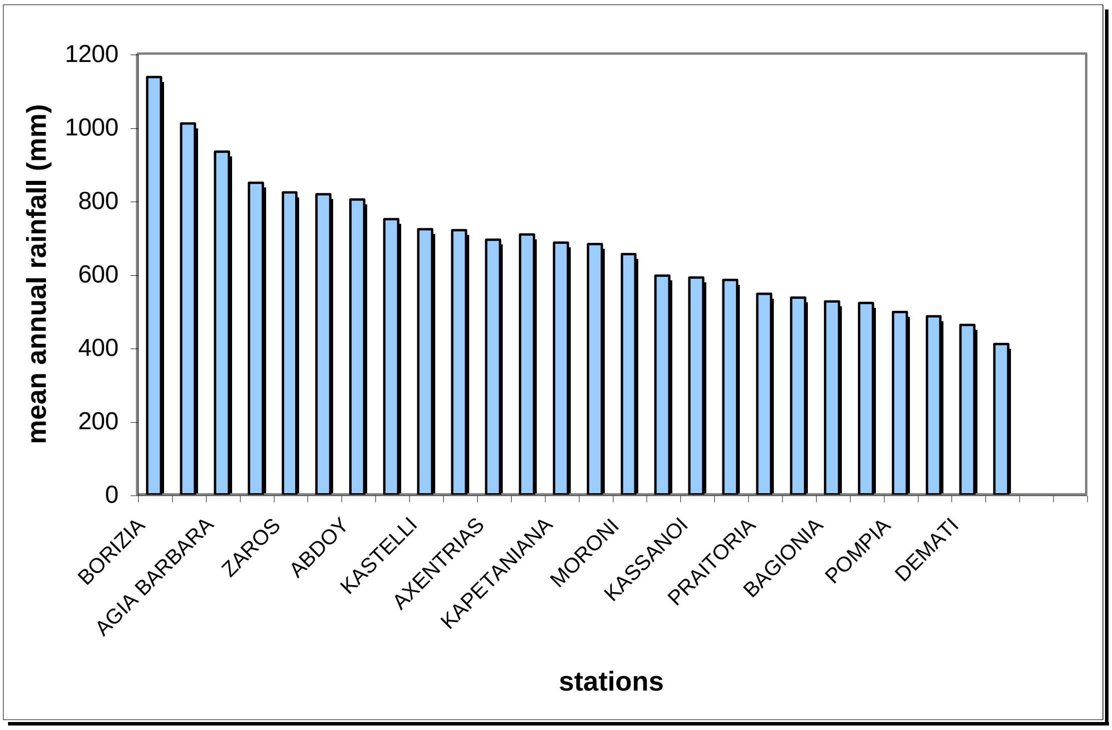


Figure 1.1.3.5: Rainfall distribution in Iraklion

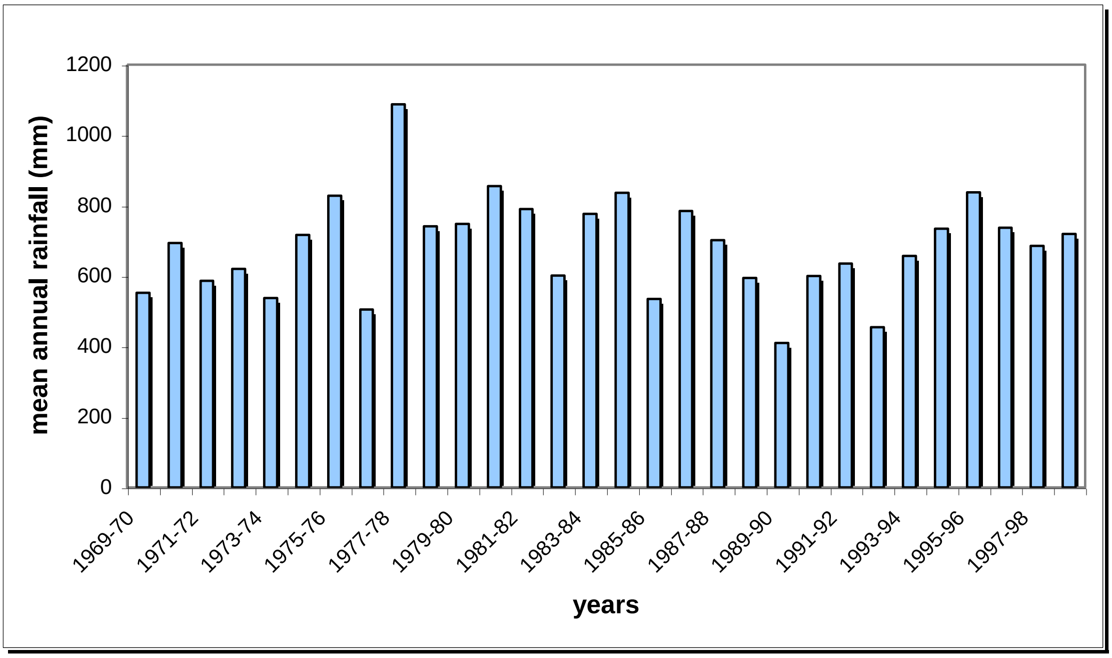


Figure 1.1.3.6: Mean annual rainfall for the prefecture of Iraklion

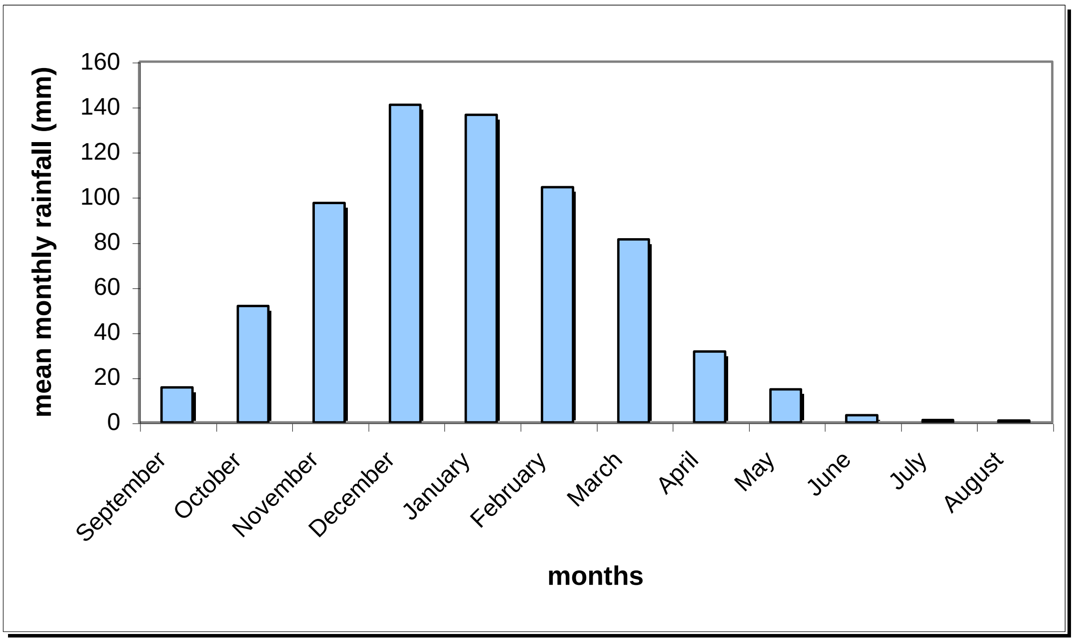


Figure 1.1.3.7: Mean monthly rainfall pattern for the prefecture of Iraklion

The spatial distribution of rainfall and evaporation stations in the prefecture of Lasithi is shown in figure 1.1.3.8. No direct relationship is again observed between rainfall and elevation for the prefecture (figure 1.1.3.9).

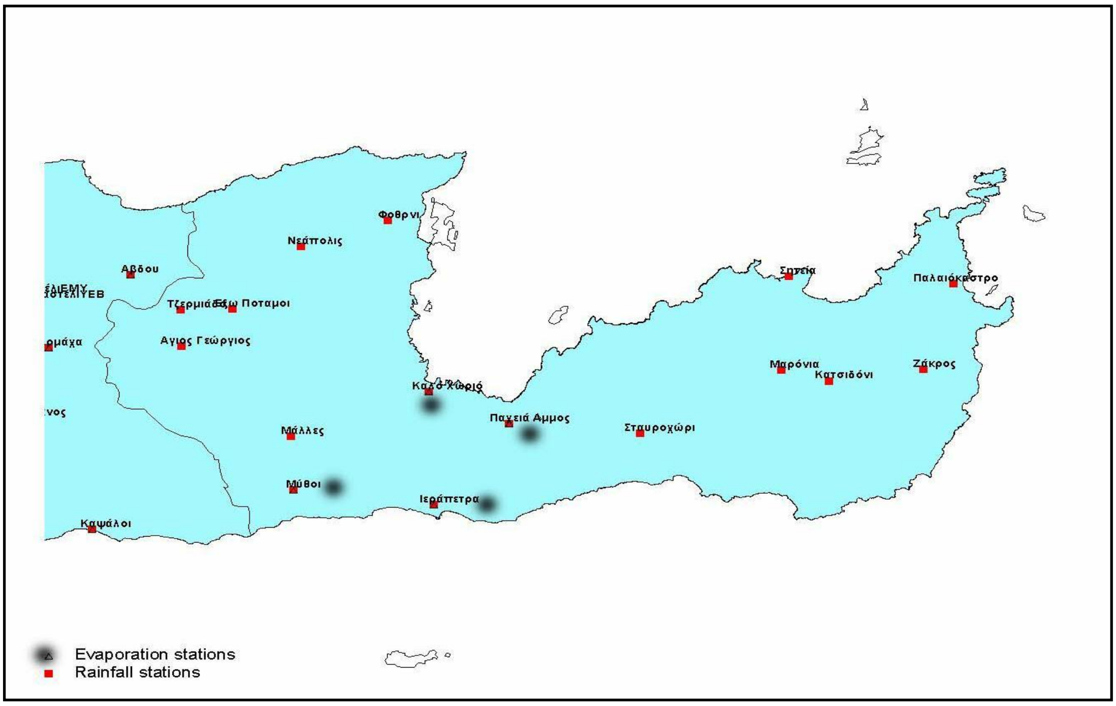


Figure 1.1.3.8: Rainfall and evaporation stations in the prefecture of Lasithi

The highest mean annual precipitation is observed at Exo Potamoi station, which has an elevation of 800 m and mean annual rainfall of 1360 mm, while the lowest mean annual precipitation is observed at Siteia station, which has as elevation of 114 m and mean annual rainfall of 490 mm.

The station with the highest elevation (Agios Georgios at 850 m) shows a mean annual precipitation of 1056 mm. Stations with lower elevations than Siteia station (Kalo Xwrio, Palaikastro, Paxeia Ammos) show higher mean annual precipitation.

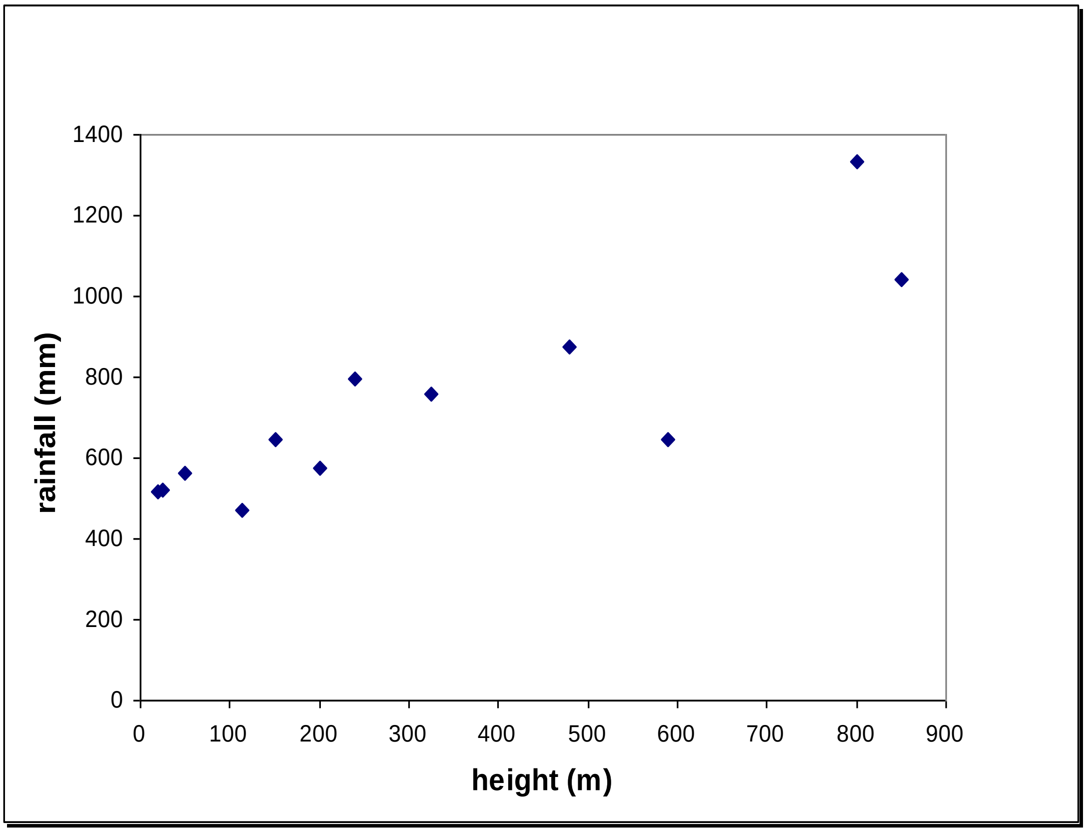


Figure 1.1.3.9: Rainfall distribution with height in Lasithi prefecture

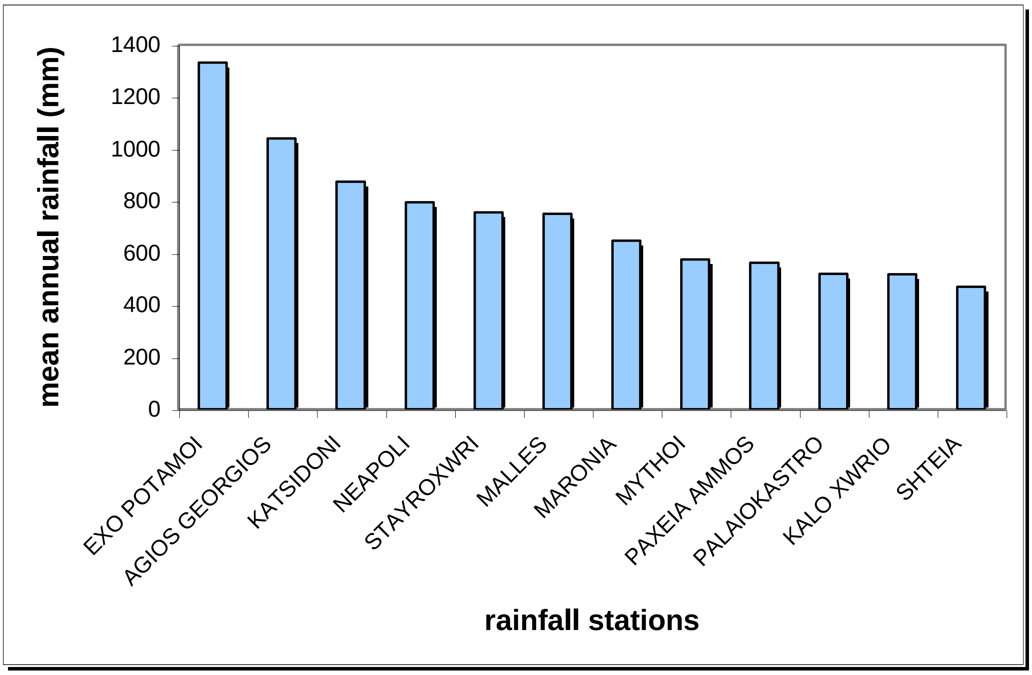


Figure 1.1.3.10: Rainfall distribution in Lasithi prefecture

The driest year for Lasithi was the hydrological year 1989-1990 and the wettest the hydrological year 1986-1987.

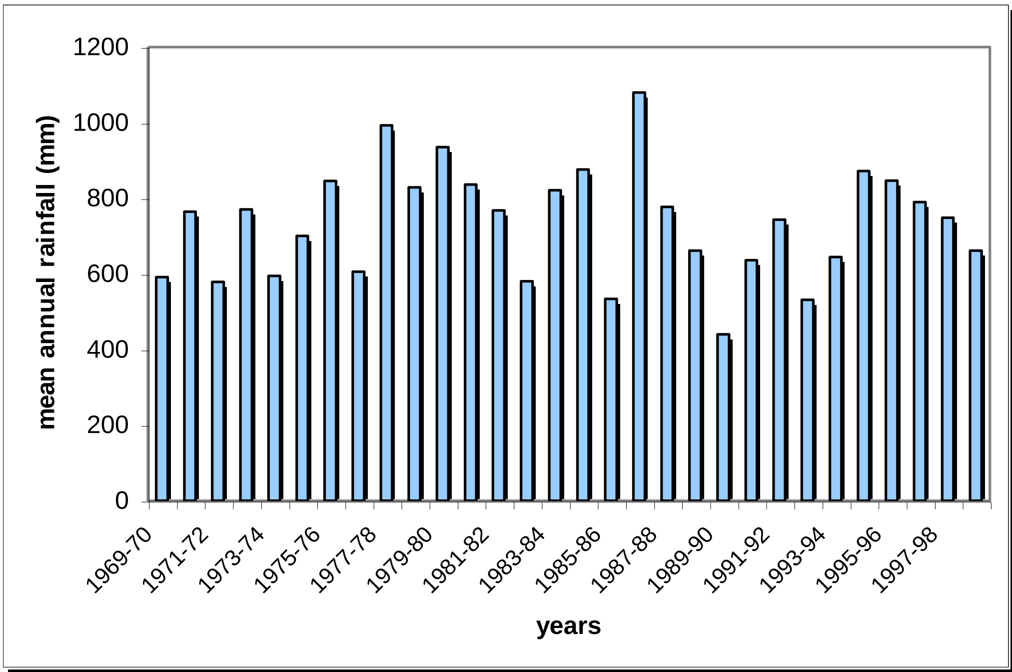


Figure 1.1.3.11: Mean annual rainfall in Lasithi prefecture

In Chania prefecture the existing rainfall stations, are set up at elevations between 20 and 740 m as shown in figure 1.1.3.12. According to these particular stations, rainfall increases with height.

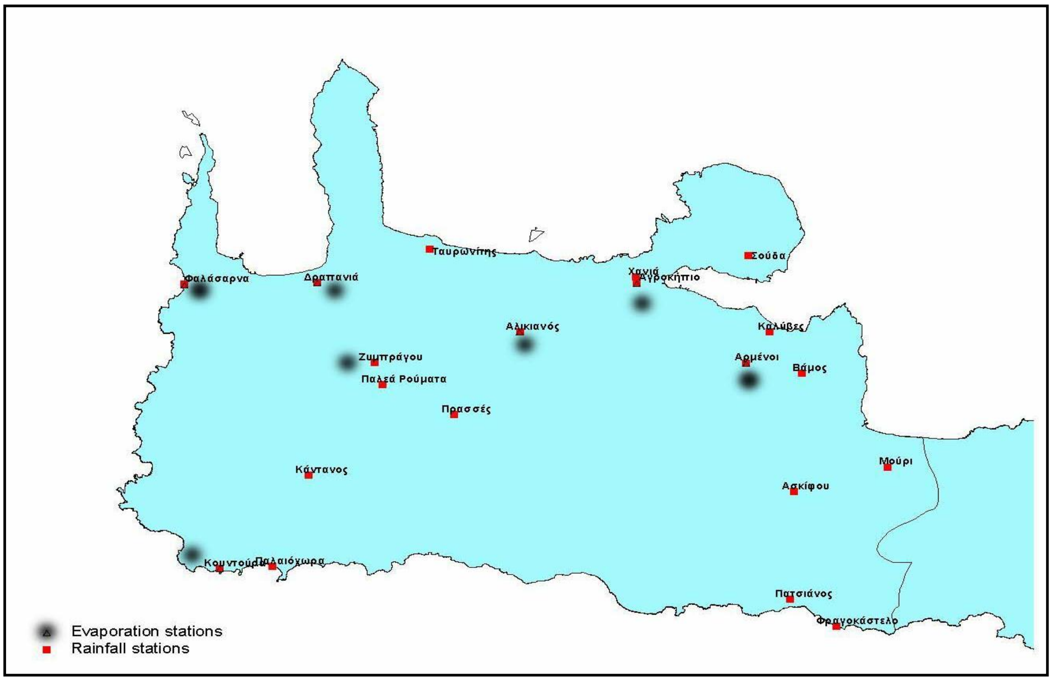


Figure 1.1.3.12: Rainfall and evaporation stations in Chania prefecture

The highest precipitation is observed at Askifou station while the lowest precipitation is observed at the island of Gaydos at the very south of the prefecture, which has an elevation of 10 m and mean annual precipitation of 330 mm.

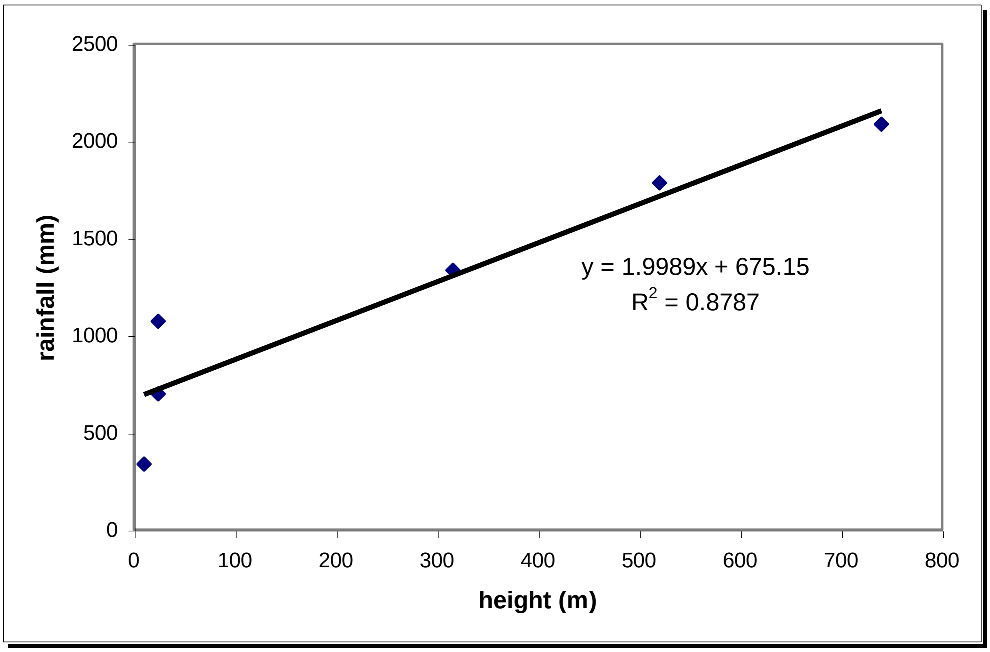


Figure 1.1.3.13: Rainfall distribution with height in Chania

The rainfall distribution in the prefecture of Chania is depicted in figure 1.1.3.14.

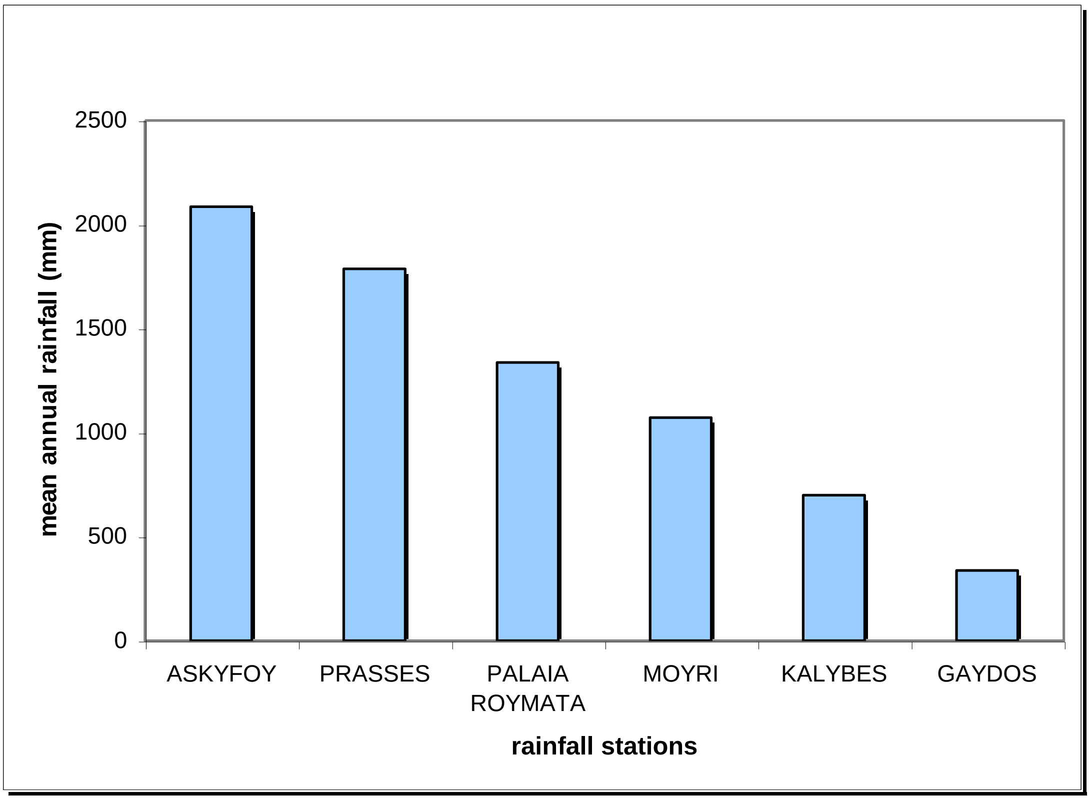


Figure 1.1.3.14: Rainfall distribution in Chania

For Rethymnon prefecture the spatial distribution and the height distribution of the rainfall stations are shown in figures 1.1.3.15 and 1.1.3.16 respectively.

The highest precipitation is observed at Garazo station and the lowest at Agia Galini station. Garazo station has an elevation of 260 m and shows mean annual rainfall of 1370 mm. Agia Galini station lies in the south of the prefecture near Tympaki and has an elevation of 20 m and mean annual precipitation of 570 mm. The station with the highest elevation in the prefecture is Anogeia station, which is located 740 m ASL. Anogeia station shows a mean annual precipitation of 1030 mm. The rainfall distribution in the prefecture is depicted in figure 1.1.3.17.

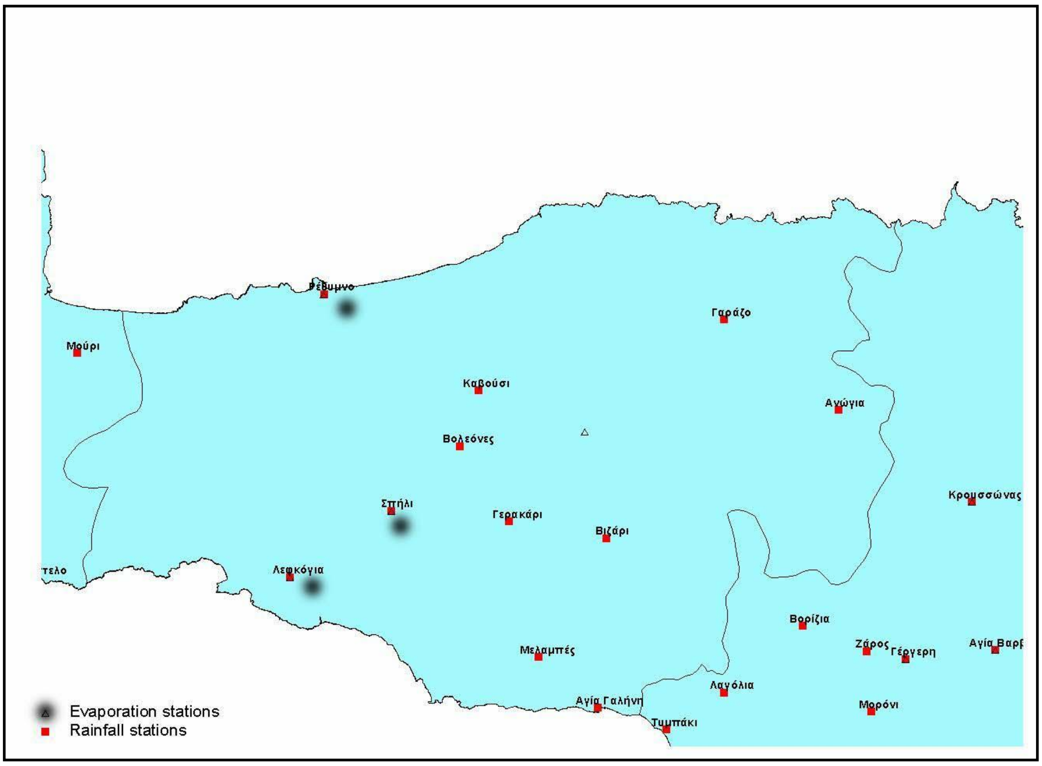


Figure 1.1.3.15: Rainfall and evaporation stations in Rethymnon prefecture. (Source: RGC)

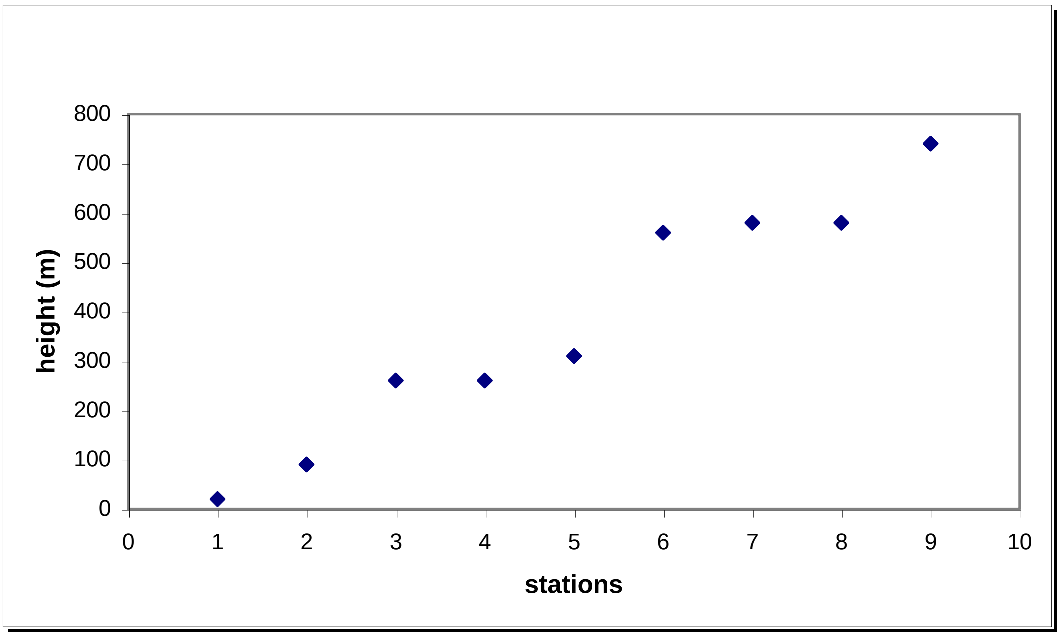


Figure 1.1.3.16: Rainfall stations height distribution in Rethymnon

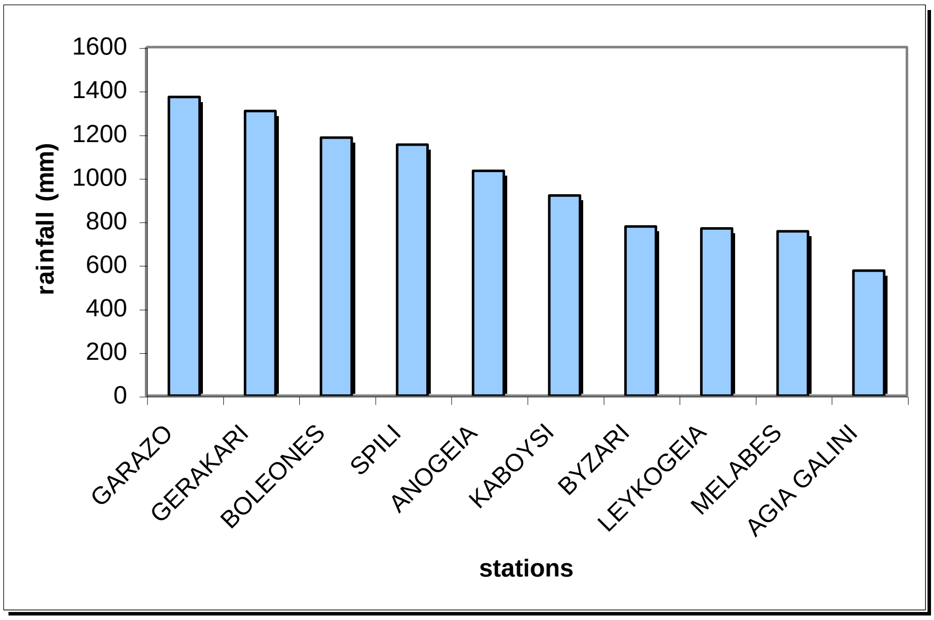


Figure 1.1.3.17: Rainfall distribution in Rethymnon

The rainfall data of the past thirty years of the stations in Rethymnon show that the driest year for the prefecture was the hydrological year 1977-1978 while the wettest year was 1989-1990. The same situation is observed for Iraklion prefecture. Figures 1.1.3.18 and 1.1.3.19 show the mean annual and mean monthly rainfall in Rethymnon prefecture.

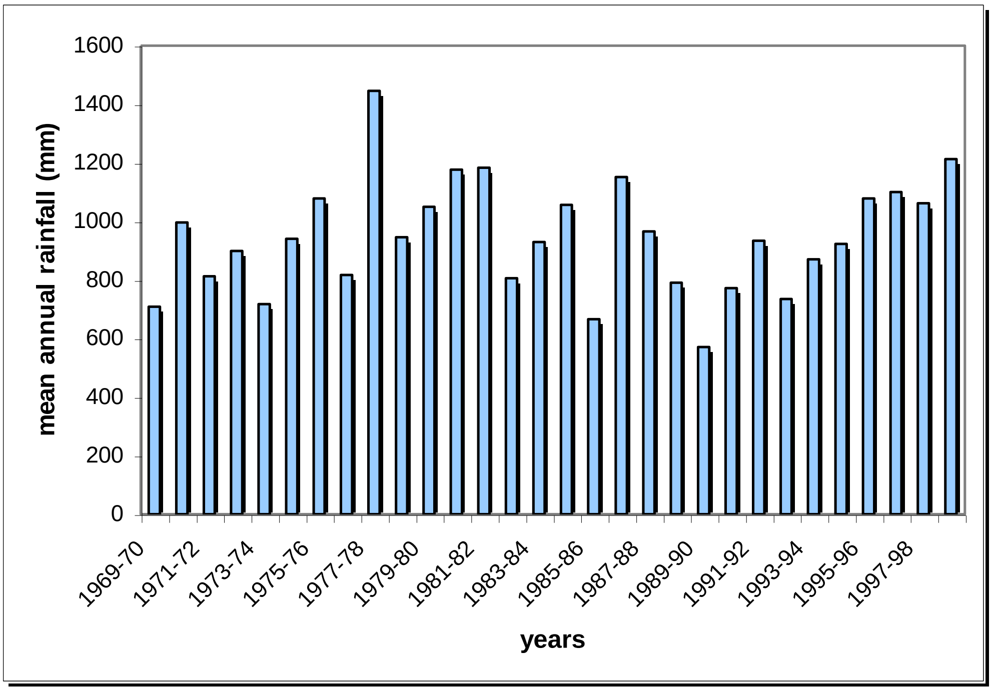


Figure 1.1.3.18: Mean annual precipitation in Rethymnon

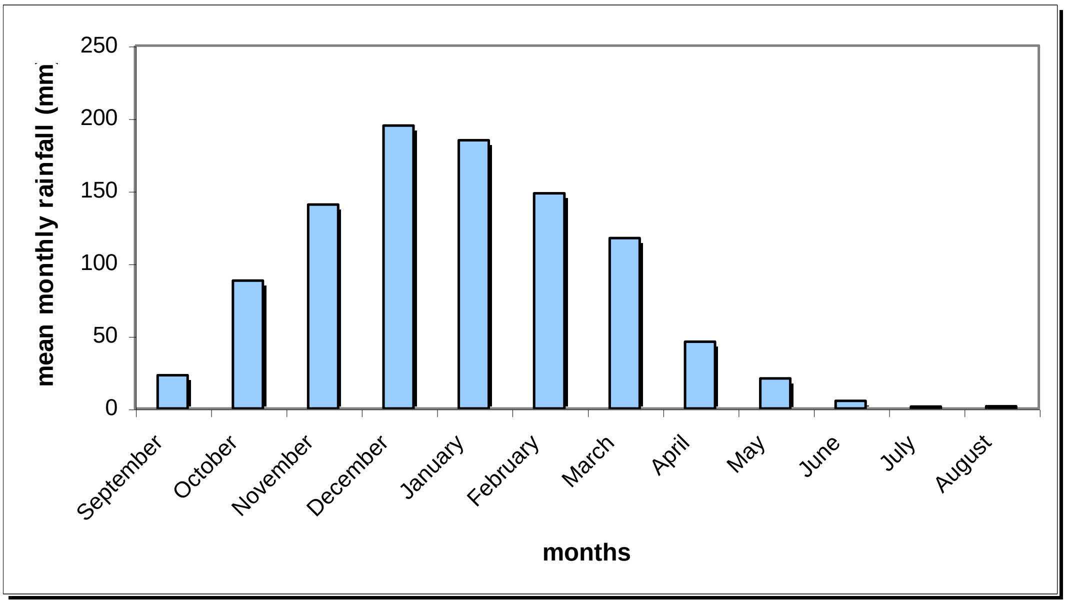


Figure 1.1.3.19: Mean monthly rainfall in Rethymnon

Data from the 56 existing rainfall stations in Crete shows that the highest precipitation is observed at Askifou station in Chania prefecture and the lowest at the island of Gaydos, south of Chania prefecture. This pattern is depicted in figure 1.1.3.20.

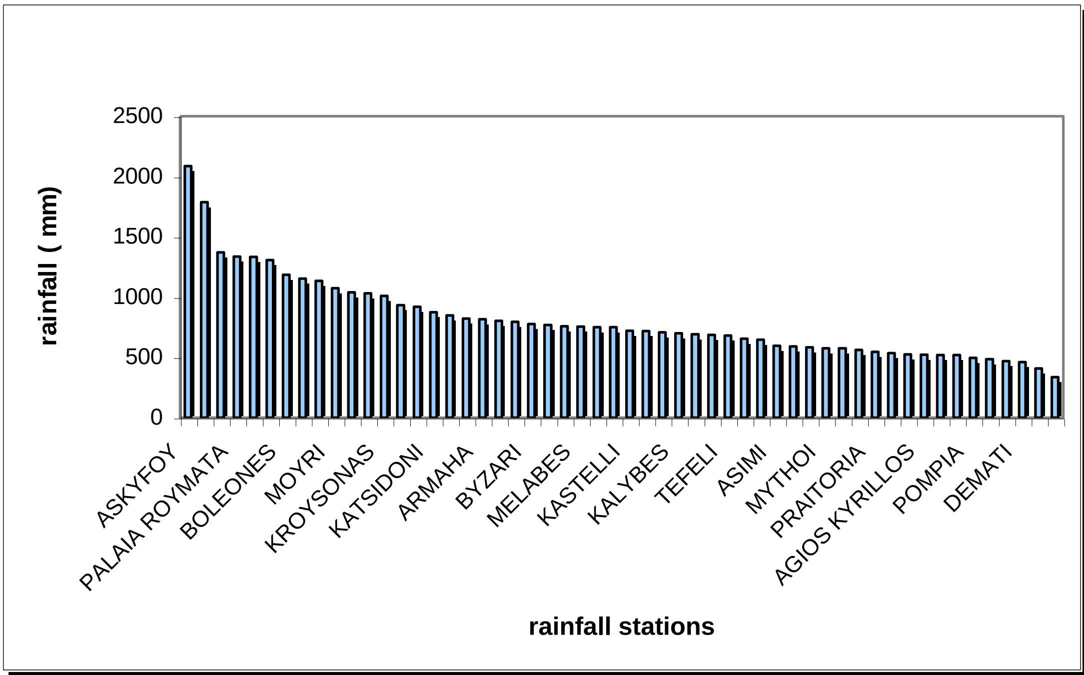


Figure 1.1.3.20: Rainfall distribution for Crete

Rainfall in Crete is not uniformly distributed throughout the year. It is mainly concentrated in the period from November to April while the drought period is extended to more than six months (May to October). The mean annual precipitation in eastern Crete is 816 mm while in the western Crete is 927 mm. About 60% of the annual precipitation occurs in months December to February. On average the number of rainy days ranges from 15 in December and January to 0.3 in July and August. Snowfall is restricted to the main mountain ranges (Source: Regional Governor of Crete). Long series rainfall data all over Crete does not show any significant change in precipitation (Markou-Iakovaki, 1979; Macheras & Koliva-Machera, 1990).

1.1.3.2 Temperature

Temperature in the island of Crete shows great variation. Air temperature increases from west (17^{o}C at Alikianos station) to east (18.7^{o}C at Siteia station). The southern part of the island is warmer than the northern and the warmest of Greece (Chartzoulakis et al., 2001). The mean annual temperature at Siteia station (north part of Lasithi prefecture) is 18.7^{o}C while the mean annual temperature at Ierapetra station (south part of Lasithi prefecture) is 19.6^{o}C. The mean monthly temperature range at Siteia station is depicted at figure 1.1.3.21.

During the cold period, temperature increases with decreasing latitude while in the warm period and especially in the period from May to August, temperature increases from the coast to the mainland and particularly in the plains (Chartzoulakis et al., 2001).

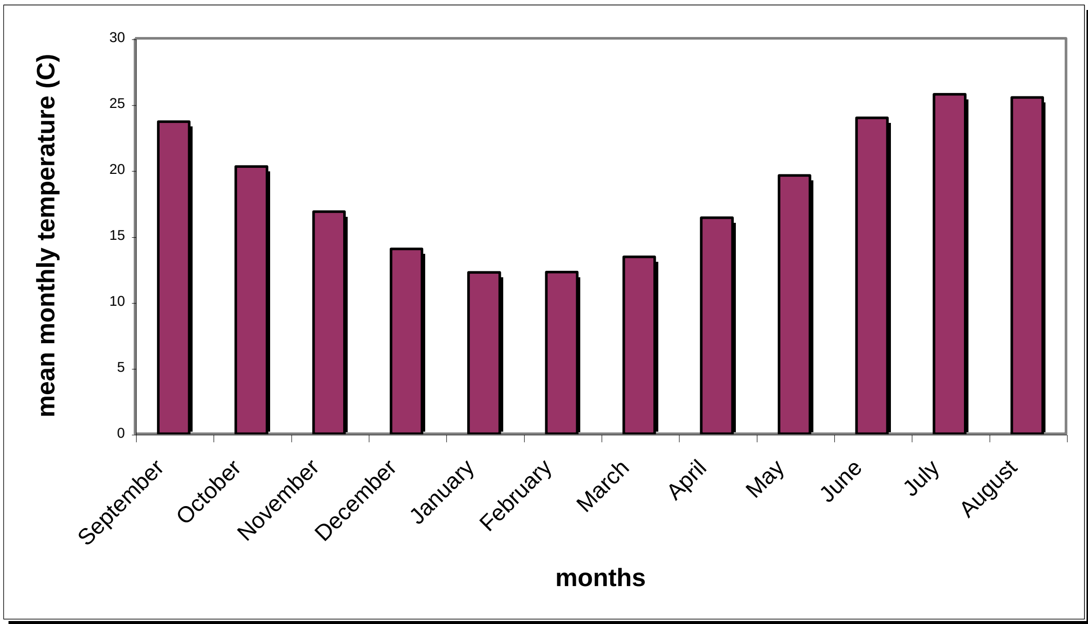


Figure 1.1.3.21: Mean monthly temperature at Siteia station

At Anogeia station, in Rethymnon prefecture, which is located at elevation of 740 m ASL, the mean annual temperature is 15.2 ^{o}C. The mean annual temperature at Kapsaloi station, in the mainland of Iraklion prefecture, which is located at an elevation of 10 m ASL, is 19.6 ^{o}C (figure 1.1.3.22).

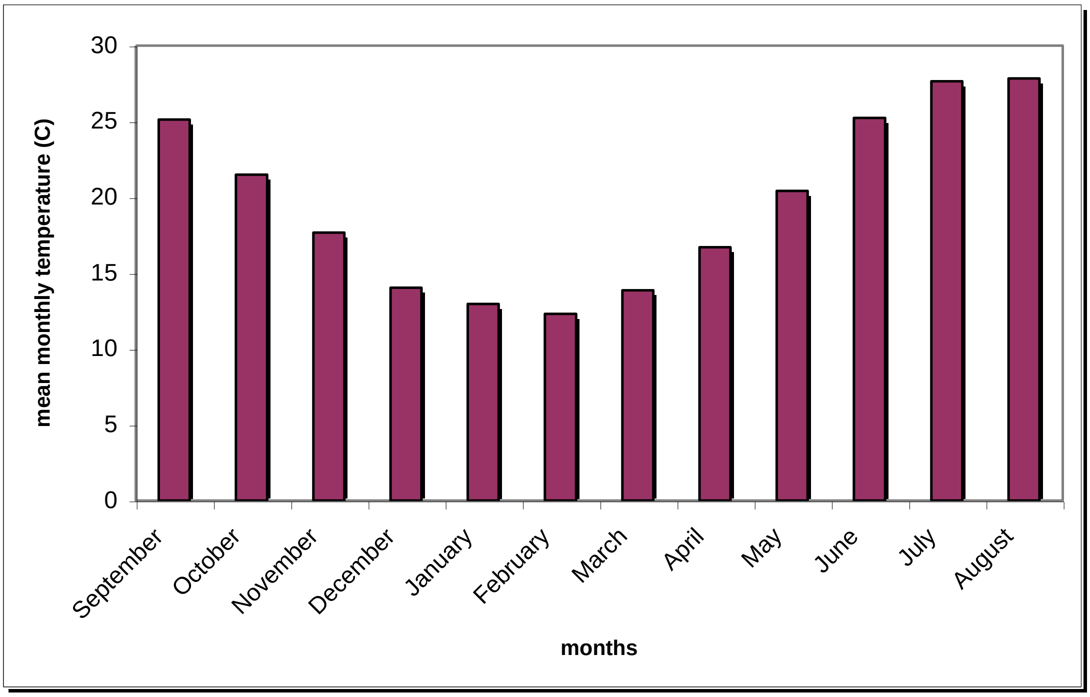


Figure 1.1.3.22: Mean monthly temperature at Kapsaloi station

During the summer, temperatures exceeding 40°C may occur in the lowlands of Crete. In winter, the lowest temperatures scarcely fall below 0°C in the plains. The mean annual temperature range is from 17°C to 20°C. The largest temperature variation within a year is observed at Paxeia Ammos station, where temperature ranges from 10.5°C in February to 26.3°C in August. Generally, the highest temperatures of Crete are observed between July and August and the lowest in January and February. Figure 1.1.3.23 shows mean annual temperature for different stations in Crete.

1.1.3.3 Evaporation

The potential evapotranspiration in Crete varies from 1370 mm/a to 1570 mm/a. The mean annual actual evapotranspiration has been estimated to represent 75% to 85% of the mean annual precipitation in low elevation areas (less than 300 m ASL) and 50% to 70% in high elevation areas (Source: Regional Governor of Crete).

There are 24 stations in Crete measuring pan evaporation. Of those stations 11 are located in Iraklion, 3 in Rethymnon, 4 in Lasithi and 6 in Chania prefecture. The spatial distribution of the stations in each prefecture is shown in figures 1.1.3.2, 1.1.3.8, 1.1.3.13 and 1.1.3.16. The highest mean annual pan evaporation is observed at Kapsaloi station in the mainland of Iraklion prefecture. Kapsaloi station is located at 10 m ASL and shows a mean annual pan evaporation of 2039 mm/a. The mean annual pan evaporation for different stations in Crete is shown in figure 1.1.3.24.

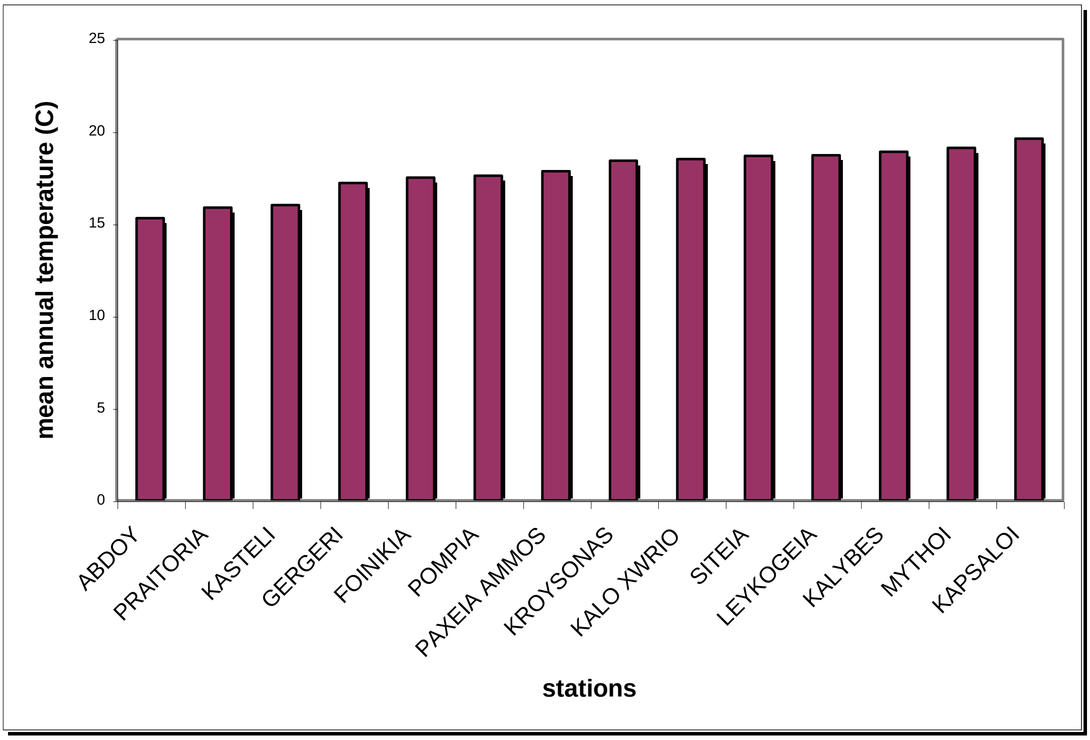


Figure 1.1.3.23: Mean annual temperature at different stations in Crete

According to figures 1.1.3.23 and 1.1.3.24 it seems that evaporation and temperature follow the same pattern. The mean monthly pan evaporation for Kapsaloi station is shown in figure 1.1.3.25. The highest evaporation values are observed in July while the lowest values are observed in December and January. The mean annual evaporation range is from 40 to 265 mm. The highest variation of pan evaporation values within a year is observed at Lefkogeia station in Rethymnon prefecture. Lefkogeia station is located at 90 m ASL and shows a value of mean evaporation of 60 mm in January and of 341 mm in July.

1.1.3.4 Wind direction

The prevailing wind direction is north and northwesterly. High wind speed can occur any time during the year, but is mostly observed in February and March in western Crete and July in eastern Crete (Source: Regional Governor of Crete).

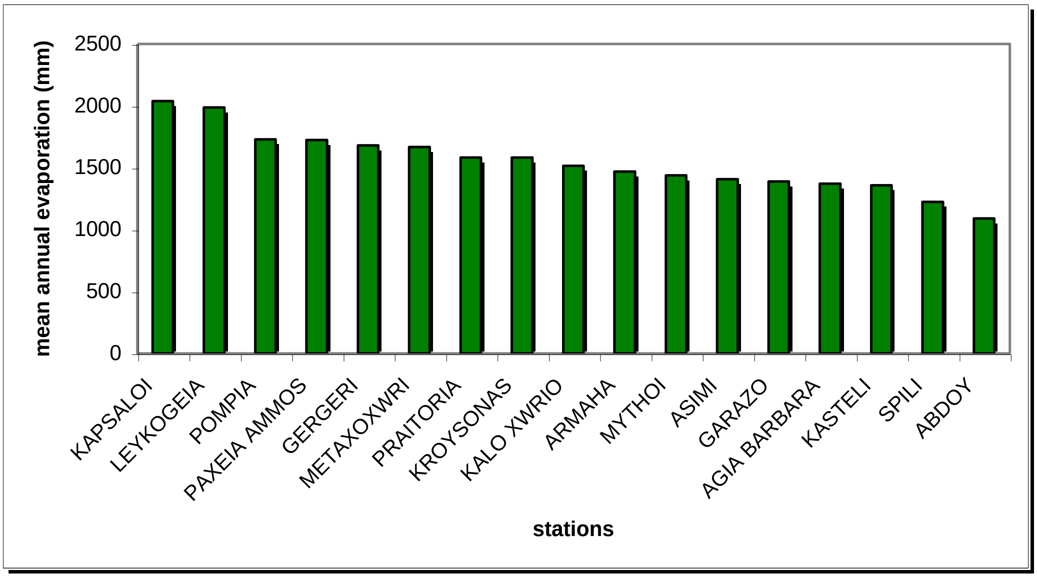


Figure 1.1.3.24: Mean annual pan evaporation for different stations in Crete

1.1.3.5 Humidity

The driest months of the year are June and July with a mean relative humidity of 48.9% at Souda station in Chania prefecture and of 59.88% at Heraklion station. The most humid month is December when the mean relative humidity at Souda station is 72% and 67% at Iraklion station (Source: Regional Governor of Crete).

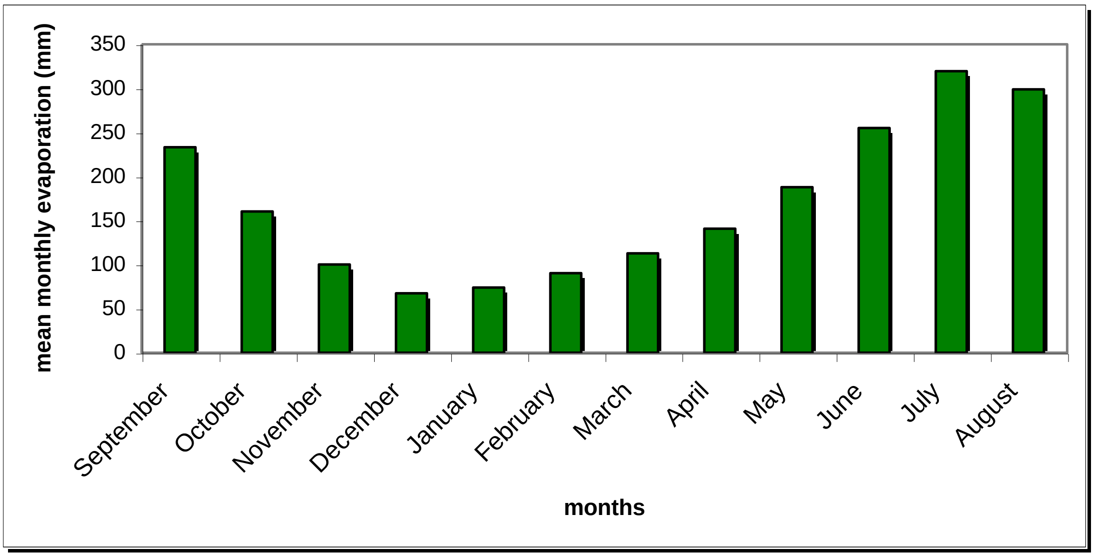


Figure 1.1.3.25: Mean monthly evaporation at Kapsaloi station

1.1.4 Surface water

The contribution of the surface water to the potential water resources of Crete is about 40%. The real contribution though is about 13%, which means that almost all the water quantity used in Crete comes from subterranean sources (springs, wells and boreholes) (Chartzoulakis et al., 2001).

In Crete there are 25 measured streams, 11 in Iraklion prefecture, 5 in Chania prefecture, 3 in Rethymnon prefecture and 6 in Lasithi prefecture. There are no perennial streams on Crete and the total mean annual runoff is estimated to be in the region of 0.83 billion m^3. Figure 1.1.4.1 shows the mean annual runoff for measured streams in the prefecture of Iraklion.

The stream with the highest runoff is Almyros near Iraklion. It has a mean annual runoff of 236 Mm^3. The stream with the highest mean annual runoff in Rethymnon prefecture is Platys with mean annual runoff of 50 Mm^3, in Chania prefecture Sepreniotis with mean annual runoff of 14.9 Mm^3 and in Lasithi prefecture Katabothres with mean annual runoff of 16.6 Mm^3. Almyros stream in Iraklion prefecture is also the stream with the highest mean annual runoff in Crete. Figures 1.1.42, 1.1.4.3 and 1.1.4.4 show a comparison of the mean annual runoff of streams in the prefectures of Chania, Rethymnon and Lasithi and in Crete generally.

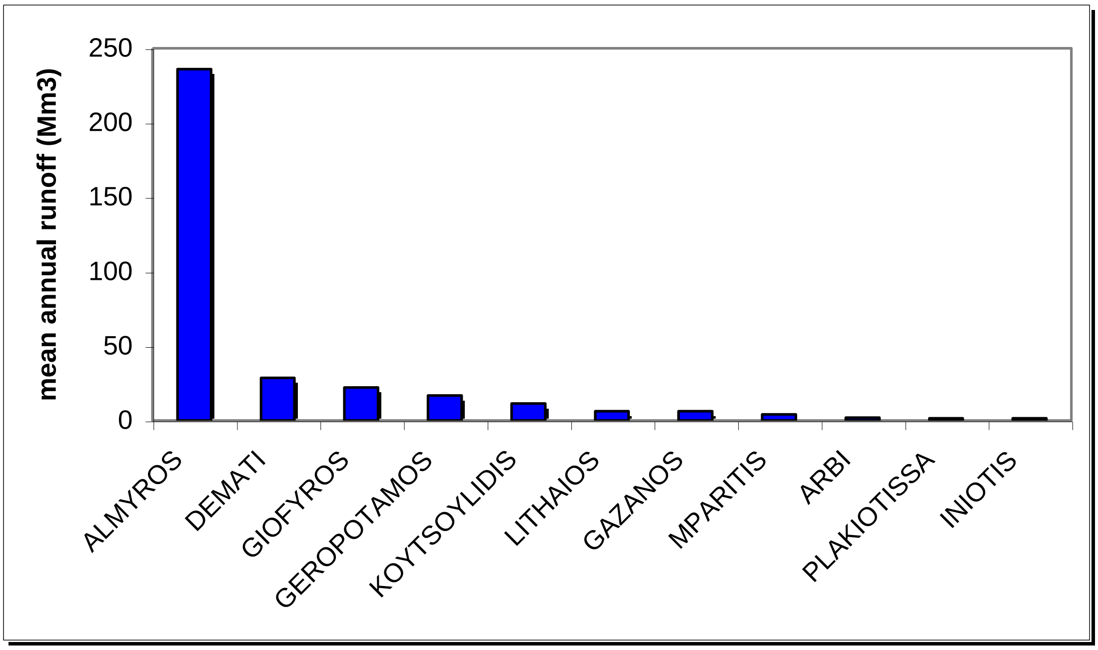


Figure 1.1.4.1: Mean annual runoff in Iraklion

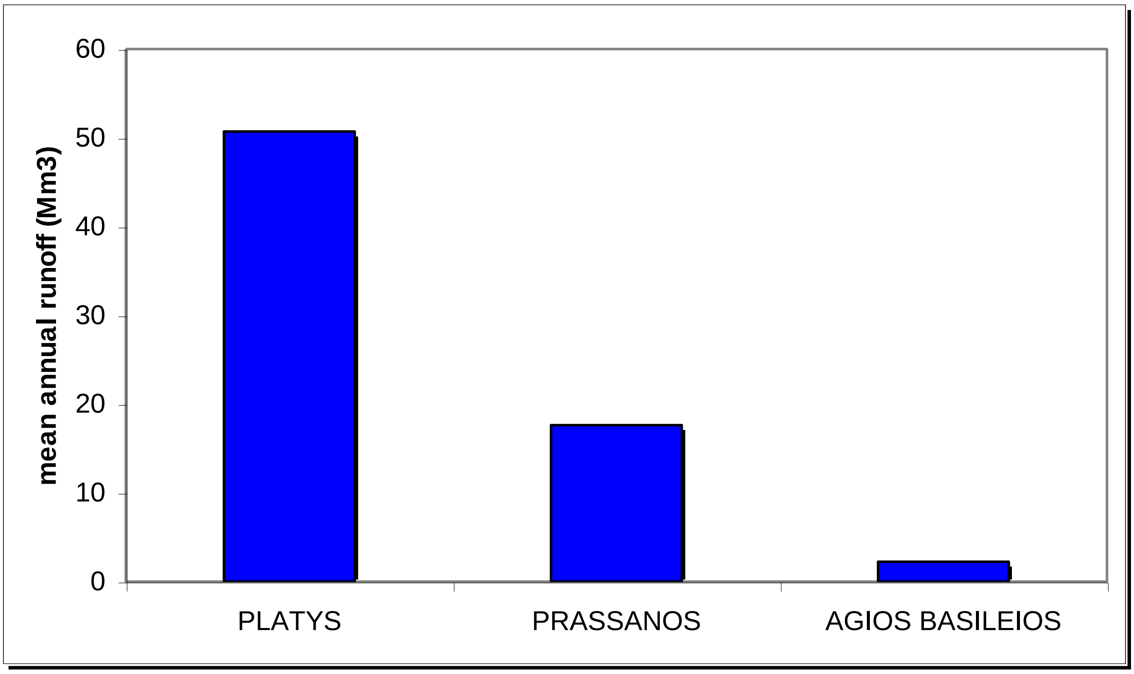


Figure 1.1.4.2: Mean annual runoff of streams in Rethymnon prefecture

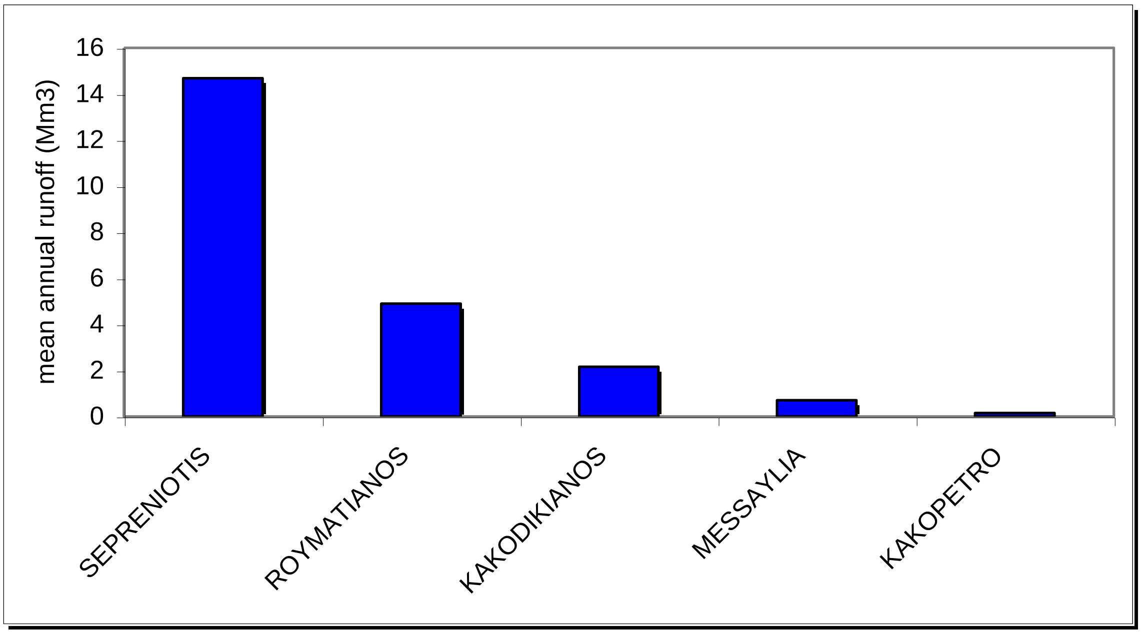


Figure 1.1.4.3: Mean annual runoff of streams in Chania prefecture

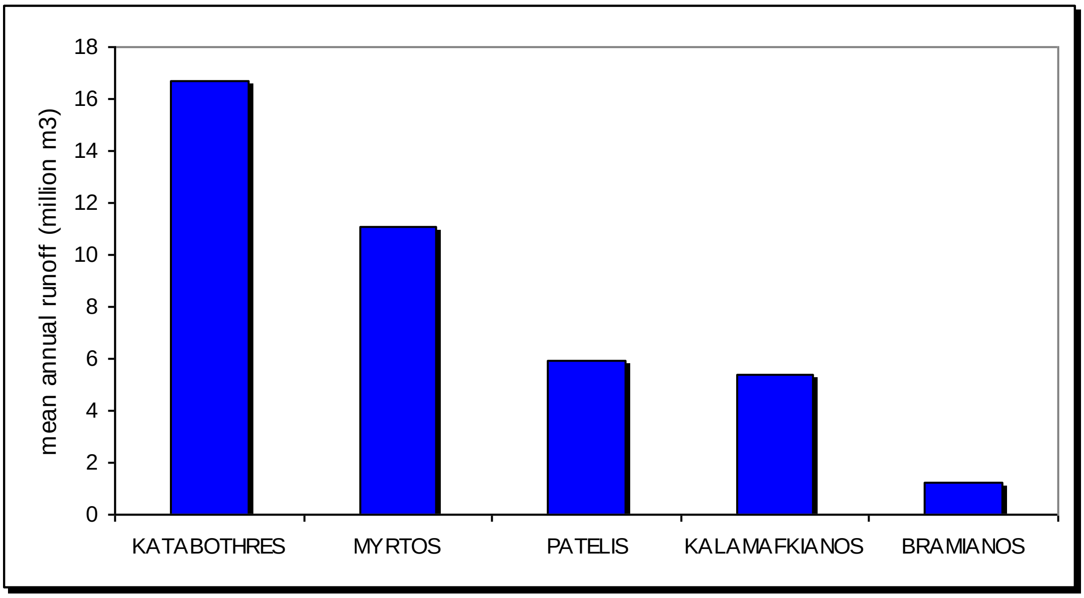


Figure 1.1.4.4: Mean annual runoff of streams in the prefecture of Lasithi

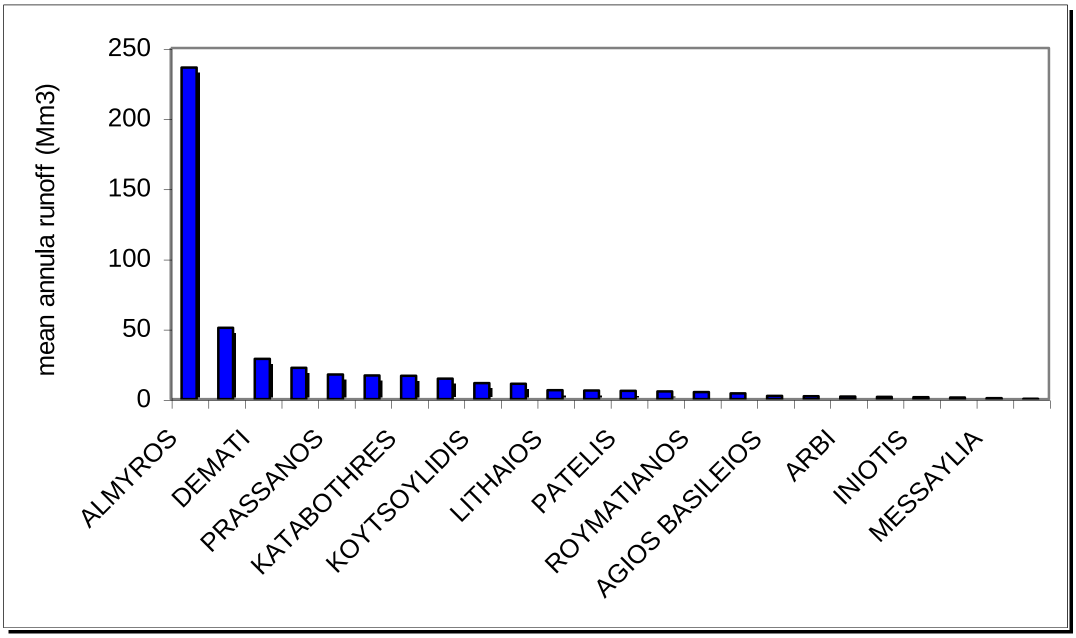


Figure 1.1.4.5: Mean annual runoff of streams in Crete

1.1.5 Groundwater

The contribution of groundwater to the potential renewable water resources in Crete is about 70%. Almost all the water quantity used in Crete comes from subterranean sources (Chartzoulakis et al., 2001). It is estimated that approximately 20% of the groundwater resources of the island, totaling approximately 1.5 billion m^3, are associated with Neogene-Quaternary aquifers while the remaining 80% are associated with their deep Karstic counterparts (Source: RGC). It is estimated that 40 to 55% of the mean annual precipitation infiltrates into the ground in Karstic aquifers, creating a renewable groundwater potential of approximately 1.25 billion m^3. Of that groundwater potential 80% is discharged from karstic springs the majority of which are unfortunately disposed along the coast being thus contaminated by intruding seawater. Shallow aquifers hosted by Quaternary alluvial deposits have a renewable groundwater potential of 0.25 billion m^3.

There are several boreholes and pumping wells on the island where the Regional Governor of Crete and other public services measure groundwater levels and chloride concentrations. In overexploited aquifers such as the Messara Valley there has been observed a drop in the groundwater level. This is mainly due to over pumping of the aquifers for irrigation purposes. In Iraklion prefecture there is an intense exploitation of the existing aquifers. In 1990 alone, approximately 500 licenses for drilling and wells were issued by the responsible public service. It is certain that many additional unauthorized drillings have also been carried out, intensifying the exploitation of the already exploited underground aquifers.

There are 46 springs in Crete for which measurements of their yields exist. The mean annual yield for various springs in Crete is depicted in figure 1.1.5.1.

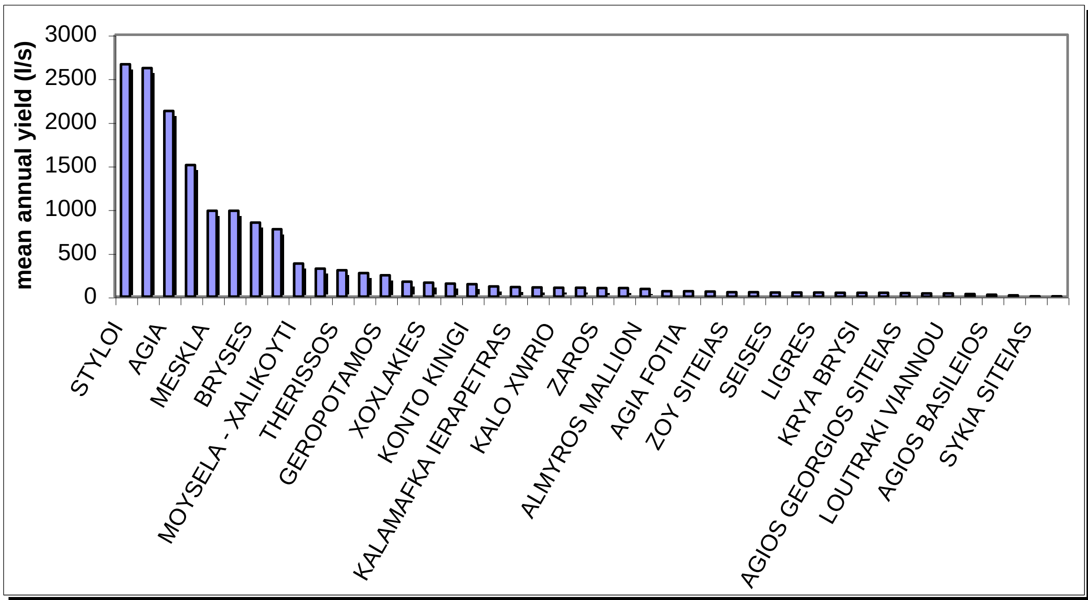


Figure 1.1.5.1: Mean annual yield for various springs in Crete

Generally, the highest yield is observed from January to April. The month with the highest yield is March or April and the month with the lowest yield is August, September or October. This is depicted in figure 1.1.5.2.

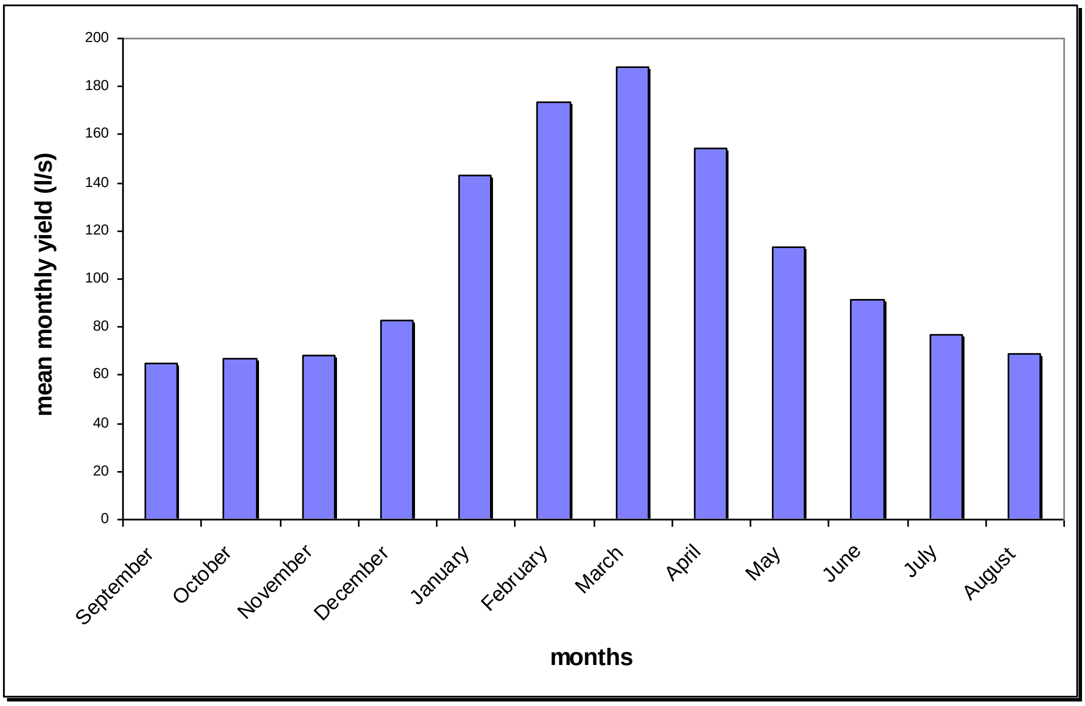


Figure 1.1.5.2: Mean monthly yield for Kalamafka

1.2 Water balance

Despite relatively high precipitation (600 mm in the plains and 2000 mm in the mountains), it is estimated that from the total precipitation in plains per year about 70% is lost to evapotranspiration, 10% as runoff to sea and only 20% goes to recharging the groundwater (Chartzoulakis et al., 2001). The island of Crete receives approximately 7.5 billion m^3 of precipitation per year. Thus, there is an approximate inflow of 1.6 billion m^3 of water in the underground aquifers of the island (Monopolis, 1993).

Table 1.2.1 depicts the estimated hydrological balance of Crete in billions m^3 per year for three hydrological conditions namely a normal year with a return period equal or exceeding 50%, a wet year with a return period equal or exceeding 10%; and a dry year with a return period equal or exceeding 90%.

Table 1.2.1: Estimated hydrological balance of Crete (in billion m^3/a) Source: RGC

Hydrologic Conditions	Precipitation	Actual Evapotranspiration	Runoff	Infiltration
Normal year	7.69	5.38 (70%)	0.83 (10.8%)	1.47 (19.2%)
Wet year	10.33	7.23 (70%)	1.12 (10.8%)	1.98 (19.2%)
Dry year	5.07	3.55 (70%)	0.55 (10.9%)	0.97 (19.1%)

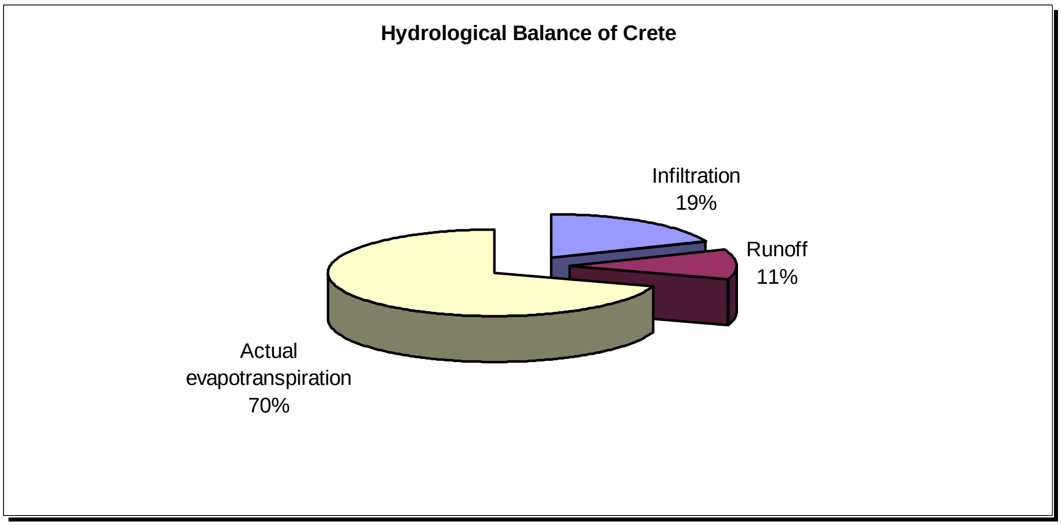


Figure 1.2.1: Hydrological balance of Crete. (Source: RGC)

1.3 Water demand and supply

As mentioned, the average annual precipitation in Crete is estimated at 750 mm. The potential renewable water resources 2650 Mm^3 and the real water used about 384 Mm^3/a. Water consumption constitutes only a small percentage less than 10 and 20% of the annual precipitation and water potential respectively. Although the contribution of the surface water to the potential water resources is around 40% (figure 1.3.1), the real contribution is about 13%, which means that almost all the water quantity used in Crete comes from subterranean sources (Chartzoulakis et al., 2001).

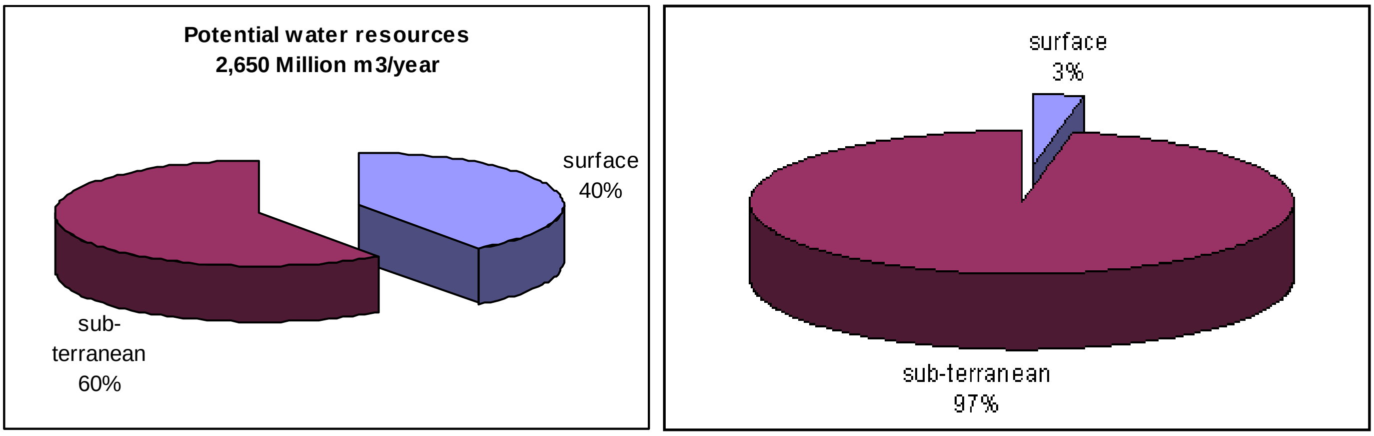


Figure 1.3.1: Water availability (potential water resources) and exploitability on the island of Crete.

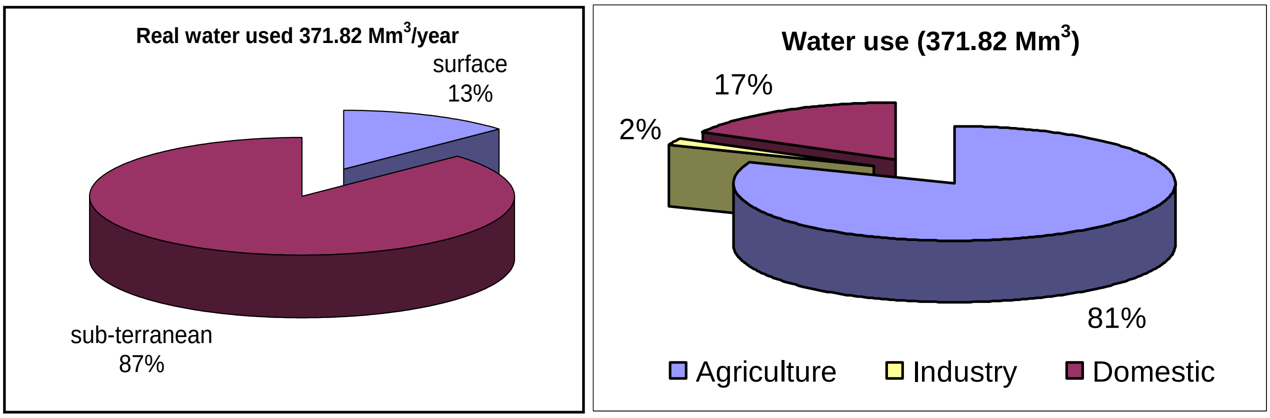


Figure 1.3.2: Water use by sources and sectors on the island of Crete

The major water use in Crete is in irrigation for agriculture (81% of the total consumption) while domestic use including tourism is 17% and industrial use only 2% (mainly for olive extraction plants, packaging plants, livestock and water bottling companies) (figure 1.3.2). Irrigation covers around 31% of the total cultivated land and uses mainly groundwater from wells or spring outflows. Only a very small percentage of irrigation water comes from surface water impounded in reservoirs.

Water used for irrigation is higher in the interval May-September with peak demand during July and August. Household consumption also shows a peak during July and August.

Another sector related to water use is tourism (domestic and international), an important economic activity in Crete, which is still significantly increasing. The total number of tourists in Crete in 1999 exceeded two million. The tourism industry requires huge quantities of water supply, with peak consumption during the high season and excess capacity in the low season (Chartzoulakis et al., 2001).

In Crete in the year 1986 total consumption of water was estimated at 280 $x10^6$ m^3 (233.5 $x10^6$ m^3 for irrigation, 39 $x10^6$ m^3 to supply houses, 3.5 $x10^6$ m^3 for industrial use and 4 $x10^6$ m^3 for the remaining uses) (Source: Ministry of Agriculture).

According to research done by the National Statistical Service of Greece in 1999 56.5% of the municipalities and communities in Crete, which represent 44.5% of the island's population, have sufficiency in water all year round, while the remaining 43.5%, which represent 55.5% of the population have problems with the water supply (Xepapadeas, 1996).

It should be noted that water availability in average terms is not the limiting factor. Much more important are the significant regional and seasonal variations which Crete shows in water availability and demand. About 70–80% of annual rainfall occurs in three to four months, while summers are usually long and dry. This situation is further worsened by a seasonal and regional variation in water demand. Both agriculture and tourism require increased supplies in late spring, summer, and early autumn, when water is less abundant (Table 1.3.1). Also, domestic use of water increases during dry and hot periods. On the average, Crete has relatively high per capita water availability, i.e. around 4,800m3/inh/a, which is lower than that of Greece (6700m3/inh/a (Chartzoulakis et al., 2001).

Table 1.3.1: Water demands and deficit in the island of Crete (Mm^3)

Water use	Estimated demands	Consumption	Deficit	Cover Percentage %
Irrigation	458.37	302.06	156.31	65.9%
Domestic & other	77.34	69.75	7.59	90.2%
Total	535.71	371.81	163.90	72.2%

* Irrigation demands are the required quantities for optimum crop yield.

1.4 Environment protection

Water Quality

Hydrogeological and biological factors affecting water quality in Crete include salinity due to the intrusion of seawater in coastal aquifers and high concentration of sulfuric ions originating from gypsum aquifers. The intense exploitation of existing underground aquifers has increased salinity concentrations. As a result the quality of irrigation water is reduced and this could potentially have negative external effects on agricultural production (Xepapadeas, 1996).

Pollution due to human activities has dramatically increased in recent years. This includes groundwater contamination due to the disposal of untreated domestic and industrial wastewater and the widespread use of fertilizers and pesticides in agriculture. However it should be noted that chemical and biological analysis of groundwater has shown that the majority of waters are within the drinking standards.

Wastewater treatment and reuse

In Greece, today, there are 270 Municipal Wastewater Treatment Plants (MWTPs) in operation that serve about 60% of the country's permanent population. For the remaining 26%, it is estimated that 2,000 MWTPs serving more than 500 population equivalent (P.E.) will be needed (Tsagarakis et al., 2001). Fourteen percent of the population is in villages of less than 500 P.E. for which on site sanitation technologies should be used (Tsagarakis, 1999). In Greece specific technologies for municipal wastewater treatment have been developed. Among these systems, 88% percent are activated sludge systems, 10% are natural systems, and 2% are attached growth systems. Among the activated sludge systems 85% are extended aeration systems, 10% are conventional systems and 5% are sequencing batch reactors. Approximately 44% of the activated sludge systems have nitrogen removal, and 15% have considered phosphorous removal. In Crete it is estimated that at present more than 100,000 m^3/d of secondary treated wastewater effluent is produced (Chartzoulakis et al., 2001). There are 23 MWTPs operating in Crete. Among these, 22 are activated sludge systems and 1 is a constructed wetland. Activated sludge systems are currently in operation in the municipalities of Iraklion, Chania, Rethymnon and Agios Nikolaos (Tsagarakis et al., 2001). Conventional wastewater treatment plants are also operating in the municipalities of Chersonisos, Archanes, Tympaki and Matala treating municipal wastewater in the prefecture of Iraklion. There is also a small wastewater treatment plant in the Industrial area of Iraklion treating industrial effluents. There is a constructed wetland in operation in the community of Pompia in Iraklion prefecture. Many municipalities and communities in Crete are in the process of designing and building wastewater treatment plants, a number of those having reached the stage of conducting Environmental Impact Assessment studies. Such a case is the construction of a wetland in the community of Episkopi in Iraklion prefecture. The trend in Crete is towards the construction of wetlands for treating wastes of small communities.

Tsagarakis (1999) has classified the MWTPs in operation in Greece according to their performance, taking into account effluent qualitative parameters and the effluent quality requirements. Of existing MWTPs in Greece, 42% were operating well, 41% moderately and 17% poorly. Qualitative and quantitative values from some large MWTPs of Crete in comparison with others in the rest of Greece are shown in table 1.4.1.

The uneven atmospheric precipitation (spatially and seasonally), the continued growth of the population, the rapid growth of the tourist industry and the periodic droughts have forced water services and other agencies to search for new and reliable water sources. The use of reclaimed or recycled wastewater for various non-potable uses has proved to be the most reliable of sources, like in most Mediterranean countries. In Greece, no guidelines or criteria for wastewater reclamation and reuse have yet been adopted. Secondary effluent quality criteria are used for discharging purposes with a Health arrangement action of 1965 (Ministries of Interior and Public Health, 1965) and are independent of the disposal, reclamation and reuse effort. Also, no regulation of wastewater reuse exists on the European level. The only reference to it is the article 12 of the European Wastewater Directive (91/271/EEC) (EU, 1991). Thus, the need for establishing wastewater reclamation and reuse standards on both European and national level is obvious (Angelakis et al., 1999). There are a few MWTPs in Greece where effluent is used for direct irrigation of agricultural land. The effluents from four plants are used for the irrigation of forestry and various amenity purposes. There is no industrial reuse of treated effluent apart from some installations that use filtration for treating further effluent that is going to be used in the installation (Tsagarakis et al., 2001). There is no wastewater reuse practiced in Crete. Nevertheless, it has been calculated that by reusing the treated effluent of today’s existing plants, a 5.3% increase of irrigated area can be obtained (Tsagarakis et al., 2001).

Table 1.4.1: Average quantitative and qualitative characteristics of treated effluent from different MWTPs in Greece (Source: Tsagarakis et al., 2001)

Parameter	Agios Nikolaos[a]	Heraklion[a]	Rethymnon[a,b]	Chania[b]	Rhodes	Ioannina[a]
P.E.	14,000	110,000	57,500	40,500	120,000	110,000
Q_e (m^3/d)[c]	1,500	15,000	7,500	10,400	8,000	17,089
BOD_5 (mg/L)	16	8	8	4	9	8
COD (mg/L)	54	15	40	29	25	38
TDS (mg/L)	-	950	1,500	-	1,250	-
SS (mg/L)	20	8	13	8	-	13
PH	7.70	7.65	7.75	7.50	7.60	7.69
TKN (mg/L)	-	20.00	2.50	4.50	-	11.50
NH4-N(mg/L)	2.10	4.50	0.65	0.40	0.50	9.65
NO_3-N (mg/L)	-	-	0.15	0.47	-	0.30
Total P (mg/L)	-	12.50	5.00	7.90	7.60	4.28
FC(MPN/100cm^3)	-	0	1,000,000	275	-	0
TC (MPN/100 cm^3)	1,000	15	23,000,000	-	-	25

[a]Average values for 1999; [b] Without desinfection; [c] Effluent average daily flow rate.

1.5 Water laws and regulations

Law 1739/87 for water resources management determines the instruments and the processes that should be employed to allow water resources management in national and regional level. According to this law, water resources management is the set of activities and processes necessary for the best possible cover of water demand for all uses. The main goal of water resources management is coping with problems such as water inefficiency, areas and users of conflict and conservation of the highest possible water quality and quantity according to use, today and in the future. Other goals of water resources management are the orientation of water demand towards uses that comply with research and development programs of the country and the rational development of investigation, exploitation and protection of water resources.

The basic regulations of Law 1739/87 for the achievement of the above-mentioned goals are:

- Institutional framework
  - Enactment of the division of the country in 14 water districts, i.e. areas demarcated by watersheds or islands, which include hydrographic networks with similar hydrological-hydrogeological conditions;
  - The ministry of development is designated as the ministry in charge of natural resources and water resources management;
  - Advisory committees are established for decision making: Ministerial Committee of Water Resources in national level and 14 regional committees for water resources management;
  - Public services are designated in charge of each water use.

- Water resources development
  - Development programs are classified as long-term national, mid-range national and regional in each water district. Implementation and supervision of the development programs is one of the main tasks of water resources management instruments in national and regional level;
  - The main principle on which development programs are based is water availability and demand budget. The water budget takes into account the current situation of water resources as well as future scenarios.

Parallel to law 1739/87 and complimentary to it, law 1650/86 for environment protection is in force. In articles 9 and 10 of this law water is defined as a natural element and legislative measures are foreseen for monitoring and evaluation of water resources quality. In the framework of law 1650/86 the Hellenic ministry for the environment, physical planning and public works presented a comprehensive program for water resources protection. This program was part of the “A’ European Union support framework” (1983-93), which established the necessary infrastructure for water resources monitoring. The water resources quality-monitoring network was completed with the “B’ European Union support framework”.

Apart from these two laws there is a number of legislative decrees, joint ministerial decisions, sanitary regulations and articles of the civil code that refer to the investigation, exploitation and protection of water resources.

1.6 Institutional framework and constraints

The institutional framework for water resources management in Greece was shortly described in paragraph 1.5. In more detail the institutional framework in Greece can be seen in figure 1.6.1.

Figure 1.6.1: Institutional framework for water resources management in Greece

The ministry in charge of natural resources and water resources management on national level is the Ministry of development. There is also a ministerial committee for water resources in national level, which is an advisory and decision-making instrument. Water resources management options are proposed from the ministry of development to the ministerial committee, which then decides on a certain policy option that should be employed by the ministry of development. The ministry for development has a regional structure with 14 regional committees for water resources, one for each water district that Greece is divided in. Water districts are areas demarcated by watersheds or islands, which include hydrographic networks with similar hydrological-hydrogeological conditions. The regional committee of the ministry for development in Crete is the Regional Governor of Crete (RGC). RGC is an advisory and decision-making instrument. The section of water resources of RGC is in charge of water resources management in the island of Crete, which forms a separate water district. The water resources management policy of RGC is employed by public services. The public service responsible for domestic and public water supply is the regional service of municipalities and communities and users include the municipal service of water supply and sewerage, municipalities and private users. The directorate of land reclamation works is in charge of agricultural water management and users of water for agriculture are local water boards and farmers with private irrigation projects. The National Tourism Organisation regulates water used for tourist activities and services for environment protection regulate water necessary for the protection and conservation of natural systems.

1.7 Management, institutional and policy options

Water resources management is a key issue on the island of Crete mainly due to the spatial and temporal variation of the rainfall events, in relation to the geological setting of the island and also the intense water uses such as tourism and farming. The main issue in water resources management on the island is focused on the uneven geographical distribution of water resources in relation to the water demand hotspots on the island. In general there is abundance of water resources in the west compared to the east of the island. Furthermore, the demand for tourism and farming activities is increased in the east of the island. This combination of availability and demand places the water resources and their management under pressure.

The main stakeholders on the island can be classified in two categories depending on the scale of the areas of responsibility and the nature of the stakeholders' responsibilities. On regional scale the Section of Water Resources Management of the Region of Crete (RGC) comprises the main stakeholder and its main duty is the integrated water resources management and identification of water resources problems on the island, as well as suggestion of actions for future sustainable development. On regional scale the municipal water companies and the local water boards comprise the main stakeholders. They deal with domestic water supply and irrigation water provision and management respectively.

The difficulty of local people in understanding the objectives of a water resources management plan and the misleading belief of the farmers that an increase to the suggested irrigation water volumes leads to a higher farming production, create significant frictions in regional scale. The misconception of water resources ownership status, and the continuously increasing demand and water use are the main reasons for the creation of such frictions. This leads to water resources overexploitation, reduction of the water resources potential, failure of existing infrastructure and results in natural water quality deterioration. Human activities also intensify the pressure for a sound water resources management especially in alluvial plain aquifers.

Under the above conditions, the section of water management has taken into consideration the following proposals in order to protect and to restore the environment in the view of sustainable development:

- Protection of Groundwater Resources Against Over-Exploitation;
- Restrictions in issuing groundwater abstraction licenses in areas under pressure;
- Pollution Control of surface and ground water. Monitoring of Water Quality;

- Protection of Coastal Aquifers from saline intrusion;
- Exploitation of Un(der)Exploited Aquifers such as Karstic Aquifers;
- The establishment of a water plan on a watershed basis for detailed water management;
- The investigation and implementation of artificial recharge of aquifers;
- Feasibility studies for further introduction of surface reservoirs;
- The improvement of the information services on the rural scale;
- The application of modern and effective irrigation methods;
- Improved Freshwater Storage and Transport. Groundwater Recharge promotion;
- Reuse of water after treatment;
- Utilization of Untapped Surface Water Sources. Interbasin Transfer;
- Demand Reduction: Agricultural, Industrial and Domestic.

The implementation of the Water Framework Directive in combination with the application of a strategy that aims to inform local people about the existing issues will assist the regional stakeholders to a geographically balanced water resources management of the island.

1.8 Agricultural situation

1.8.1 Cultivated crops and cultivated land

Agriculture represents an important sector of the local economy in Crete. It contributes 13% to the GDP of the island, while services and tourism represent 77% and industry 10%. Approximately 6.7% of the active island employees are working in the agricultural sector.

Crete is an olive-producing island and the olive oil production is the most important agricultural sector of the island. 99.8% of the olives produced are used for oil production and only 0.21 % of the total production is for edible use (HNSS, 1999). Olives take 38% of the total cultivated land on the island while that percentage is increased on Iraklio prefecture where it takes 53%. Olives cover more than 90% of the total tree crops, followed by citrus 3.4%, almonds and avocados. Along with olives, citrus (oranges, lemons and mandarins), apricots and cherries are cultivated. Tomatoes, cucumber, potatoes, melons and watermelons are the most widely cultivated vegetable crops, while almost all of the row crops are fodder crops and legumes. The total cultivated land is 3223.2 km^2 including fallow land. The main groups of crops and the surfaces covered in Crete are shown in the Table 1.8.1 and their development within the last 40 years in figure 1.8.1. The production of some groups of crops in the four prefectures of Crete is shown in Tables 1.8.2, 1.8.3 and 1.8.4. (HNSS, 1999). The main vegetable crops grown in Crete are fresh tomatoes, cucumbers, potatoes, eggplants, onions, watermelons, melons, cabbages and peppers, while among fruit crops olive covers more than 89% followed by citrus 3.4%, almonds and avocados (Chartzoulakis et al., 2001).

Table 1.8.1: Area and crops cultivated in Crete (km²), Regional Governor of Crete, 2002

Category	Cultivated Area (km²)	Percentage of the total
Row crops	320	9.9
Vegetable crops	80	2.7
Vineyards	309.5	9.6
Fruit crops	1850.2	57.4
Fallow fields	653.5	20.4
Total cultivated land	3223.2	100.0

Table 1.8.2: Crop production in thousand tons/year: vegetables

Vegetables							
	Tomatoes	**Cauliflowers & Cabbages**	**Onions**	**Egg-plants**	**Potatoes**	**Melons**	**Water-melons**
Iraklio	55.73	8.36	3.53	1.33	33.66	8.41	20.49
Lashithi	38.23	2.41	0.65	6.25	39.19	3.32	0.78
Rethimno	5.39	1.37	0.92	0.22	6.79	0.78	4.37
Chania	30.93	1.07	1.59	0.45	8.20	2.43	8.31
Total	130.27	13.21	6.69	8.25	87.84	14.94	33.94

Table 1.8.3: Crop production in tons/year: arable land

Crops on arable land								
	Wheat	**Barley**	**Oats**	**Maize**	**Broad beans**	**Beans**	**Chick peas**	**Lentil**
Iraklio	2894	2688	684	16	556	129	72	24
Lashithi	1378	360	600	54	331	142	39	10
Rethimno	629	1031	1595	90	384	216	41	24
Chania	55	124	681	60	216	127	9	2
Total	4956	4203	3560	220	1487	614	161	60

Table 1.8.4: Crop production in thousand tons/year: tree crops

Tree crops									
	Lemons	**Oranges**	**Manda-rins**	**Pears**	**Peaches**	**Apri-cots**	**Cher-ries**	**Olives**	**Olive oil**
Iraklio	4.67	11.17	1.95	3.39	1.33	45.89	13.78	307.66	66.21
Lashithi	1.04	3.01	0.80	1.15	6.25	3.88	0.19	64.17	22.63
Rethimno	1.10	3.91	0.38	1.38	0.22	4.29	0.43	80.52	20.76
Chania	3.41	107.55	4.50	1.26	0.45	9.25	0.62	182.10	37.58
Total	10.21	125.64	7.63	7.15	8.25	63.31	15.01	634.45	147.17

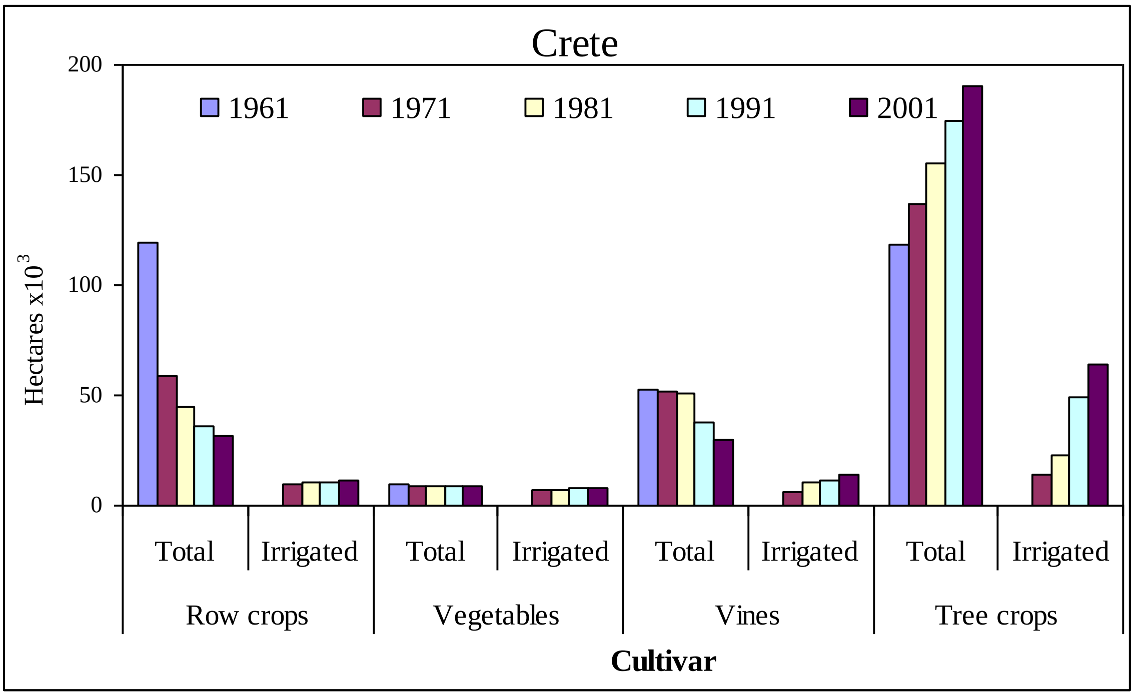


Figure 1.8.1: Area and crops cultivated in Crete in the last 40 years (Source: Hellenic National Statistical Service).

1.8.2 Irrigated area and irrigated crops

Demand for irrigation water is high especially in summer months (agriculture is the major water consumer), adding more pressure on the aquifers, which already suffer from the increased demand for domestic use those months.

In Crete 42% of the available agricultural land is irrigated (RGC, 2002). As shown in Figure 1.8.2 in Crete there was an increase of irrigated land of more than 55% in the last 15 years, while the average increase at the same time in the country was 15% (Fig. 1.8.3.)

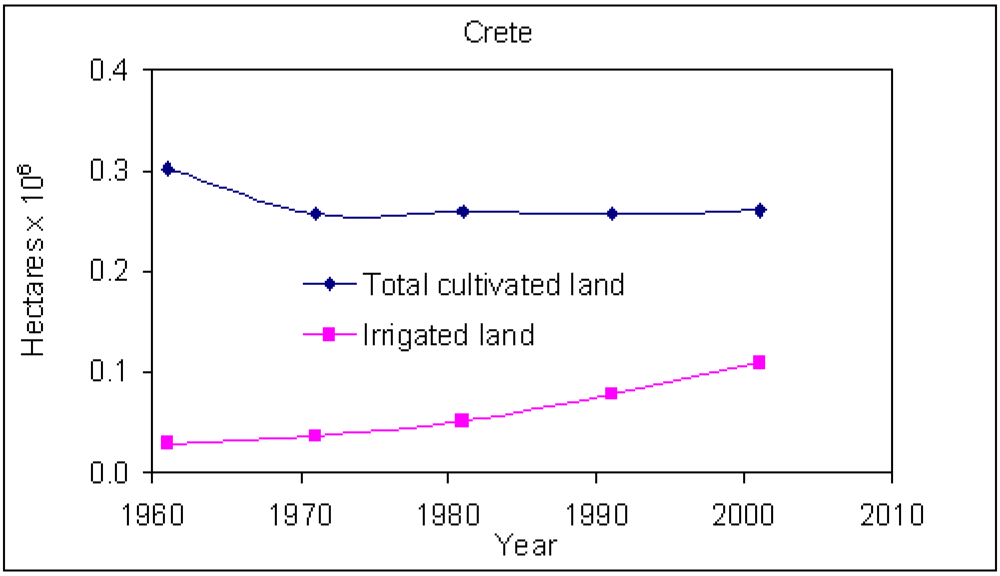


Figure 1.8.2: Total cultivated area and irrigated area in Crete, Hellenic National Statistical Service

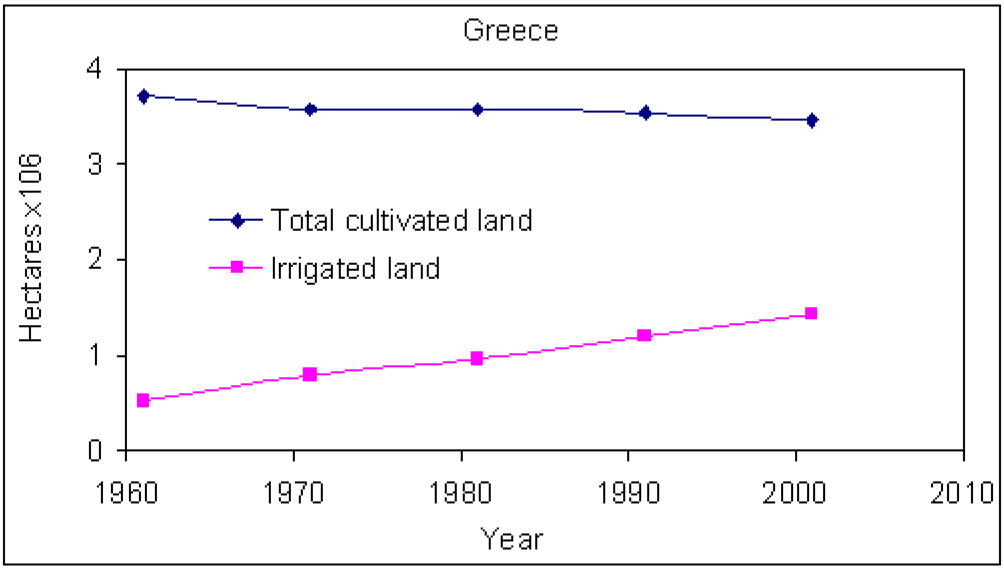


Figure 1.8.3: Total cultivated area and irrigated area in Greece, Hellenic National Statistical Service

The demand for irrigation water is high, while at the same time only 31% of the available land is irrigated, a percentage lower than that of Greece (36.3%). There was an increase in irrigated land by more than 55% within the last 15 years, while the average increase at the same time in the country was 25% (figure 1.8.2). For vegetable crops, more than 92% of the cultivated area is irrigated, while the irrigated percentage in row crops was 36.5%, in fruit trees 38.5% and in vineyards 46.8%. It should be noted that row crops are referred to cereals, fodder plants, industrial plants, melons, watermelons and potatoes while tree crops are olives, citrus, fruit trees, nut and dried fruit trees (Fig.1.8.4) (Hellenic National Statistical Service). Table 1.2.4.1 depicts the irrigated area for each crop group.

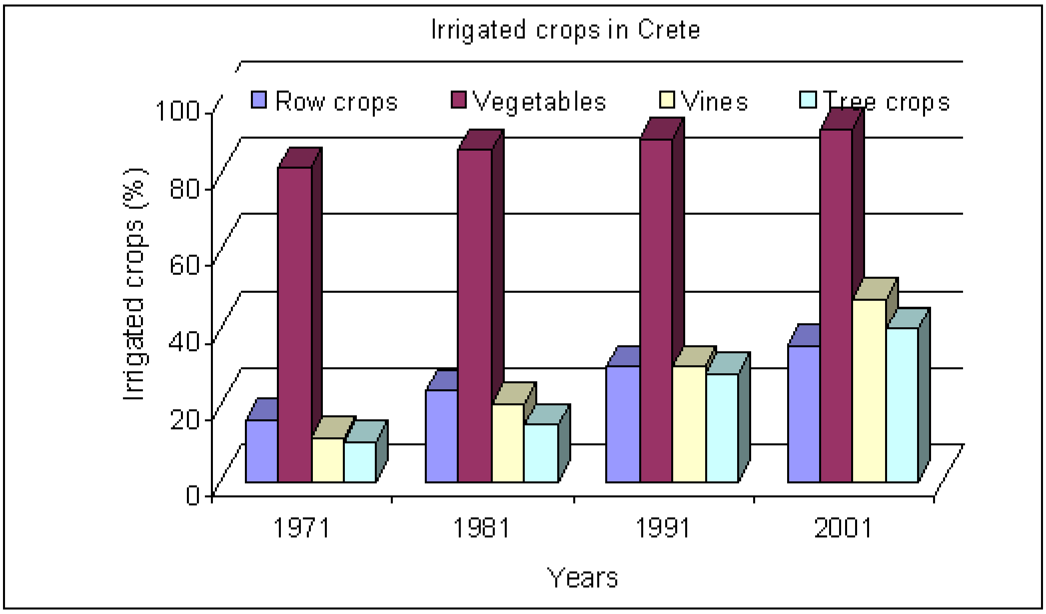


Figure 1.8.4: Irrigated crops (percentage of the total cultivated area in Crete) during the last 30 years

Table 1.8.5: Cultivated and irrigated areas in the prefectures of Crete (RGC, 2002)

Type of crop	Cultivated land (ha x 10^3)	Irrigated land (ha x 10^3)	Percentage of irrigated land	Percentage of crop that is irrigated
Row Crops	32.2	11.74	11%	36.45%
Vegetables	8.8	8.17	7.7%	93%
Tree crops	185.0	71.4	67.4%	38.5%
Vineyards	31.0	14.5	13.9%	46.8%
Total	257.0	107.90	42.0%	

Table 1.8.6 shows an estimation of the irrigation water requirements for a selection of crops in the island of Crete (RGC, 2002). The last column shows an estimation of the actual water applied per crop, which is usually higher than the recommended amount. Irrigation period varies in the island and depends on the microclimatic conditions of each area, the type of crop and the time of plantation. A mean irrigation period is shown in Table 1.8.7.

Table 1.8.6: Crop water requirements (RGC, 2002)

Type of crop	Water required (m^3/ha)	Water applied (m^3/ha)
Vineyards	1780	3000 – 3500
Forage crops	-	7000
Olives	3140	2500
Open field vegetables	5700	4500
Greenhouse vegetables	4350	6500
Orchards	4620	5000
Potatoes	5700	4500
Subtropical trees	-	6000

Table 1.8.7: Irrigation periods per crop type (RGC, 2002)

Type of crop	Irrigation period
Vineyards	1st April – 30th July
Forrage crops	1st April 30 th October
Olives	1st April – 30th October
Open field vegetables	1st Arpil – 30th November
Greenhouses	1st January – 31st December
Orchards	1st April – 30th October
Potatoes	1st April – 30th October
Subtropical trees	1st April – 30th October

Figure 1.8.5 depicts origin of the irrigation water.

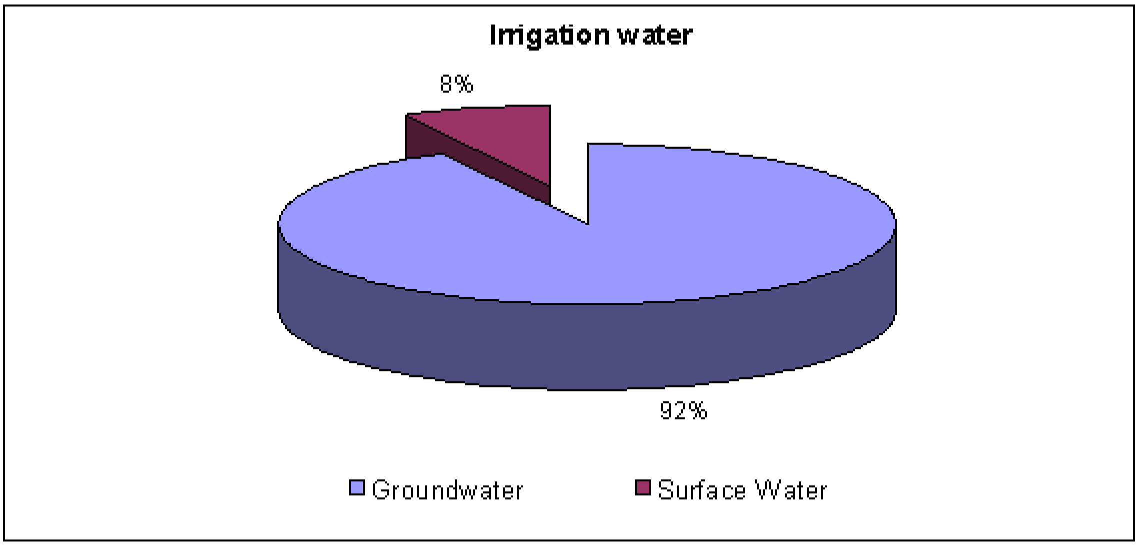


Figure 1.8.5: Origin of irrigation water in Crete

1.8.3 Animal breeding

In a study made by the Region of Crete the current water consumption for animal production in the island was estimated to 6,173,463 m^3. Small animals (sheep, goats, hens and rabbits) represent 99.3 % of the total number of animals and consume 90.5 % of the total water used for animal production. In the same study the future water needs for animal production were estimated (Table 1.8.8). The current trends indicate a significant increase in the production of smaller animals (goats, sheep and rabbits) and a steady production of larger animals (pigs and cattle) during the last decade. The number of sheep and goats was increased by 92 and 82 % respectively, in Rethimno prefecture, while the number of rabbits was in-creased by 42 % in Iraklio prefecture, during a period of 8 years. Based on these trends, the number of small animals is expected to be doubled by 2020, while production of large animals will remain at present levels. Therefore, the water consumption for animal production is estimated to increase about to 8,500,000 m^3/year by 2020 (an increase of 37.7 % compared to current levels).

Table: 1.8.8: Water consumption per animal type in Crete,RGC, 2002

Animal type	Total population	Water consumption (m^3)
Horses/Asses	13,273	265
Cattle	1,906	113
Breeding Boars	1,235	1,235
Sheep	1,258,254	8,808
Goats	545,449	3,818
Rabbits	769,479	2,308
Chickens	1,219,732	366

1.8.4 Irrigation systems

Depending on the size, irrigation projects are constructed by the government, the local authorities or private individuals. The large size irrigation schemes, which involve large hydraulic structures such as dams, conveyors, pumping stations, reservoirs and modern distribution systems, are constructed by the governmental Water Resources Services and/or Agencies. The medium size irrigation schemes of local importance are constructed by the government on behalf of the Local Authority (Prefecture or Community) and usually comprise small dams or stream ponds, or boreholes and modern distribution systems. The government finances the cost of large and medium size irrigation schemes and farmers are charged per unit of water consumed. The small size irrigation schemes, comprising a single borehole, are constructed by individuals at their own cost and are found mostly in areas overlying aquifers.

The irrigation networks are of modern type made of pressurized distribution systems with delivery of water to the farm outlets. The delivery of water to the farm outlets is done on free or modified demand or on rotation with the appropriate pressure for direct use through modern on farm irrigation systems. Although in most cases irrigation water is distributed to fields through closed pipeline networks, there are major losses (seepage, evaporation, leakage, etc.) from water delivered to the agricultural sites for irrigation (Chartzoulakis, Angelakis, & Skylourakis, 1997). It is estimated that, on average, only 65% of water diverted or extracted for irrigation is effectively used by the crop (Fig. 1.8.6). In some cases, the losses are estimated to be as much as 50% of the delivered water (Dialynas, Diamadopoulos, & Angelakis, 1995).

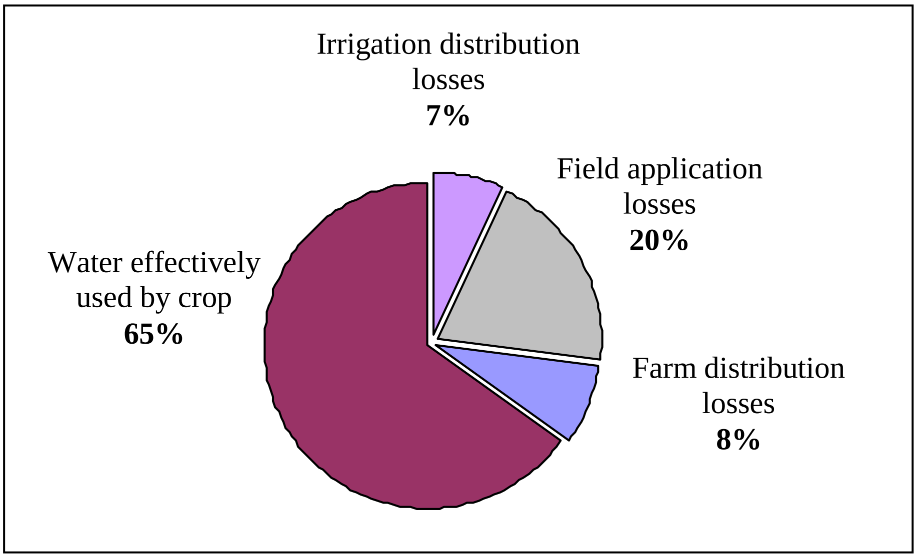


Figure 1.8.6: Average irrigation water losses in the island of Crete

Irrigation scheduling is another aspect of utmost importance for the appropriate irrigation of horticultural crops. It consists of a set of procedures which allow one, for a given crop, to find out when and how much to irrigate. Irrigation scheduling methods are based on environmental, physiological and soil parameters. For vegetables, especially in greenhouses, the analysis of soil moisture (by tensiometers, gypsum blocks or gravimetrically) is the most common method used for irrigation scheduling in Crete, since it assures low cost, simple operation and reliable estimation of soil water status. For tree crops, irrigation scheduling is mainly based on meteorological parameters (mainly Class A pan evaporation and Reference evapotranspiration ET0). Irrigation scheduling is also done empirically using soil and plant appearance. Drip irrigation systems are used for the irrigation of vegetables, vineyards and tree crops. Sprinklers are used for forrage crops and vegetables and furrow for vegetables.

1.8.5 Price of irrigation water

The price of water per cubic meter varies greatly between catchment areas and even within the same catchment area, depending mainly on the managing agency. Cretan farmers operating in publicly developed irrigation projects still do not fully cover operation and maintenance (O&M) or capital replacement costs. So in the large irrigation project of West Crete the price is as low as 0.07-0.08 euros, whereas in community projects it reaches 0.10 – 0.12 euros and in some private projects it reaches 0.23-0.35 euros (Chartzoulakis et al., 2001). These prices are much higher than in Portugal or in some regions in Spain (OECD, 1999).

1.9 Socio-economic situation

Data presented in this paragraph are for Crete and come from the Hellenic National Statistical Service. Production is divided in primary, secondary and tertiary sector. Primary sector in Greece contributes 14.1% to Gross Domestic Product (GNP), secondary sector 26.4% and tertiary sector 59.4%. The largest percentage is occupied by the tertiary sector due to inclusion of tourist services in it. Twenty seven percent of the contribution of Crete to GNP is due to primary sector, a percentage higher than that of Greece (figure 1.9.1). The industrial and commercial sectors are not as developed as in the rest of Greece, while tertiary sector seems to have the same contribution to GNP for Greece and for Crete.

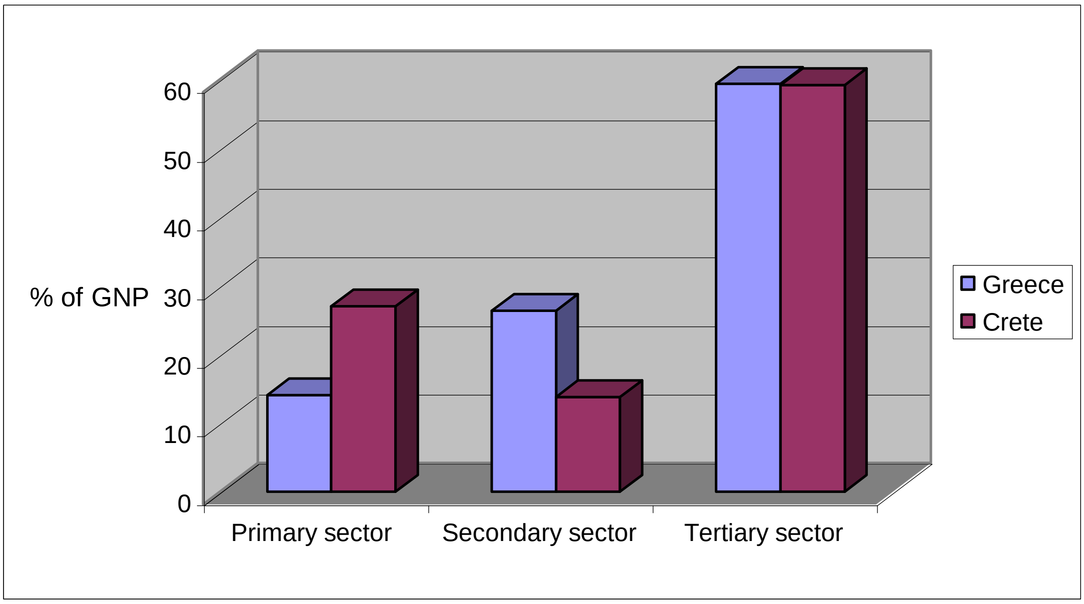


Figure 1.9.1: Production structure for Greece and Crete

The contribution of each prefecture of Crete to the primary, secondary and tertiary sector in Crete is depicted more precisely in figure 1.9.2. Thus, of the total contribution of Crete to the primary sector of Greece the prefecture of Iraklion contributes 52.2%, the prefecture of Lasithi 10.6%, the prefecture of Rethymnon 8.2%.

The fluctuations of GNP for Greece for the years 1993 to 2000 are show in figure 1.9.3. All % changes are computed for steady values reduced to year 1994. More detailed data for Crete is shown in figure 1.9.4. This figure shows per capita GNP for Crete and for different prefectures for the period 1981 to 1998.

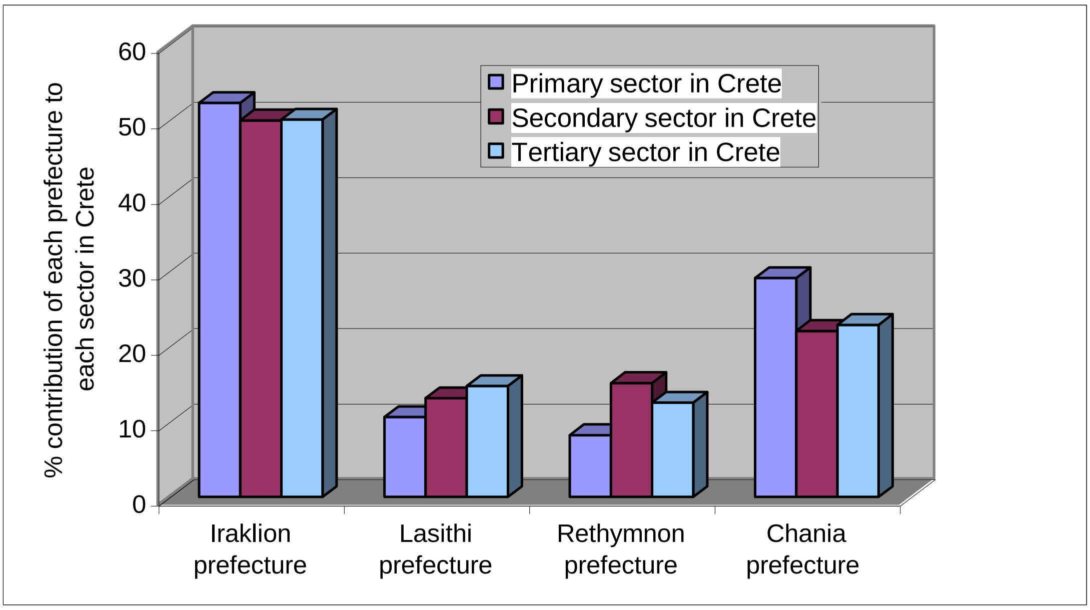


Figure 1.9.2: Production structure for different prefectures in Crete

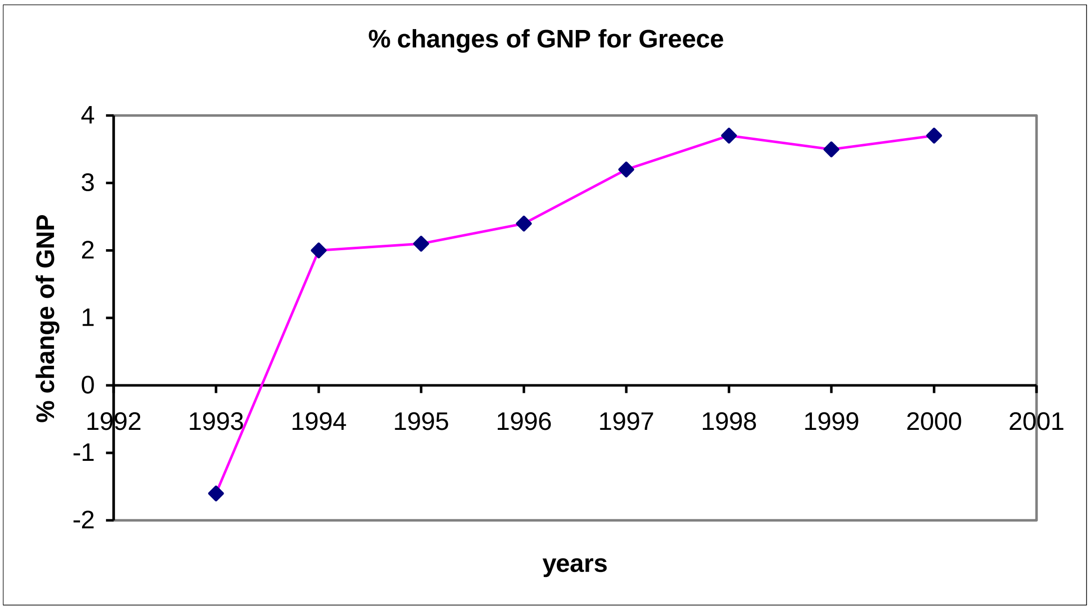


Figure 1.9.3: % changes of GNP for Greece

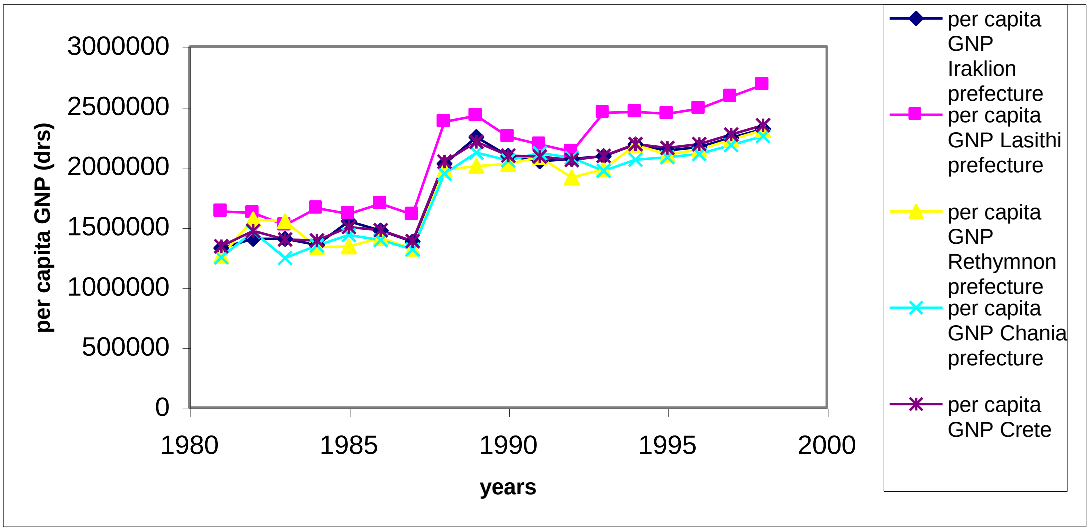


Figure 1.9.4: Per capita GNP for Crete (reference year: 1994)

Private investments in Greece showed an increasing trend since 1994. The rate of change increased from 1994 till 1997 and seems to fall after 1997 and until 1999. From 1999 to 2000 there was an increase in private investments of 8.5% (figure 1.9.5). Public investments in Greece are increasing since 1994; the rate of increase seems to fall since 1998 though (figure 1.9.6).

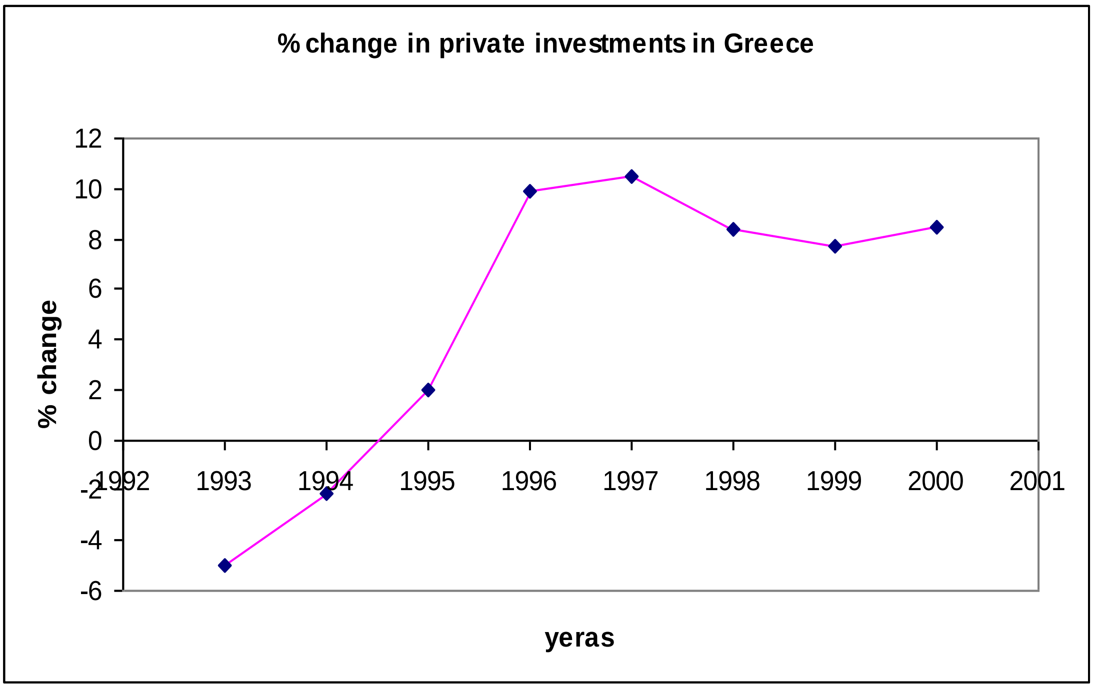


Figure 1.9.5: Private investments in Greece

The trends in private and public investments for the different prefectures in Crete are shown in figures 1.9.7 and 1.9.8.

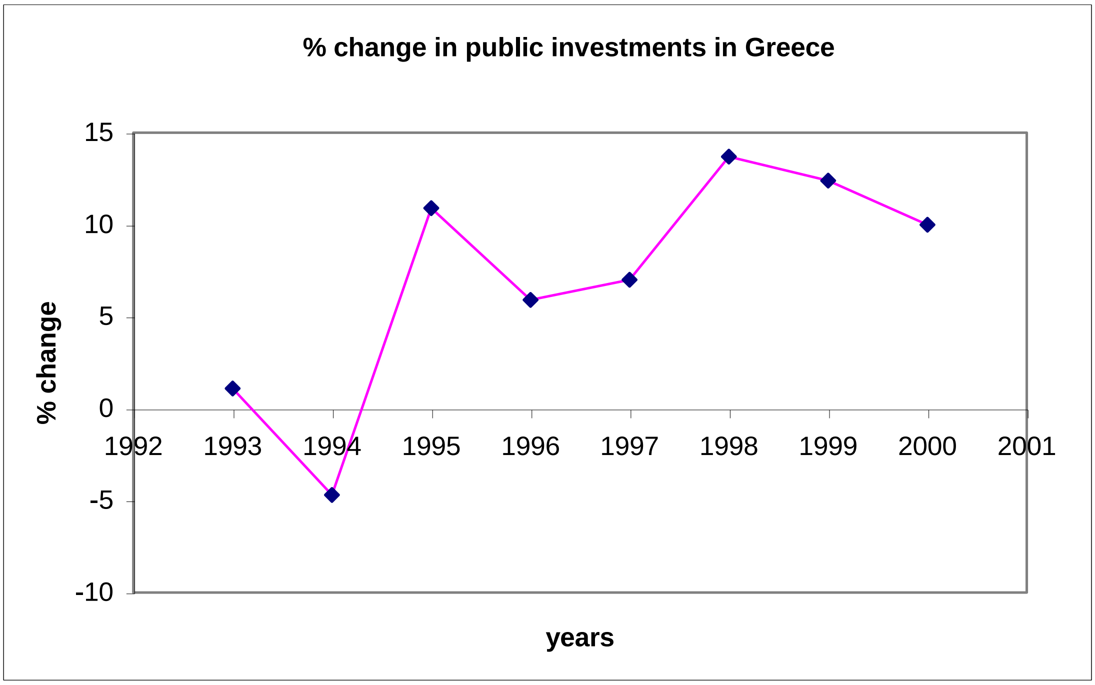


Figure 1.9.6: Public investments in Greece

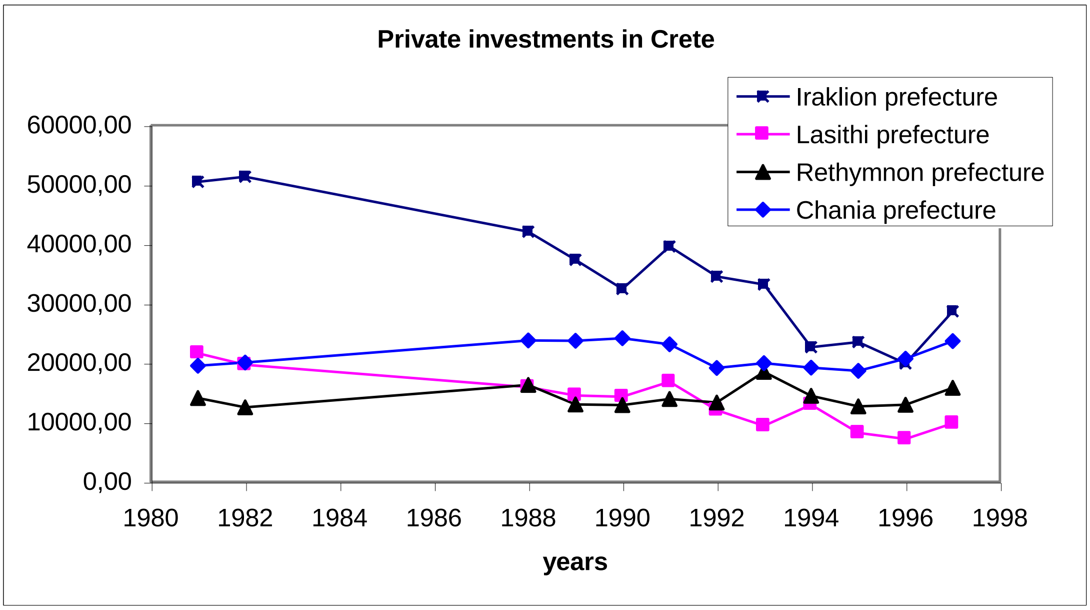


Figure 1.9.7: Private investments in Crete

Tourism is an important economic branch in Crete and in Greece generally. The total number of tourists in Crete in the year 1999 exceeded two million. The total number of tourists in different prefectures and in Crete is depicted in figure 1.9.9. Figure 1.9.10 shows the number of beds in the four prefectures and in Crete for the years 1981 to 1999. There is an obvious increase in the number of beds offered to tourists, which shows a growing interest for tourism.

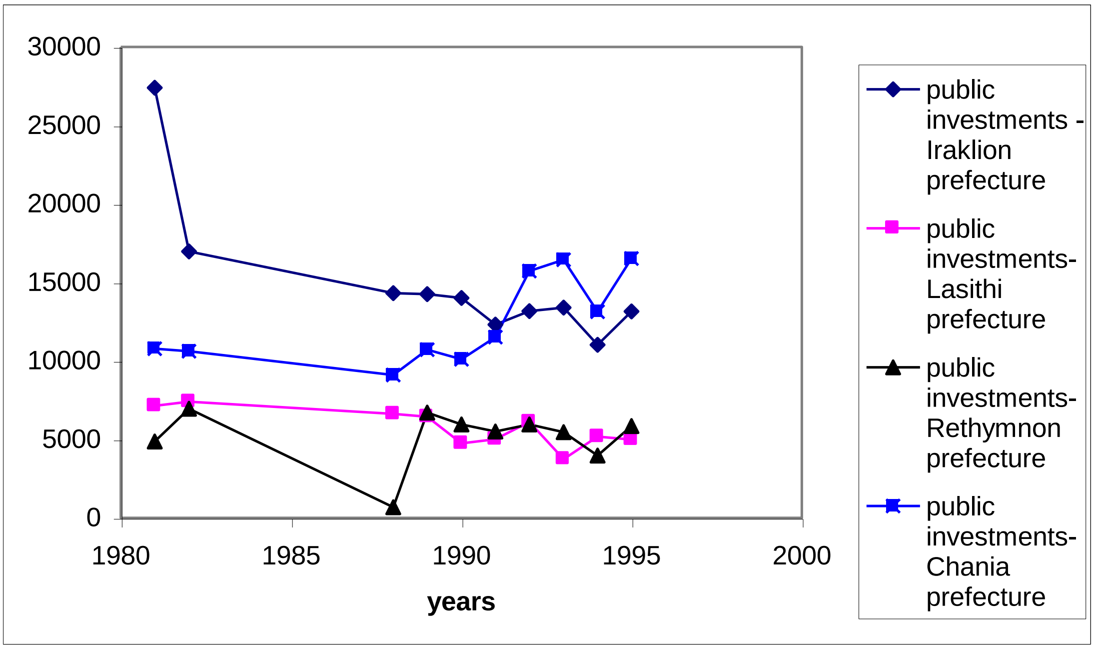


Figure 1.9.8: Public investments in Crete

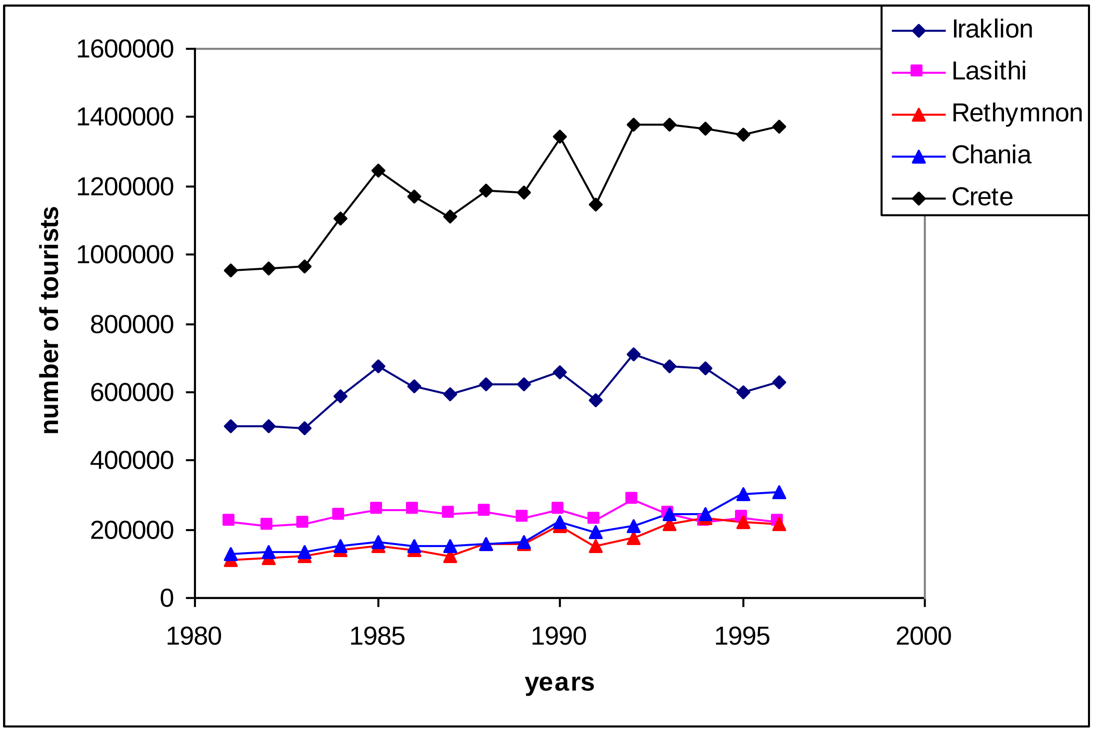


Figure 1.9.9: Number of tourists in Crete

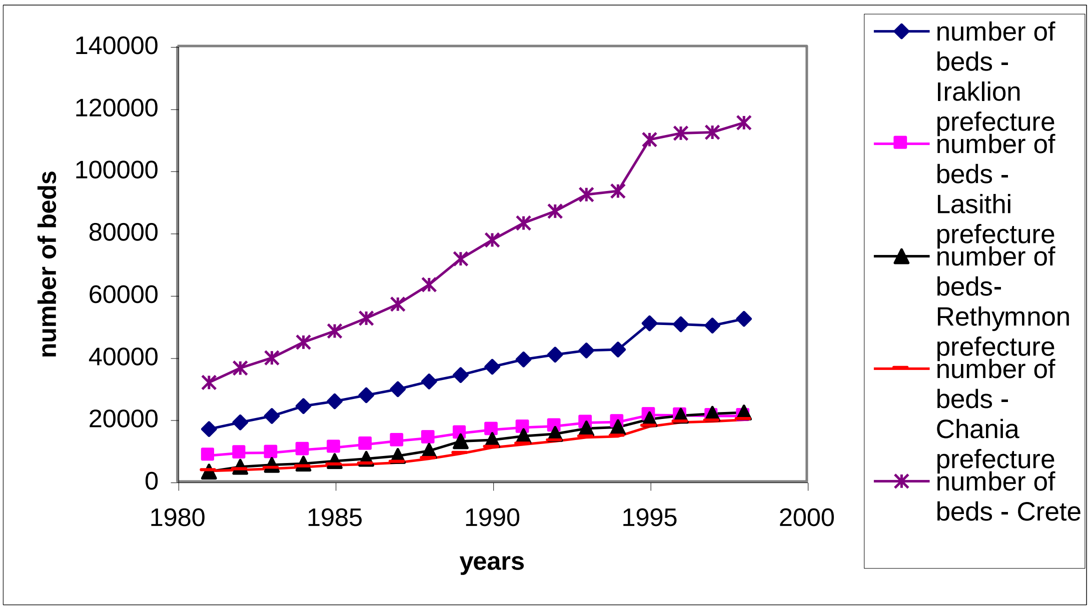


Figure 1.9.10: Number of beds in Crete

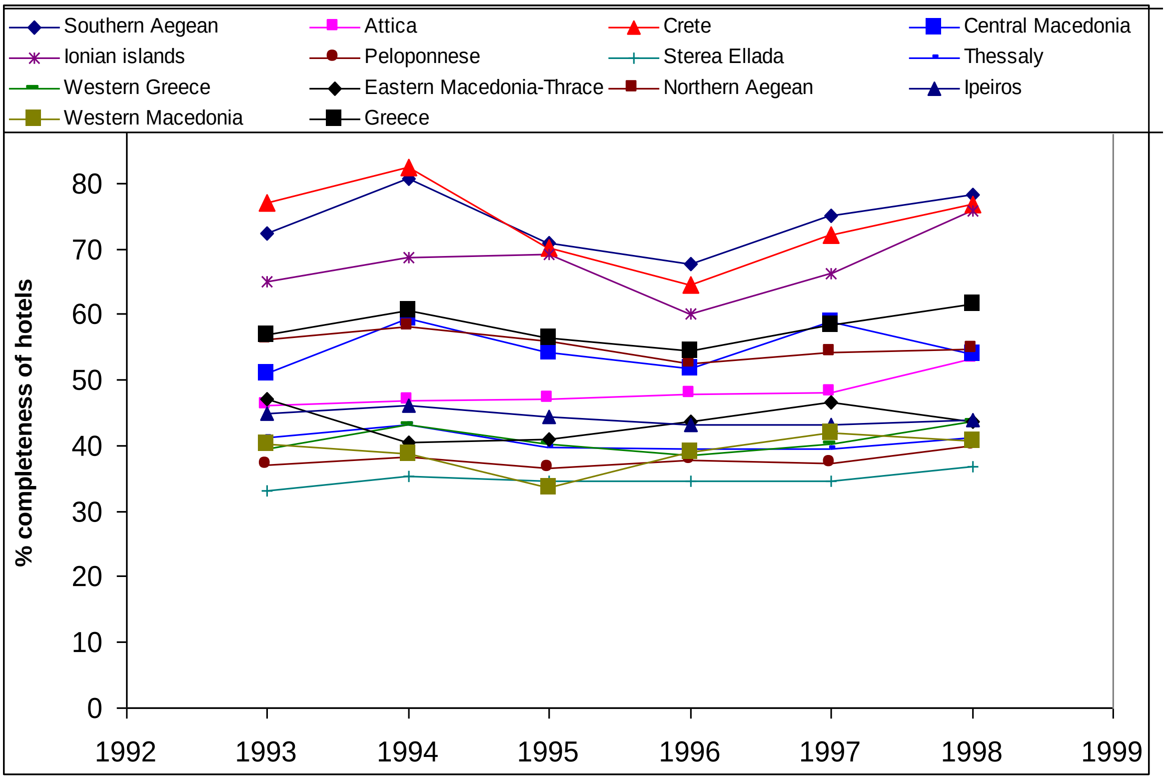


Figure 1.9.11: % of completeness of hotels in Greece

As shown in figure 1.9.11, Crete and Southern Aegean show the highest percentages of completeness of hotels during the period 1993 to 1998.

The percentages of unemployment in Greece for years 1997 to 2000 are shown in figure 1.9.12.

Figure 1.9.12: % Unemployment in Greece

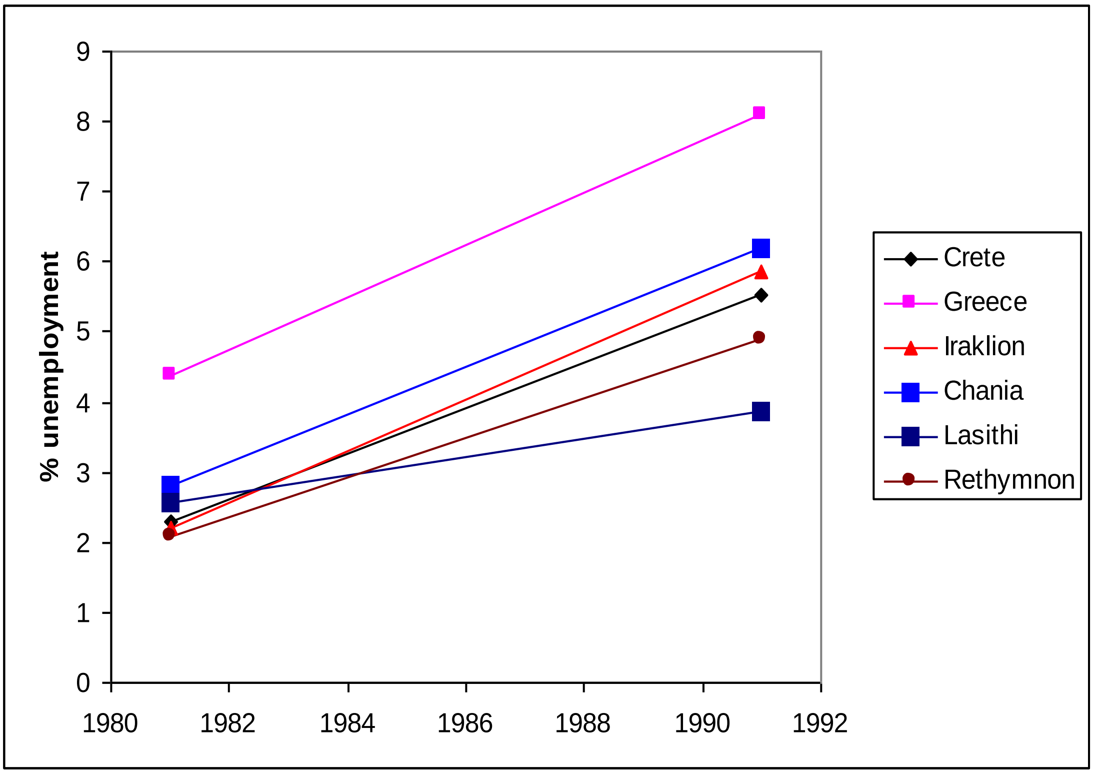


Figure 1.9.13: Unemployment in Crete.

Figure 1.9.13 shows that unemployment in Crete is substantially lower than in Greece.

The last two figures (1.9.14 and 1.9.15) give a picture of the number of students and doctors in the island.

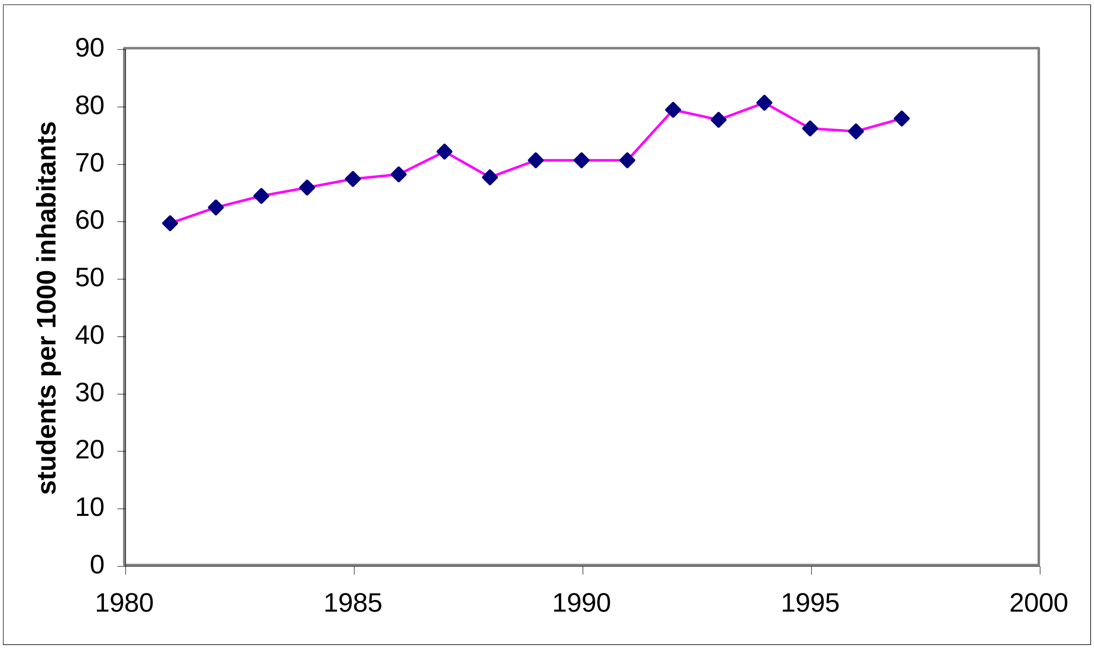


Figure 1.9.14: Average number of students in Crete

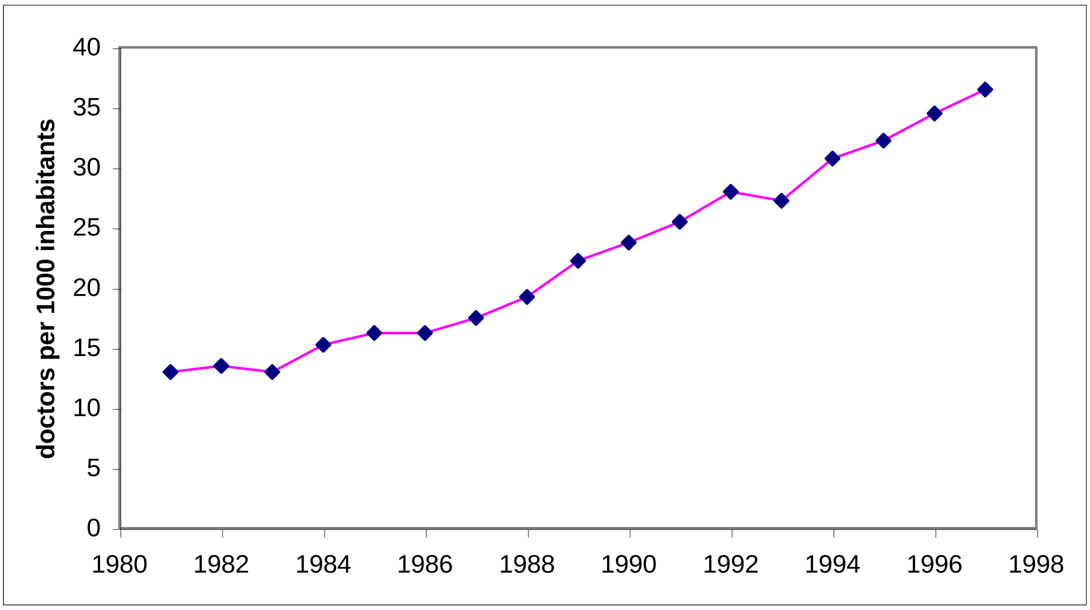


Figure 1.9.15: Average number of doctors in Crete

1.10 Conclusions

Crete is considered a semi-arid region. Although precipitation is high, only 20% of rainfall goes to recharging the aquifers and 70% is lost to evapotranspiration. This situation may worsen in the future due to climatic change. The major water use in the island is irrigation for agriculture (83%). Another sector related to water use is tourism (domestic and international), an important economic activity in Crete, which is still growing. The total number of tourists in Crete in 1999 exceeded two million, and this number may double in 2025. The tourism industry requires huge quantities of water supply, with peak consumption during the high season and excess capacity in the low season. Water availability in Crete in general is not the limiting factor. The real water used, 87% of which comes from subterranean sources is 384 Mm^3 per year while the potential water resources are 2,650 Mm^3 per year. Much more important are the significant regional and seasonal variations which Crete shows in water availability and demand. Seasonal variations in water availability are created by the seasonal pattern that rainfall exhibits in Crete. About 60-70% of annual rainfall occurs in three to four months, while summers are usually long and dry. In addition, rainfall is not uniformly distributed throughout the island. Precipitation decreases from west to east. This situation is further worsened by a seasonal and regional variation in water demand. Both, agriculture and tourism require increased supplies in late spring, summer and early autumn, when water is less abundant. Also, domestic use of water increases during dry and hot periods. Demand for water for irrigation and tourism is higher in eastern than in western Crete. This results in a situation where western Crete shows high water availability and low demand and eastern Crete low water availability and high demand.

Spatial and temporal variations of rainfall events combined with seasonal and spatial variation in water demand constituting water resources management as a key issue on the island. The lack of the local people's understanding of the objectives of a water resources management plan and the farmers' belief that the higher the irrigated water volume is, the higher is the resulted farming production respectively, created significant frictions on the local scale. The misconception of water resources ownership status from people on local scale is the main reason for such frictions. This leads to water resources overexploitation, reduction of the water resources potential and failure of existing infrastructure and results in deteriorated water quality. Contaminative human activities intensify the pressure for a sound water resources management.

Given the severe limitations of exploiting new water resources, the only solution in meeting water requirements is to use water more efficiently. Although several important advances have been made over the last several years, significant challenges still remain in the areas of technological, managerial, policy innovation and adaptation, human resources management, information transfer and social environmental considerations. The issues mentioned concern the Island of Crete, but applicable to most Mediterranean countries.
They are:

(a) Water conservation and efficient use. Since agriculture is by far the largest water user, efficient irrigation management will undoubtedly be a major conservation option for the future. It can be achieved through irrigation requirements and irrigation scheduling techniques, the use of localized irrigation systems, salinity management techniques, and a reduction of losses from water conveyance systems.

(b) Water sectorial use. Any amelioration of conflict and competition among water users will have positive effects on improving efficiency and productivity. Greater efforts are urgently needed to integrate irrigation planning and management with other sectors of economy that impinge on water use.

(c) Water pricing and cost recovery. The most important recommendation we can make is the adoption of full-cost pricing of water use and services. It will be the basis for promoting conservation, reducing losses and mobilizing resources. Furthermore, pricing could affect cropping patterns, income distribution, efficiency of water management, and generation of additional revenue, which could be used to operate and maintain water projects.

(d) Wastewater reuse. Water resources shortage and environmental concerns have already led to wastewater reuse for irrigation. Since wastewater reuse has multidisciplinary interlinkage with different sectors such as environment, health, agriculture, water resources, etc., it is necessary that the administrative responsibility for reuse activities is taken and reuse regulations are being well defined.

(e) Water quality management and use of saline water. The issue is becoming increasingly as important as water quantity, and is a far more complex task than quantity monitoring. Research has provided much knowledge on the specific interactions of saline waters on soil and plant and various strategies and criteria have been developed for the safe use of such waters for crop production.

(f) Other cost-effective technologies. Besides technologies in current use, such as reclamation and reuse of marginal waters, other cost-effective technologies, such as artificial recharge of groundwater, should be considered.

(g) Technology transfer. The availability of improved technologies or techniques is however no guarantee for their application. Farmers will play a key role in adopting more efficient and sustainable water management practices. Factors that provide the favorable conditions under which farmers may accept and adopt better and more efficient water use practices are: Clear benefits from efficient water use, investment support, adequate legislation, simple, practical and cost-effective technologies, guidance and advice in introducing new, more efficient technologies.

(h) Education and training. Extensive educational programs should be instituted at all levels of society to promote prudent use and conservation of water as one of the indispensable natural resources. The institutional framework for supporting services and the training of the staff involved in irrigation development will be the key to the introduction of new technologies in irrigation.

(i) Development of an integrated water resources plan. It is of high importance to apply a policy for water resources management, which will cover the present requirements but which will also ensure future needs (Chartzoulakis et al., 2001).

CHAPTER II

Selection of representative catchments

Four representative catchments are selected in Crete, one in each prefecture. The location of these catchments is shown in figure 2.1. West Messara Valley catchment is located in the southern part of Iraklion prefecture and represents the most important agricultural region in the island. Kissamos catchment lies in the northwestern part of Crete and constitutes another very important agricultural region on the island. Platys catchment lies next to Messara Valley in Rethymnon prefecture and is mostly cultivated with olives. Patelis catchment in the northeastern part of Crete is mostly cultivated with vines. It is an important catchment because 90% of the area is cultivated and irrigation creates peak demands in the summer in an area where precipitation is low and water demand is high, especially during the summer.

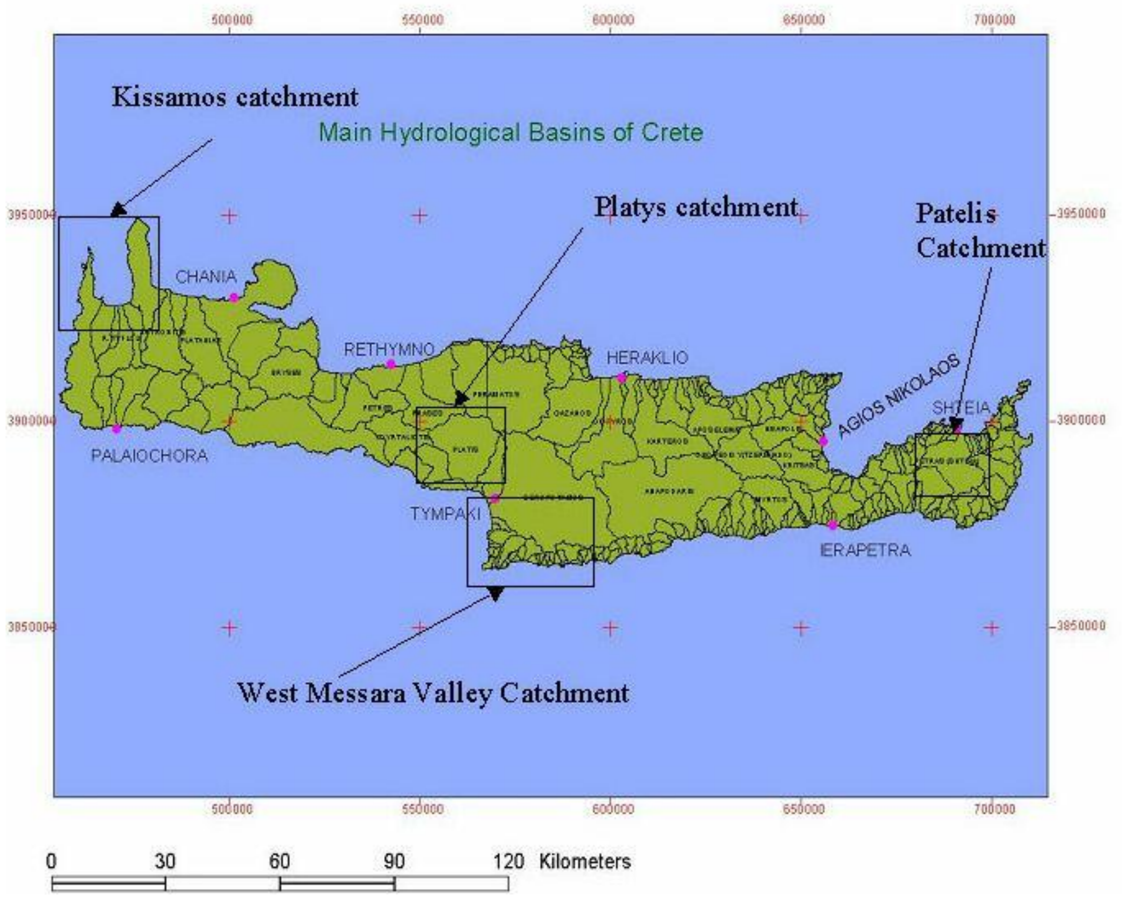


Figure 2.1: Main hydrological basins of Crete

2.1 West Messara Valley Catchment

Messara valley catchment covers an area of 398 km^2 and is located in the central-southern part of Crete, about 50 km south of the city of Heraklion (figure 2.1.1). The valley constitutes the most important agricultural region of Crete. It is also the site of the Minoan palace of Phaistos and the Roman city of Gortys. About 250 km^2 of the total

Valley area of 398 km^2 are cultivated. The main land use activities are olive-growing and grape vine cultivation. The remainder of the land is used for vegetable, fruit and cereal growing. The Messara valley has remained rural with a small population of about 40,000 inhabitants. The main source of irrigation water is groundwater as there is little surface water flow outside the winter months.

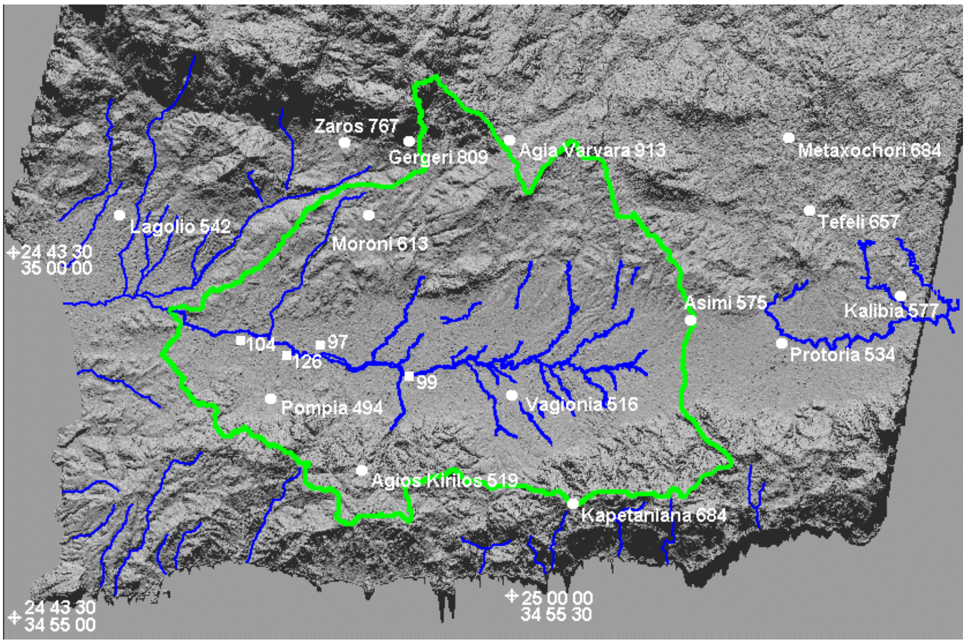


Figure 2.1.1: The Messara Valley of Crete

Shown are the sites of rainfall gauge stations, with means annual precipitation following the name of each site. The Valley's river outlet is at the Phaistos constriction in the west, beyond which is the small coastal Timbaki plain. Boreholes 97, 99,104 and 126 are shown near the Geropotamos River (Source: Vardavas et al., 1996, by permission Department of Geography, University of Cambridge).

Groundwater is the key resource controlling the economic development of the region; it is also a component of the environment under siege as water demand has increased dramatically within the last ten years. The groundwater level is thus an important index for assessing both anthropogenic and climatic causes of desertification in the Valley.

Following the detailed agricultural development study conducted by the UN Food and Agriculture Organisation in 1972 (FAO, 1972) on the exploitation of the Valley's water resources, an extensive network of pumping stations has been installed since 1984, which has converted what used to be dry cultivation of olive trees to drip-irrigated cultivation. The consequences are a rise in productivity and a dramatic drop of 20 m in the groundwater level.

Relief and Geology

The West Messara Valley catchment covers an area of 398 km^2 comprising an east-west plain of 112 km^2 about 25 km long and about 3 km wide with steeply rising mountains on the north and the south side. To the north, the divide varies from 1700 m to 600 m from west to east, with the highest point being part of the Idi mountain range (peak at 2540 m), which is a limestone massif. To the south there is the Asterousia mountain chain, which rises from 600 m in the west to 1200 m in the east and constitutes the most southern mountain range of Europe. At the Phaistos constriction in the west, the catchment outlet of the Geropotamos River is at 30 m above sea level (ASL).

The catchment area of the northern slopes covers 160 km^2 while the southern slopes constitute a catchment area of 126 km^2.

Mainly quaternary alluvial clays, silts, sands and gravels with thickness from a few meters to 100 m or more, cover the plain. The inhomogeneities of the plain deposits give rise to great variations in the hydrogeological conditions even over small distances. The northern slopes are mainly silty-marly Neogene formations while the southern slopes are mainly schists and limestone Mesozoic formations. The outlet of the catchment is narrow, confined to a channel cut into an impermeable barrier of lower Tertiary near Phaistos. The geology of the catchment is shown in figure 2.1.2.

The study area encompasses the Mires basin and the up thrown Vayionia block. The major groundwater basins and surface water catchments are depicted in figure 2.1.3. The Mires basin is a down faulted trough roughly 14 km long and an average of 3 km wide. The trough is filled with alluvial sediments of Quaternary to Recent age, which form an extremely variable and complex inter-bedded sequence of gravels, gravely sands, sands, silts, silty sands and clays. This gives rise to a multi-aquifer system in which permeable sand and gravel horizons are locally separated both laterally and vertically by less permeable clays and silts. An area of particularly coarse gravel is present in the trough at the point where the Litheos River discharges into the valley. Material derided from adjacent sandstone (Flysch) has been deposited as a fan, 3 km long and 1.5 km wide. These gravels are productive aquifers. Other smaller fan deposits occur in several bay-like depressions at the foot of the Asterousia Mountains to the south, but these are not as extensive or important as the Litheos fan.

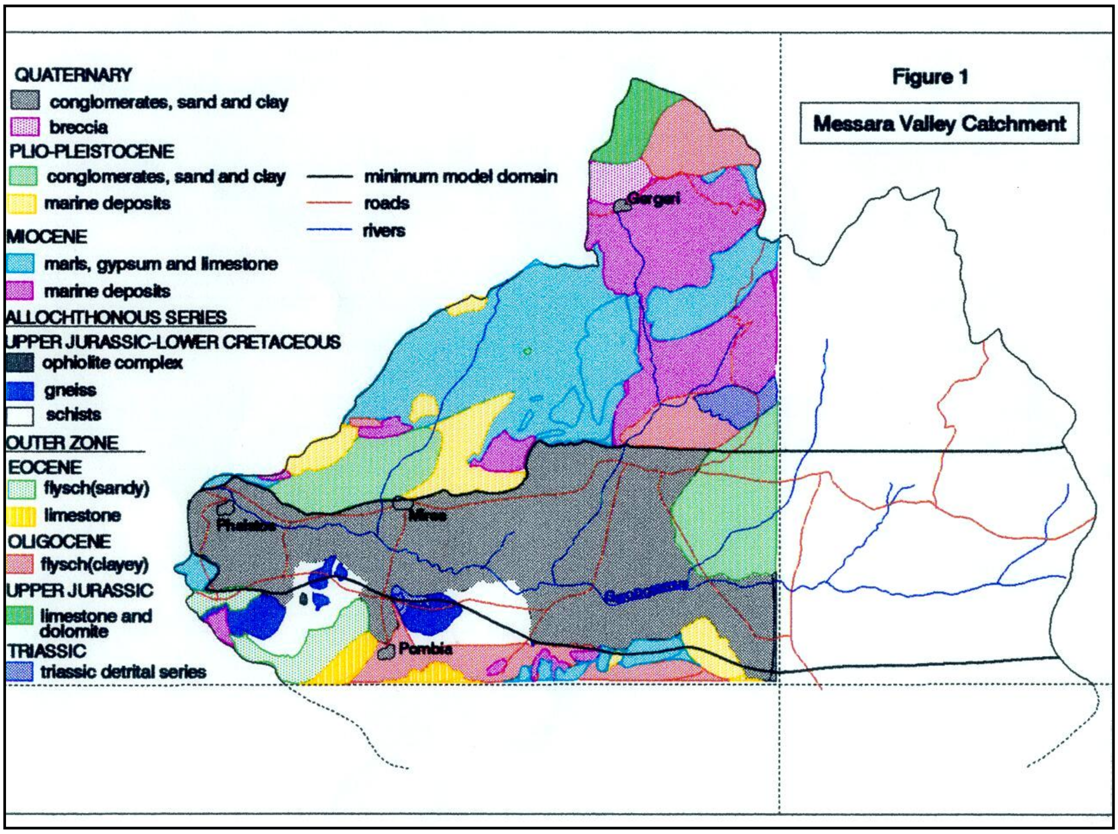


Figure 2.1.2: Geological map of Messara Valley

Geophysical surveys have revealed the flanks of the Mires basin to be steep-sided, which may reflect the presence of E-W trending step faults, or the bank of an erosional channel cut into the underlying lower Pleistocene sediments. Whatever is the true nature of the trough boundaries, extensive faulting parallel to and across the valley is present and has resulted in a variable thickness of alluvium throughout the basin. The elevation of the base of the alluvium-lower Pleistocene aquifer ranges from –50 to +100 m A.O.D., the lowest points of the elongated trough being to the NE of Petrokefali and N of Koustouliana. This surface is based on the elevation of the lowest permeable unit identified from borehole logs. The saturated thickness ranges from less than 20 m to over 100 m in the lowest part of the trough. The aquifer unit as a whole comprises an alternating sequence of clays, silts, sands and gravels; the thickness will inevitably include a substantial proportion of impermeable material (An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996).

The Vayionia block is an up-faulted block of lower Pleistocene-upper Pliocene age, which extends eastward from the longitude of Agioi Deka to the surface water divide near Asimi. The block is 12 km long and 5 km wide. In this region the ground surface is much more undulating than the Mires basin, and the gradient of the Valley floor increases from 1:150 to 1:75. The lithology is complex and comprises a variable sequence of fluvial and lacustrine conglomerates, sandstones, siltstones and silty clays with a thin mantle of alluvial sediments covering the southern half of the region. Drilling and pumping tests showed the region to be poorly productive. The lithology is dominantly clayey or marly with sandstone and conglomerate horizons being thin and few in numbers. Moreover, surface cementation is widespread and infiltration is severely inhibited. Nevertheless, under natural conditions there is sufficient water in storage to supply a number of perennial springs, which provide some base flow to the Geropotamos River in the dry season. The base of aquifers in the Vayionia block is difficult to determine, partly because borehole records are scant and partly because in some cases it is difficult to recognise any aquifer at all. Saturated aquifer thickness ranges from less than 20 m to over 70 m (An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996). A simplified geology of the west Messara catchment is shown in figure 2.1.4.

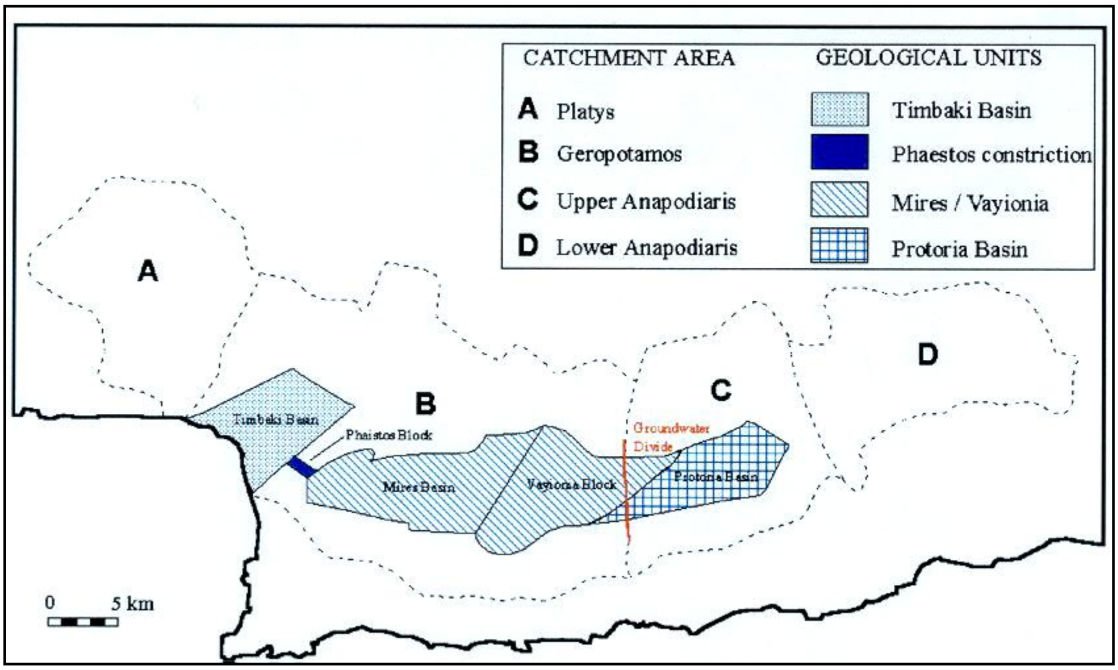
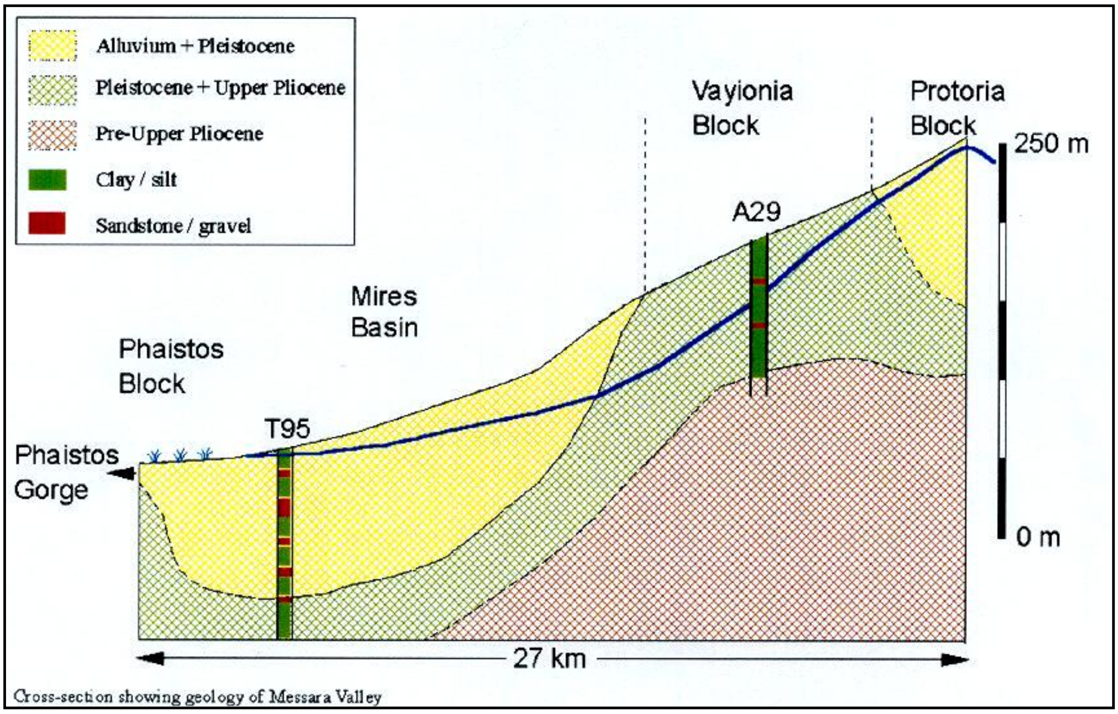
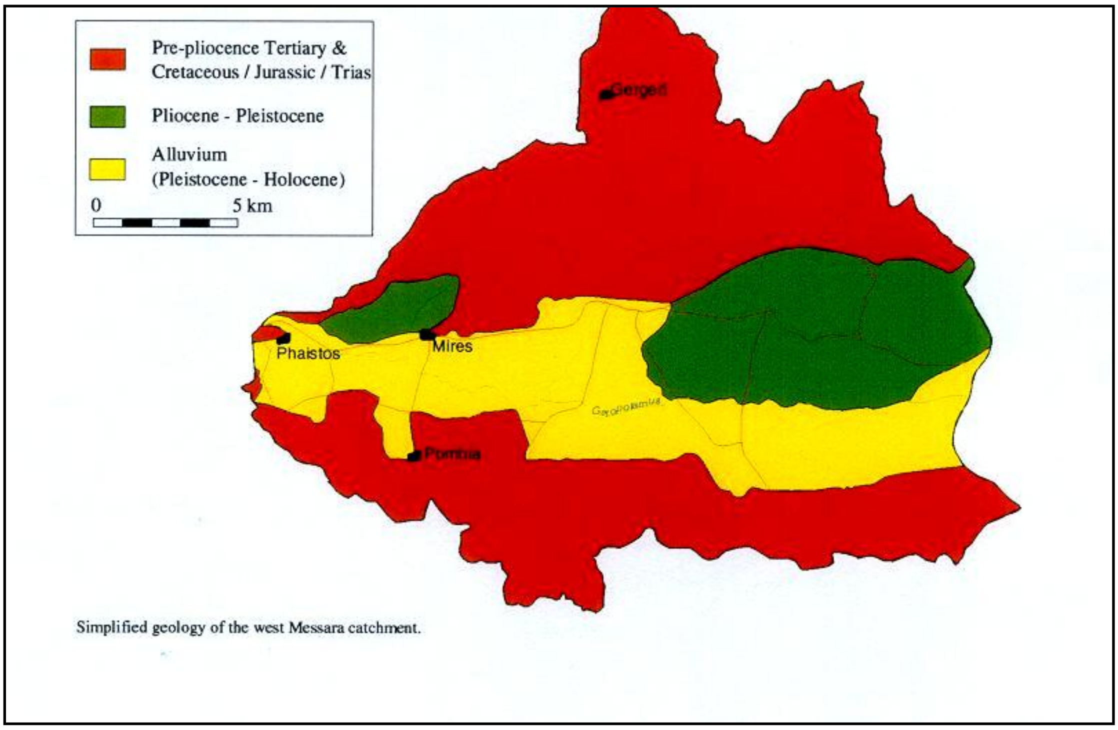


Figure 2.1.3: The major groundwater basins and surface water catchments (Source: An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996)



Cross-section showing geology of Messara Valley

Figure 2.1.4(a): Simplified geology of the West Messara catchment
(Source: An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996).



Simplified geology of the west Messara catchment.

Figure 2.1.4(b): Simplified geology of the West Messara catchment
(Source: An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996).

Climate and Hydrology

The climate of the Valley is sub-humid with mild, moist winters and dry, almost cloud-free, hot summers. The hydrological year may be divided into a wet and dry season.

About 40% of precipitation occurs in the months of December and January while from June to August there is negligible rainfall. Although the valley receives on average of 600 mm of rainfall per year it is estimated that about 65% is lost to evapotranspiration, 10% as runoff to the sea and only 25% goes to recharging the groundwater store. Pan evaporation is estimated at 1500±300 mm per year while the winds are mainly westerly. The potential evaporation is estimated at 1300 mm per year (Vardavas, 1994) and so the ratio of mean annual rainfall to potential evaporation for the valley is about 0.5 and it is hence classified as dry sub-humid according to UNCED (1994) definitions. The average winter temperature is 12^{o}C while for summer it is 28^{o}C. Relative humidity in winter is about 70% while in summer it is about 60%.

The Department of Agriculture in Crete has monitored the valley's water resources for around thirty years. There are daily measurements of rainfall from 15 stations. The mean annual rainfall for the different stations in Messara valley is shown in figure 2.1.5

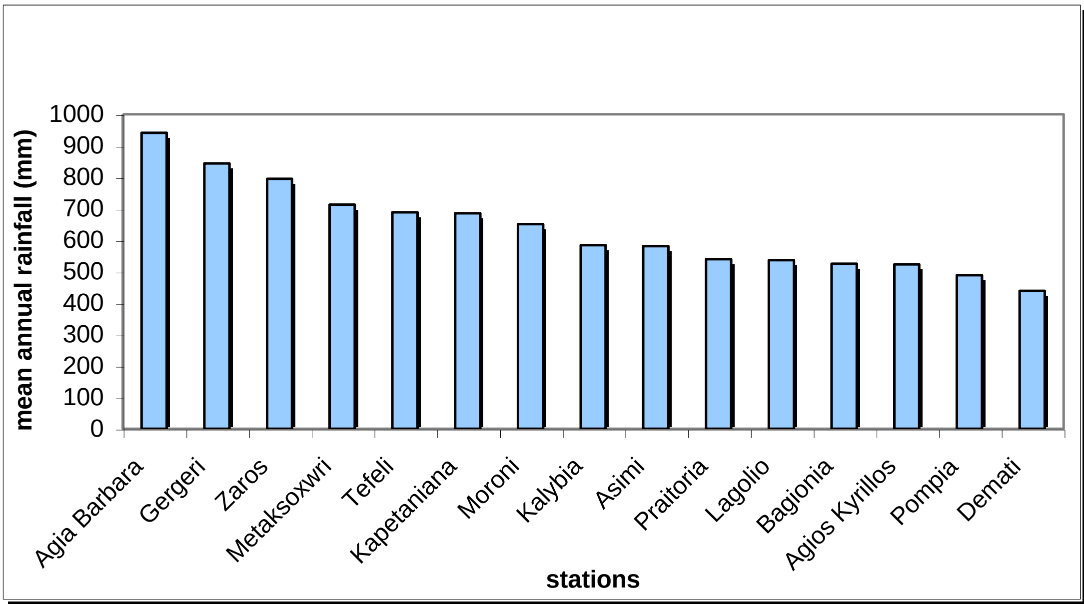


Figure 2.1.5: Rainfall distribution in Messara Valley

Rainfall increases with elevation from about 500 mm on the plain to about 800 mm on the valley slopes and 1100 mm on the Asterousian Mountains. There is a variation in the measured rainfall with increasing elevation. Figure 2.1.6 shows the total rainfall for 1970 for the 15 stations plotted against their elevation. The south side of the catchment clearly has a lesser dependence of rainfall with elevation compared with the north side. For the north and south side, the rainfall shows a linear trend with elevation, with the fits being, respectively:

$P_i = 361 + 0.94z_i$

$P_i = 470 + 0.19z_i$

P_i and z_i = rainfall (mm) and the elevation (m) of a particular location in the catchment

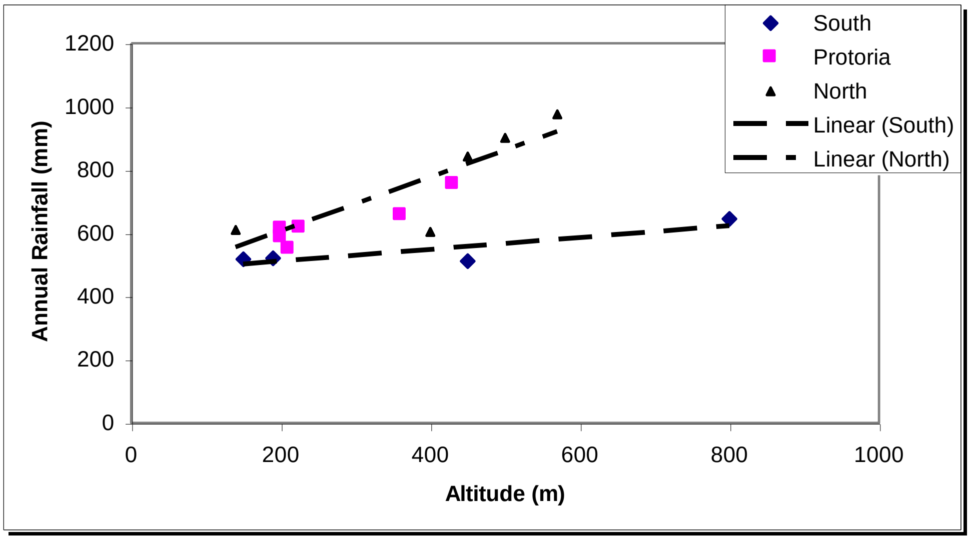


Figure 2.1.6: Rainfall for each of the 15 stations plotted against elevation
Data from three regions are shown: north and south of the catchment, and in the neighboring Protoria basin (which closely matches the distribution for the north of the catchment).

Demati is one of the rainfall stations showing lowest mean annual precipitation of the existing stations in Crete. Figure 2.1.7 shows the mean annual rainfall for Messara for the years 1969 to 1998. As shown in the figure, the driest year was the hydrological year 1989-1990 and the wettest year was the hydrological year 1977-1978.

Figure 2.1.8 depicts the mean monthly rainfall for the catchment. The wet season lasts from November to March or April while the dry season extends form June till October.

There are five stations measuring pan evaporation in Messara Valley. For these stations daily pan evaporation values exist since 1969. The mean annual measured pan evaporation for each of these stations is shown in figure 2.1.9. The mean annual pan evaporation for Messara Valley is depicted in figure 2.1.10. Pan evaporation is estimated at 1500 ± 300 mm per year.

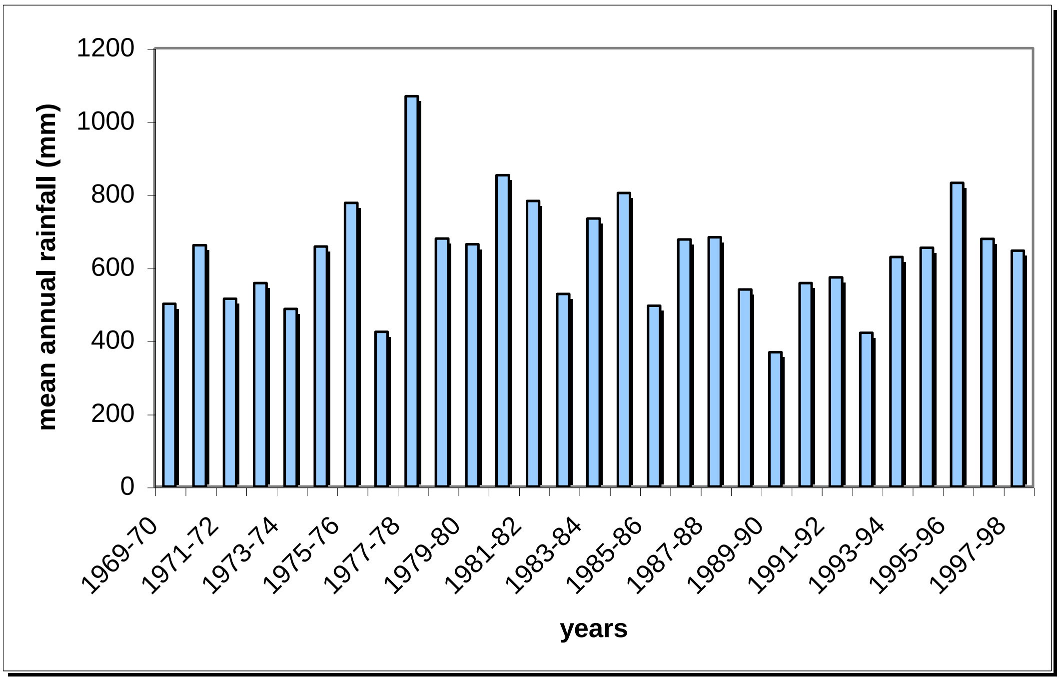


Figure 2.1.7: Mean annual rainfall for Messara Valley

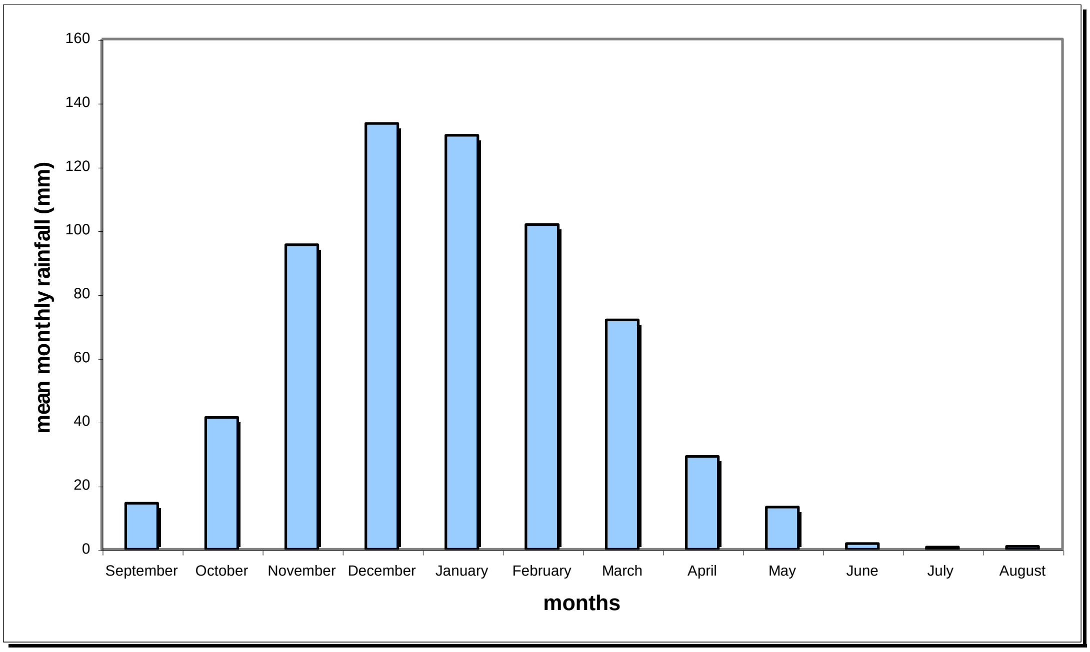


Figure 2.1.8: Mean monthly rainfall for Messara Valley

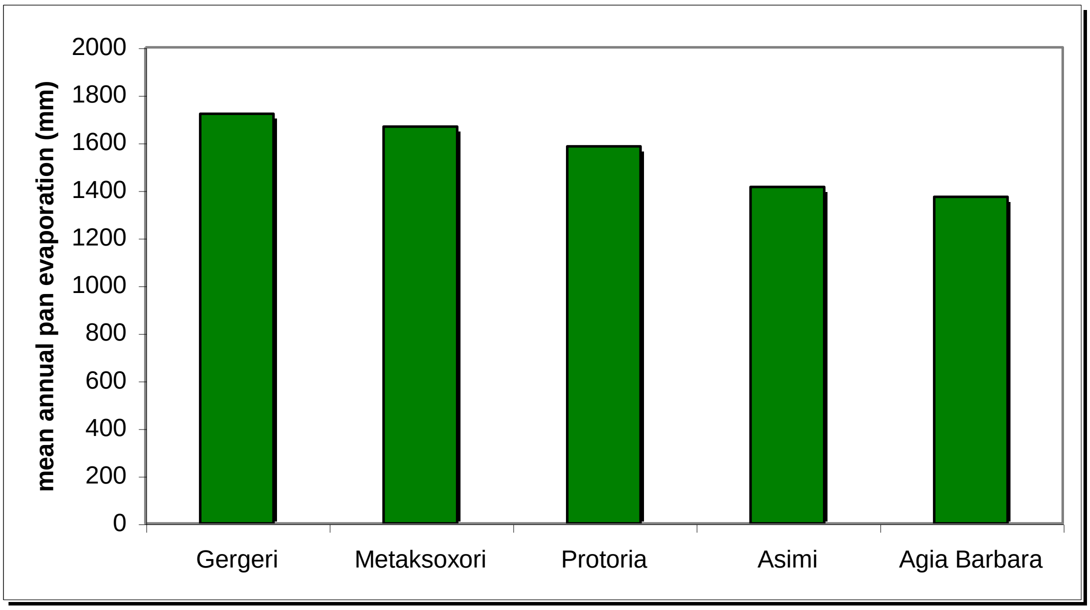


Figure 2.1.9: Pan evaporation for different stations in Messara Valley

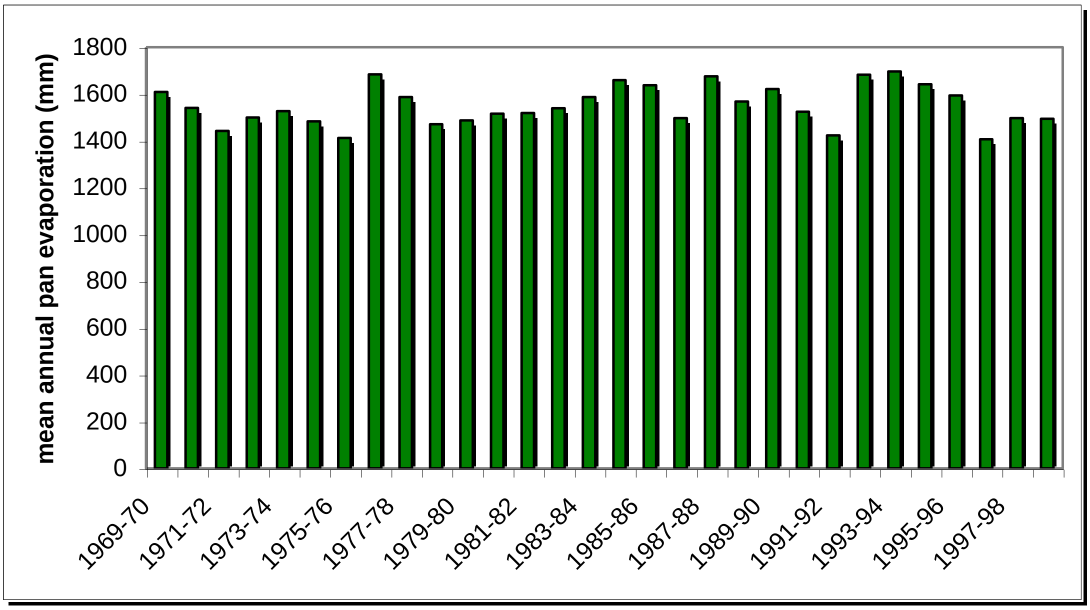


Figure 2.1.10: Pan evaporation for Messara Valley

The highest values of pan evaporation are observed in July while the lowest occur in December and January. Pan evaporation ranges form 38 mm in January to 270 mm in July. Gergeri station shows the greatest range between lowest and highest pan evaporation values within a year, with an average pan evaporation ranging from 304.5 mm in July to 42.3 mm in January. Mean monthly pan evaporation for Messara Valley is shown in figure 2.1.11.

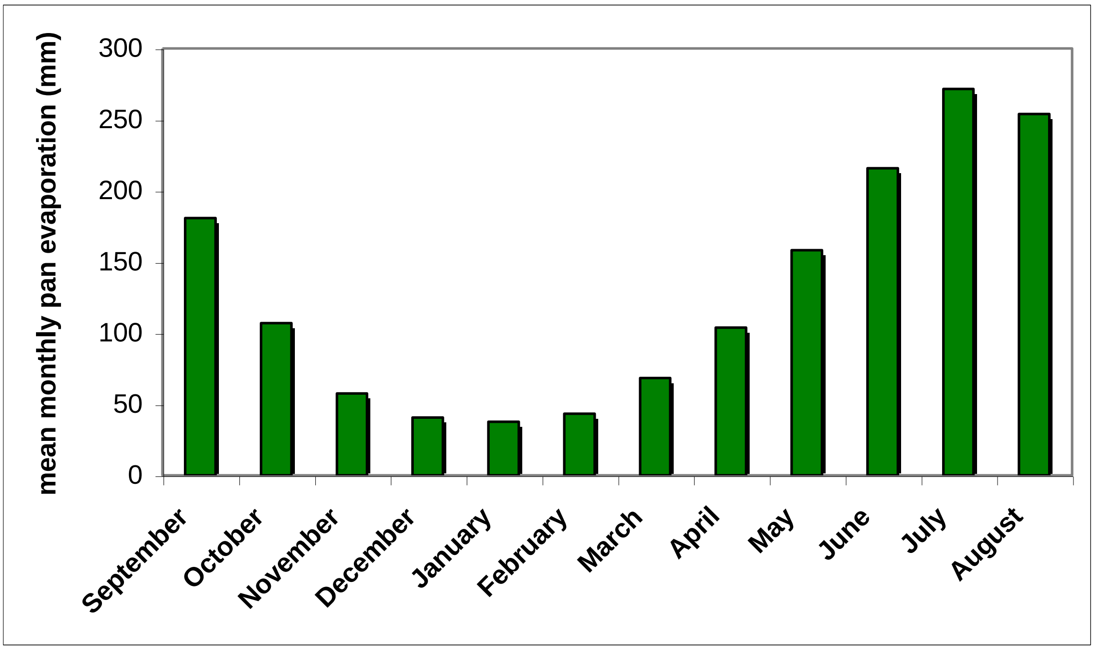


Figure 2.1.11: Mean monthly evaporation for Messara Valley

Potential evaporation is estimated from data of the five pan evaporation stations and using monthly mean lake-to-pan coefficients estimated from the potential evaporation via the Penman equation, which requires meteorological and surface radiation budget data. A comparison between the monthly mean Penman evaporation and the mean pan evaporation data available for the catchment, gives an estimate of the monthly variation of the pan coefficient. Vardavas et al., 1997, have estimated the mean monthly pan coefficients for Messara Valley (figure 2.1.12)

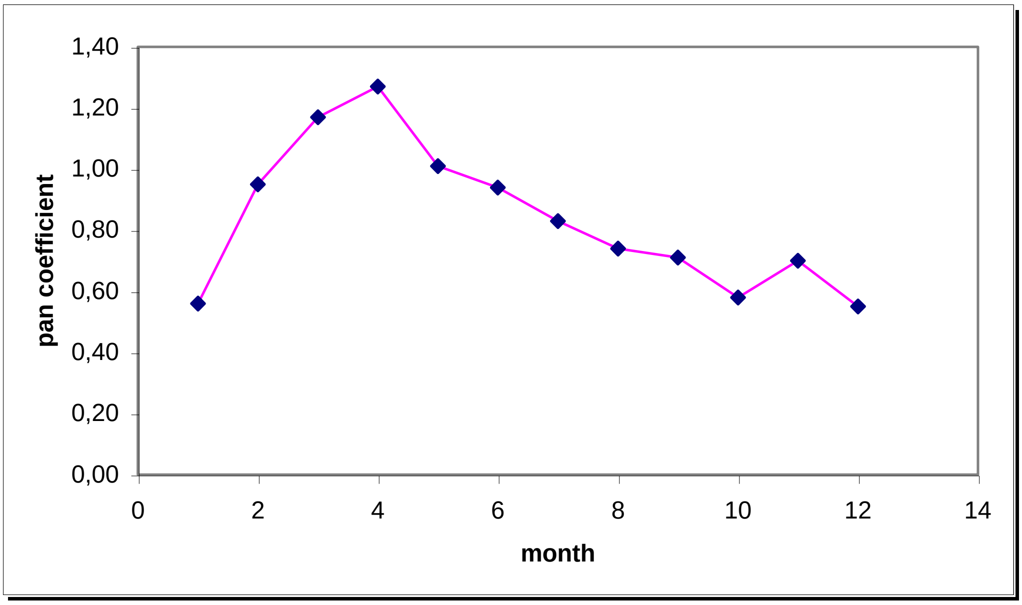


Figure 2.1.12: Monthly mean pan coefficient

The mean annual temperature for Messara Valley is estimated at 17 $\pm 2^oC$. Temperature is measured in three different stations in the valley. The mean annual temperature for the different stations and the valley are shown in figures 2.1.13 and 2.1.14.

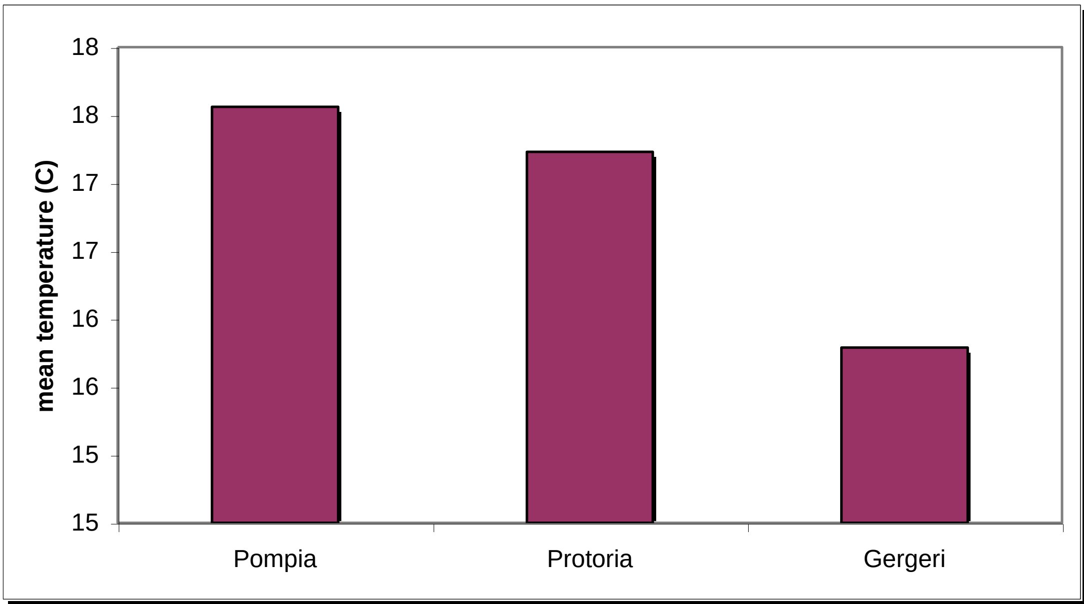


Figure 2.1.13: Mean annual temperature for different stations in Messara

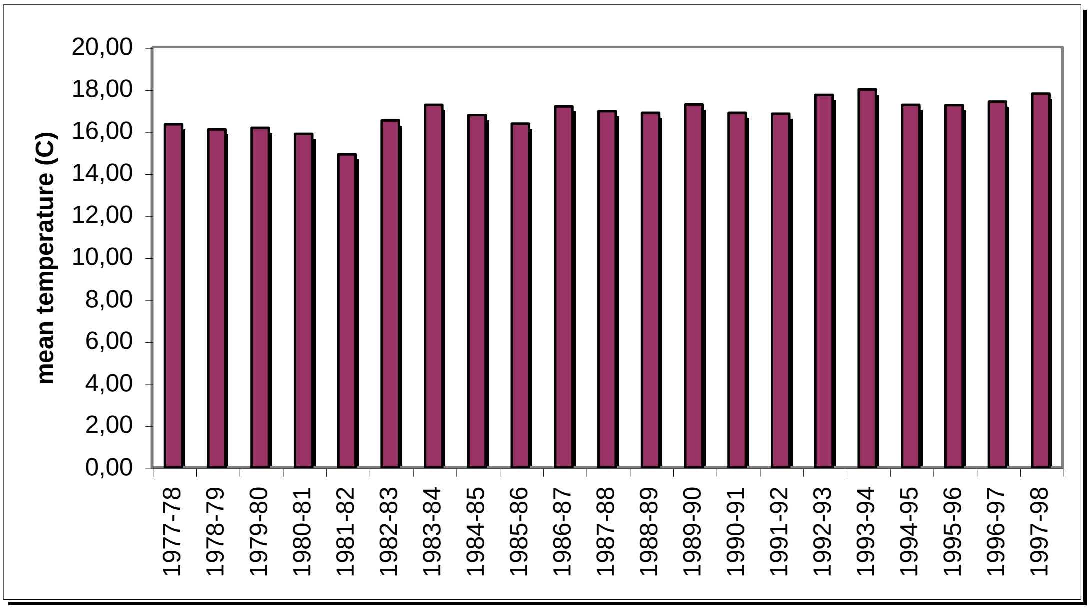


Figure 2.1.14: Mean annual temperature for Messara valley

The lowest mean monthly temperatures are observed in January and February (9.6^{o}C) and the highest in July and August (25-26 ^{o}C). The average winter temperature is 12^{o}C while for summer it is 28^{o}C. The mean monthly temperature for the valley is shown in figure 2.1.15.

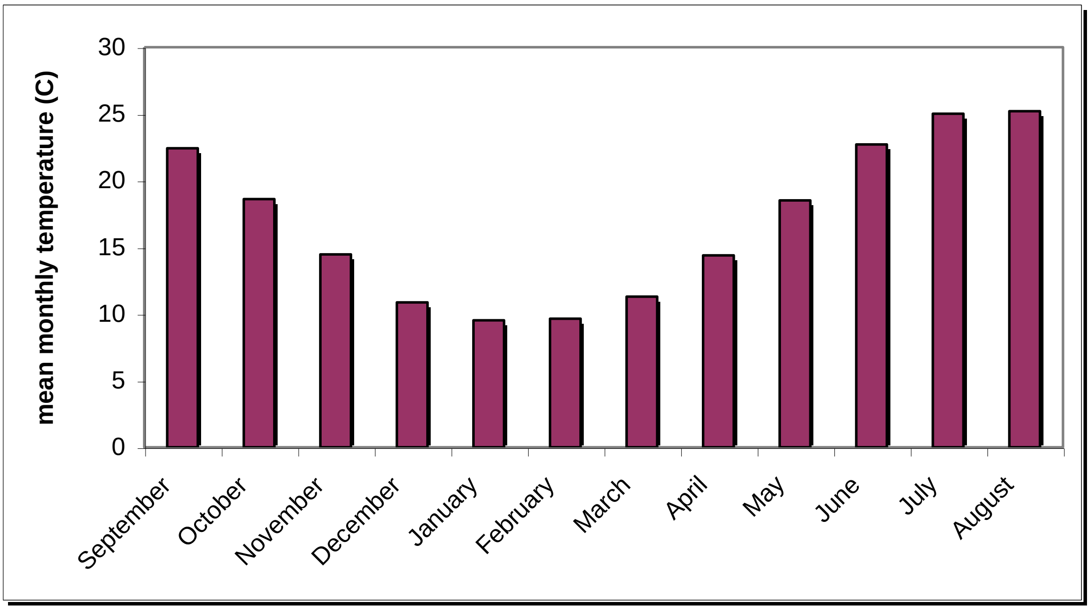


Figure 2.1.15: Mean monthly temperature for Messara valley

Surface water

The main outlet of the catchment is the Geropotamos River at the Phaistos constriction in the west. The catchment outlet of Geropotamos River is at 30 m above sea level (ASL). In addition, the outlet of the catchment is narrow, confined to a channel cut into an impermeable barrier of lower Tertiary near Phaistos. In its natural state, the Geropotamos River of the Messara Valley flowed continuously, and there was a wetland located near the catchment outlet.

The drop in the groundwater level has resulted in the wetland drying up, with no flow in the river in the dry season through the 1990 and even in the wet season of 1992. During the hydrological year 1992-1993 there was no river flow out of the Valley. This was the first time that the main riverbed remained dry according to the records. There are daily measurements of runoff at the Valley's outlet at Phaistos. The mean annual runoff is shown in figure 2.1.16. The mean annual runoff observed is 16.88 Mm^3. The mean monthly runoff for Geropotamos River, compared to other streams in Iraklion prefecture, is depicted in figure 2.1.17. The highest mean monthly runoff is observed in January and February and the lowest in July and August (figure 2.1.18).

The mean annual runoff coefficient for the valley is shown in figure 2.1.19. The mean runoff coefficient for the valley is 0.07 with a standard deviation of 0.05. This value of a runoff coefficient can be observed in catchments where pumping takes place.

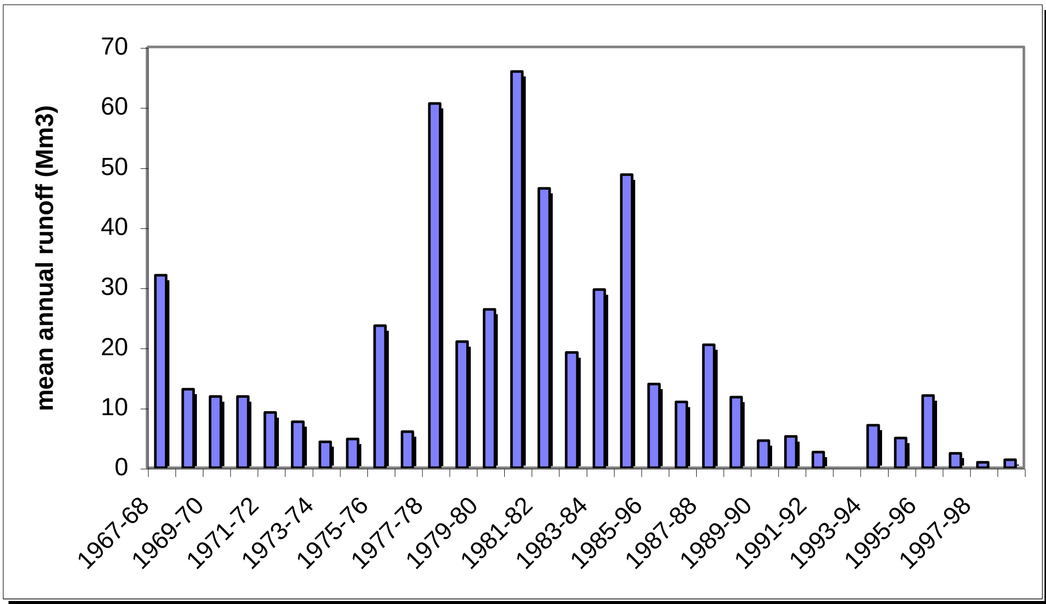


Figure 2.1.16: Mean annual runoff for Geropotamos River

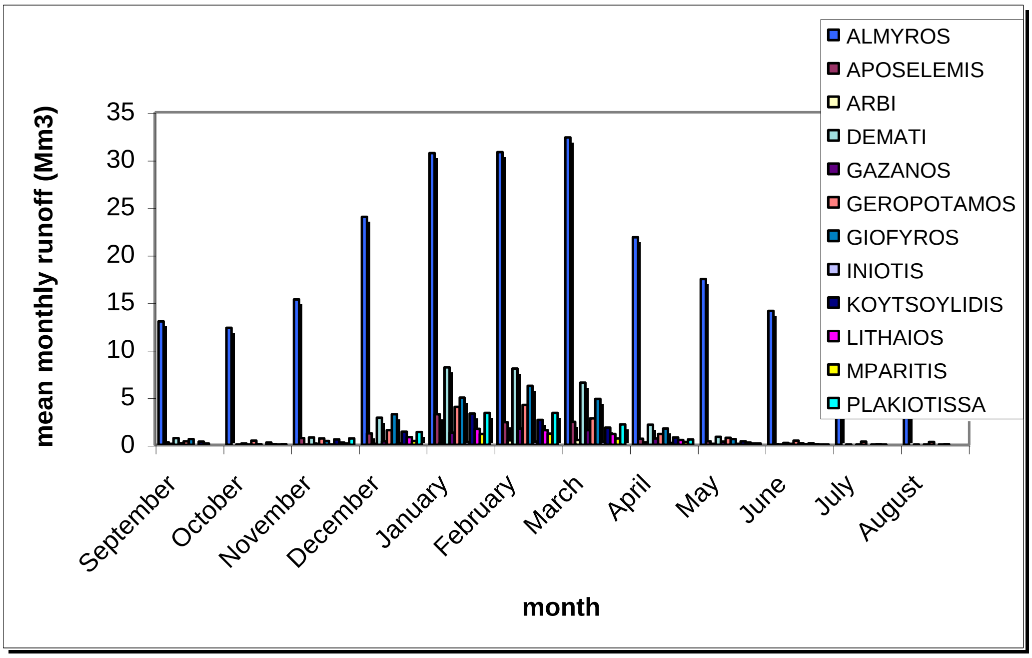


Figure 2.1.17: Geropotamos River compared to other rivers in Iraklion prefecture

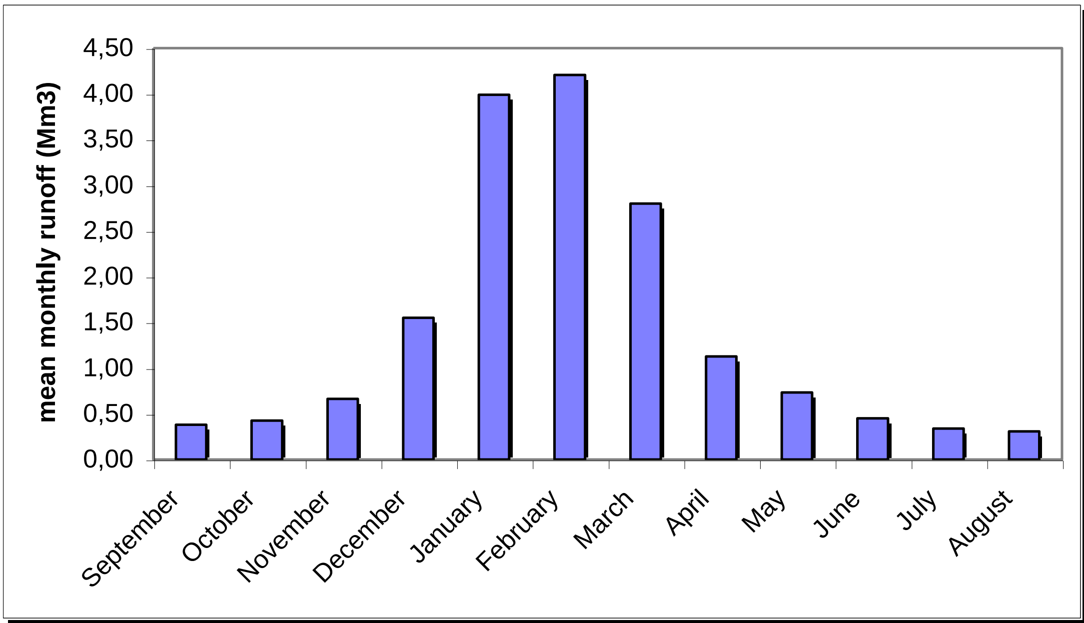


Figure 2.1.18: Mean monthly runoff for Geropotamos River

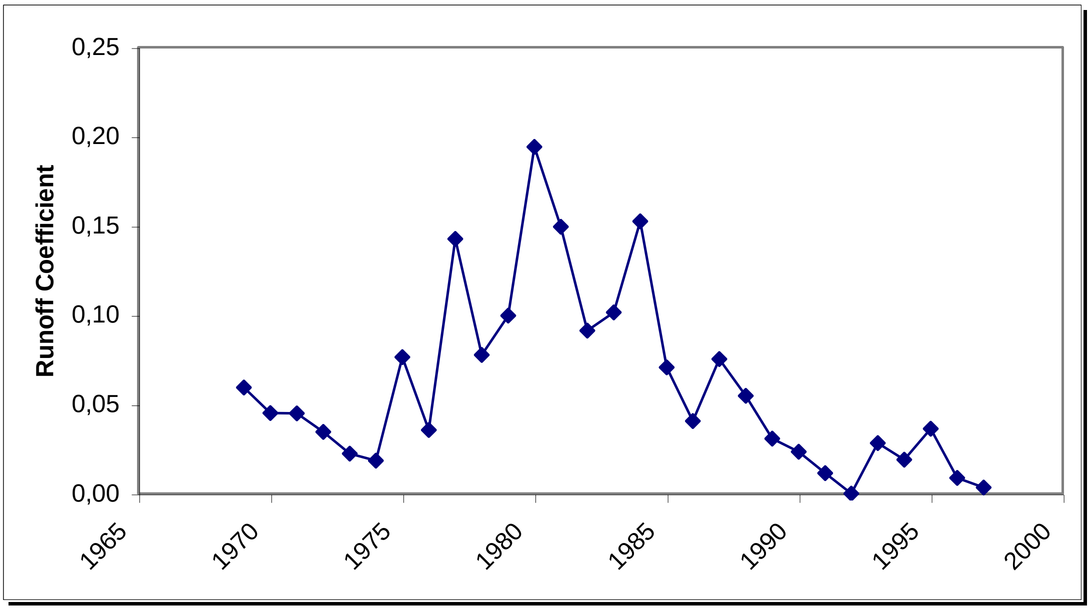


Figure 2.1.19: Annual runoff coefficient for Messara Valley for the period 1969 to 1997

Groundwater

The plain contains several aquifers and aquicludes of complex distribution and properties. There are monthly measures of groundwater levels for over 25 sites. Groundwater levels are maximum in March or April with long recessions until recharge occurs in winter. Figure 2.1.20 shows the groundwater levels within a year for a selected borehole in the Mires basin. The aquifers were high yielding with discharge rates as high as 300 m^3/hr in the early seventies but now are reduced to about one tenth of this. From pumping tests, the specific yield ranges between 0.1 and 0.2 while the horizontal transmissivity ranges between 0.1 and 0.01 m^2/s.

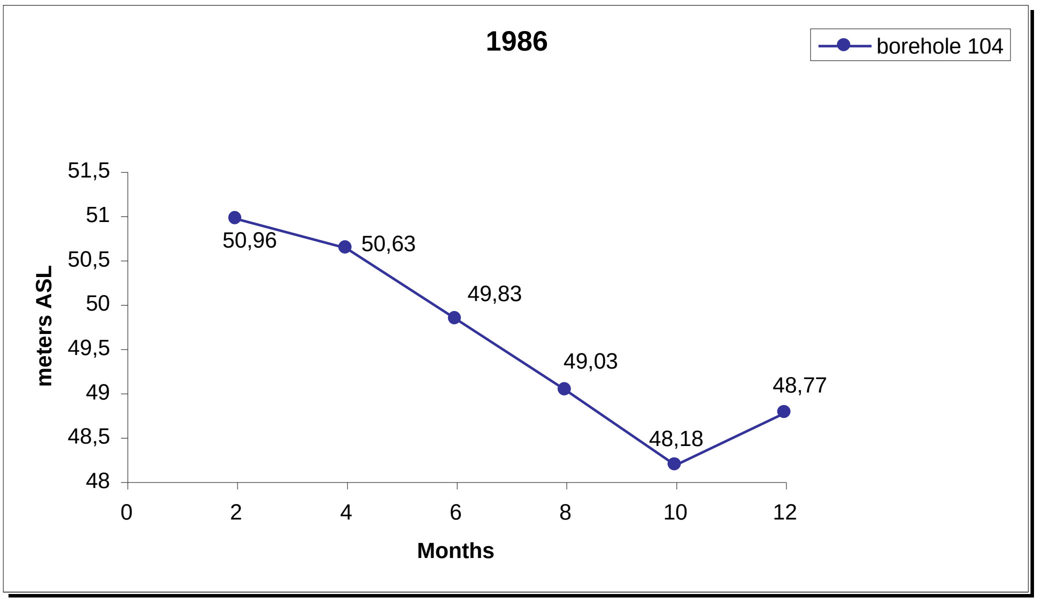


Figure 2.1.20: Annual variation of groundwater levels for borehole 104

Lateral groundwater outflow from the valley is small compared with the vertical groundwater outflow. An extensive network of pumping stations has been installed since 1984, which has converted what used to be dry cultivation of olive trees to drip-irrigated cultivation. It is estimated that around 10 Mm^3 of groundwater were pumped from the aquifer before the installation of the network, while after the installation of the network around 40 Mm^3 are being pumped per year. The consequences are a rise in productivity and a dramatic drop of 20 m in the groundwater level. At present, there is little surface runoff and the groundwater store is being depleted rapidly. Before the installation of the groundwater irrigation system, the average discharge out of the Valley was about 20 Mm^3/a corresponding to 50 mm of the annual rainfall lost as runoff to the sea. It is estimated that the annual recharge of the groundwater store was about 60 Mm^3/a (150 mm) and evapotranspiration loss was about 160 Mm^3/a (400 mm). The interannual variation in the groundwater level for a selected borehole can be seen in figure 2.1.21. The pattern of water level change is the same at each site; a period of declining water levels took place from 1971 to 1977, which is followed by a recovery until 1985 when water levels once again began to decline, a trend, which has persisted until the present day.

Most subsurface geological information is drawn from the logs of 26 exploration boreholes drilled in the area by FAO between 1968 and 1970. (Source: An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996). Most of the higher values of permeability are concentrated in the Mires basin, where permeabilities between 10 and 120 m/d reflect the presence of a large number of gravel and sand horizons in the alluvial sequence.

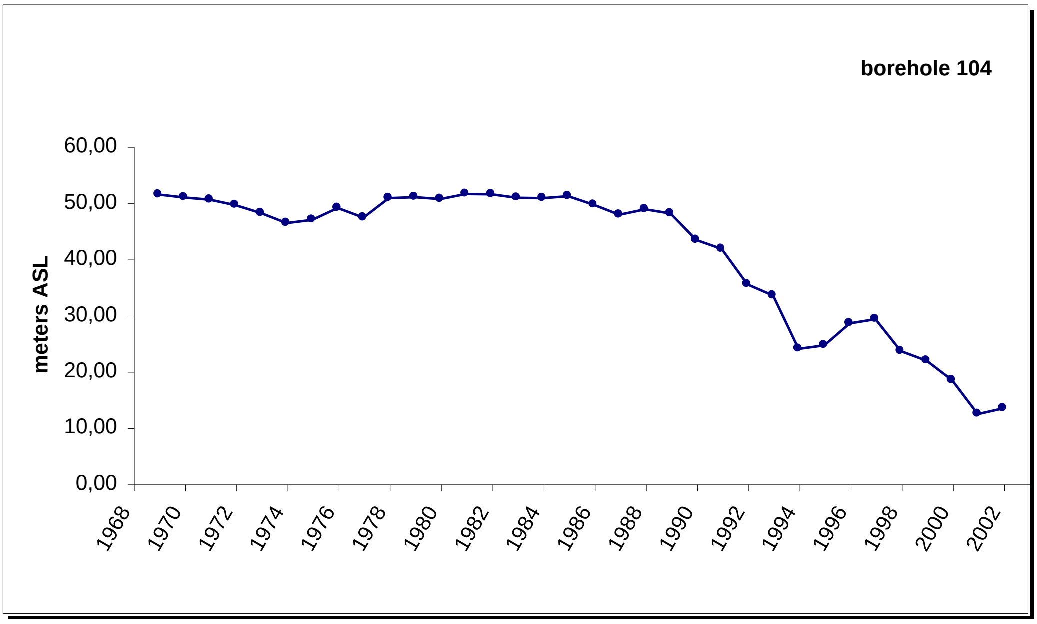


Figure 2.1.21: Interannual variation of groundwater level for borehole 104 for the years 1969 to 2002

The least permeable areas are in the Vayionia block, where the paucity of gravel and sand means that values are reduced to an average of only 1 m/d. Lower values also occur on the northern side of the Mires basin, where lower Pleistocene rocks, similar to those of the Vayionia block, crop out. Two regions of higher permeability occur in the eastern part of the area. The first is at the eastern boundary, where values increase locally to 40 m/d. A second area of high permeability is located in the southern part of the Vayionia block at the foot of the Asterousia Mountains. In this area permeabilities of up to 200 m/d are probably related to the presence of a small fluvial fan carrying a high percentage of coarse gravel (Source: An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996).

Aquifer storage coefficients have also been obtained from FAO pumping tests. Results from these tests and the nature of the water table show that although heterogeneous and locally confined, the aquifer at a regional scale behaves as an unconfined unit.

Agricultural situation

Messara Valley constitutes the most important agricultural region of Crete. About 250 km^2 of the total valley area of 398 km^2 are cultivated. Of the total area cultivated 56% are Tree crops (mostly olives cv Koroneiki), 10% are vines, 11% are row crops and 7% are vegetables (mostly in open fields and some greenhouses) (HNSS, 1999). Olives occupy mostly areas of flat land and show a steady increase in density of cover as one moves east along the Geropotamos River. Density also diminishes as slopes become steeper on the northern edge of the Timbaki and Mires plains. Vines are less widespread with two main concentrations to the south east of Mires and in extreme north east of the catchment. The distribution of arable farming is predominant in the area to the south and east of Mires and on flat ground in the vicinity of Gortyna. Glasshouses and market gardening dominate the Timbaki plain. The forest classes exist only in relatively inaccessible parts of steep gorges, which are not suitable for olives or farming and where water is accessible from river channels. The quite large areas of forest to the south and east of Psiloritis are protected by legislation. Vegetation on the upper slopes of Psiloritis is extremely sparse in a very rocky landscape (Source: An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996).

Drip irrigation is used for olive orchards and tree crops, micro-sprinklers for potatoes and drip irrigation for the rest of the vegetables. The amount of the water applied is empirically defined. Empirically, various forms of N-fertilizers are applied during the winter, after harvest. Weed control is performed with tillage (80%), while herbicides are used rarely.

Cultivated crops and cultivated land

Of the total crops cultivated more than 50% are olives (cv Koroneiki), 10% is vines, 2% are citrus and 7% are vegetables (mostly open field and some greenhouses) (Fig. 1.2.7.4). Olives occupy most areas of flat land and exhibit a steady increase in density of cover as one moves east along the Geropotamos River. Density also diminishes as slopes become steeper on the northern edge of the Timbaki and Mires plains. Vines are less widespread with two main concentrations to the south east of Mires and in extreme north east of the catchment. The distribution of arable farming is predominant in the area to the south and east of Mires and on flat ground in the vicinity of Gortyna. Glasshouses and market gardening dominate the Timbaki plain. The forest classes exist only in relatively inaccessible parts of steep gorges, which are not suitable for olives or farming and where water is accessible from river channels. The quite large areas of forest to the south and east of Psiloritis are protected by legislation. Vegetation on the upper slopes of Psiloritis is extremely sparse in a very rocky landscape (Source: An integrated Monitoring and Modelling study of Desertification and Climatic change Impacts in the Messara Valley of Crete, final scientific report, 1996).

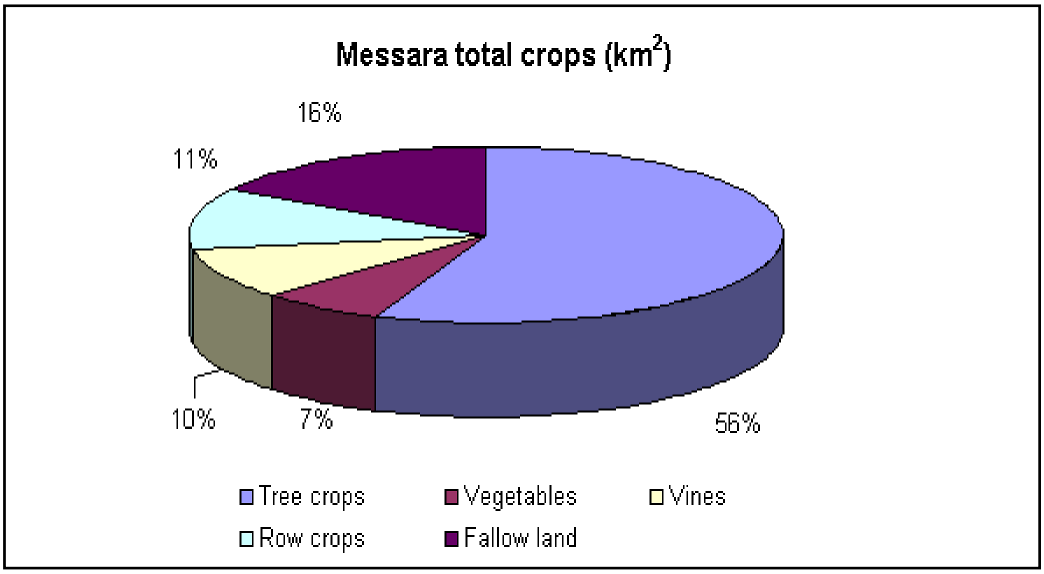


Figure 2.1.22: Crops cultivated in Messara catchment (HNSS 1999)

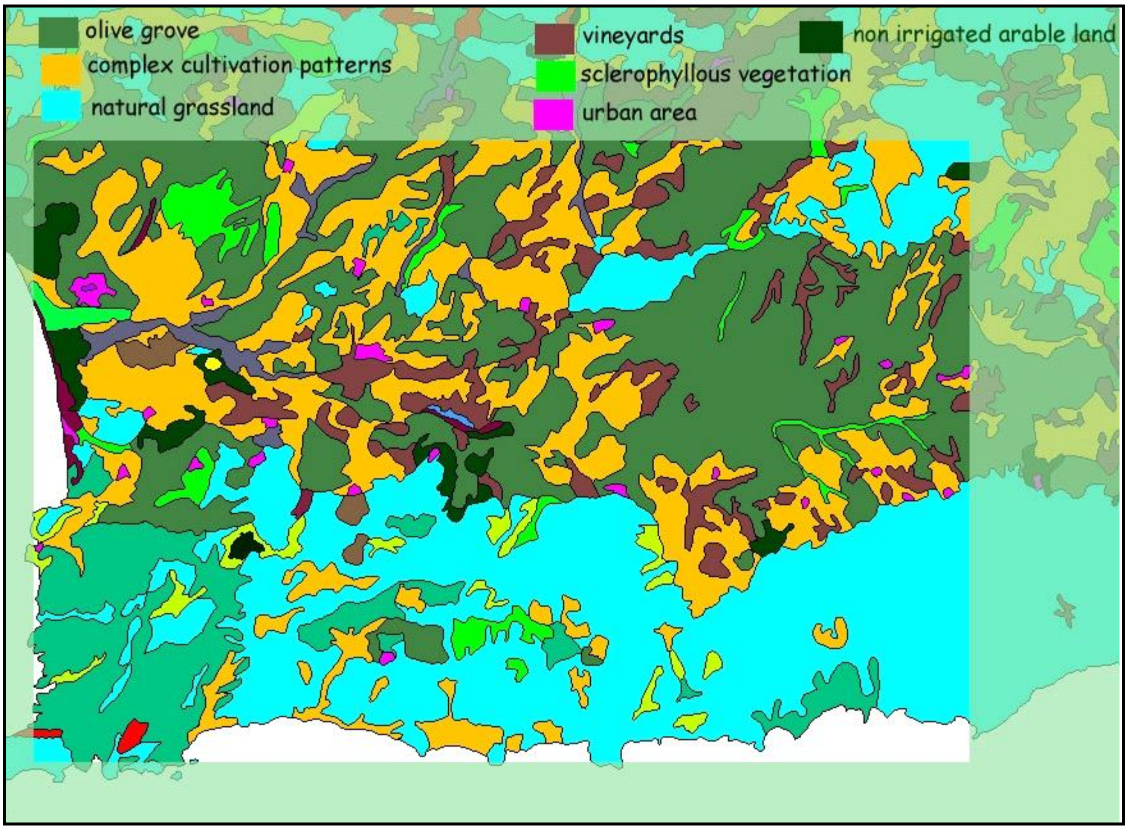


Figure 2.1.23: Landcover classification in Messara Valley (CORINE)

Irrigation systems and scheduling

Drip irrigation is widely used for olive orchards and tree crops, micro-sprinklers for potatoes and drip irrigation for the rest of the vegetables. Modern type irrigation systems are used the last decade increasing the water use efficiency. The amount of the water applied is empirically defined and it comes from drills. Messara valley is separated into 4 irrigation zones and water price varies from 0,10 – 0,13 €/m^3. The biggest TOEB (Local Board of Water Management) in Messara that irrigates 350000 ha, has set limitations in water use for each crop and any exceeding of this limit, has financial penalty for the farmer.

Crop water requirements

Reference evapotranspiration was estimated in three stations in Messara catchment for the period 1975 - 2001 (Pombia at southern part of the catchment, Zaros at north and Protoria at the eastern part). The average reference evapotranspiration of the three stations was used in order crop evapotranspiration to be estimated for Messara catchment using the Penman – Monteith (FAO 56) method. Missing data were filled from Gergeri and Timbaki stations. Crop water requirements for the main crops in the catchment are presented on Table 1.2.7.1. In estimating crop water requirements for greenhouses, the water required for salt dilution and percolation, is not taken into account.

Table 2.1.1. Crop water requirements in Messara catchment

Crop	**Crop water requirements (m^3x10^2/ha)**												
	J	F	M	A	M	J	J	A	S	O	N	D	**SUM**
Olives	-	-	-	-	3.5	6.0	7.5	7.0	4.0	(1.0)*	-	-	**28.0 (29.0)***
Citrus	-	-	-	-	7.5	11.0	14.0	12.5	8.0	4.0	-	-	**57.0**
Table vines	-	-	-	-	-	9.0	11.5	10.0	(6.5)*	-	-	-	**30.5 (37.0)***
Vines for wine	-	-	-	-	-	9.0	11.5	-	-	-	-	-	**20.5**
Greenhouse tomato (Oct – May)	2.0	2.0	3.5	5.5	11.0	-	-	-	-	3.5	2.5	2.0	**32.0**
Greenhouse cucumber (Aug – Nov)	-	-	-	-	-	-	-	4.5	10.0	9.0	6.0	-	**29.5**
Greenhouse cucumber (Mar – Jun)	-	-	3.5	7.0	9.5	10.0	-	-	-	-	-	-	**30.0**
Watermelon (Mar – Jun)	-	-	1.5	5.0	10.0	14.0	(18.0)*	-	-	-	-	-	**30.5 (48.5)***
Watermelon (May – Aug)	-	-		-	7.0	12.0	18.0	15.0	-	-	-	-	**52.0**
Melon	-	-	1.5	5.0	9.5	13.0	-	-	-	-	-	-	**29.0**
Potatoes (spring)	-	-	2.0	5.5	9.0	13.0	-	-	-	-	-	-	**29.5**
Tomatoes open (Jun – Oct)	-	-	-	-	-	8.0	12.5	14.5	10.0	5.0	-	-	**50.0**
Tomatoes open (Aug – Nov)	-	-	-	-	-	-	-	9.0	7.5	5.0	1.5	-	**23.0**

* Additional irrigation due to low rainfall and/or high temperatures and/or extended crop

Taking into account the estimated crop water requirements, citrus is the most highly water demanding crop in Messara catchment, followed by watermelon and vegetables (open field tomatoes). Table vines seem to need a significant amount of water but the area they take among the other crops is not very large.

Fertilisers

Various forms of N-fertilizers applied empirically during winter, after harvest is over, are used. Of the four catchments in Crete, fertigation (application of fertilizers through the irrigation system) is more frequent in Messara and it is usually applied in vegetables crops.

Weed control

Weed control is mostly done with tillage with milling machinery, while herbicides are used in some areas usually in addition to tillage when needed and rarely as a sole weed control technique.

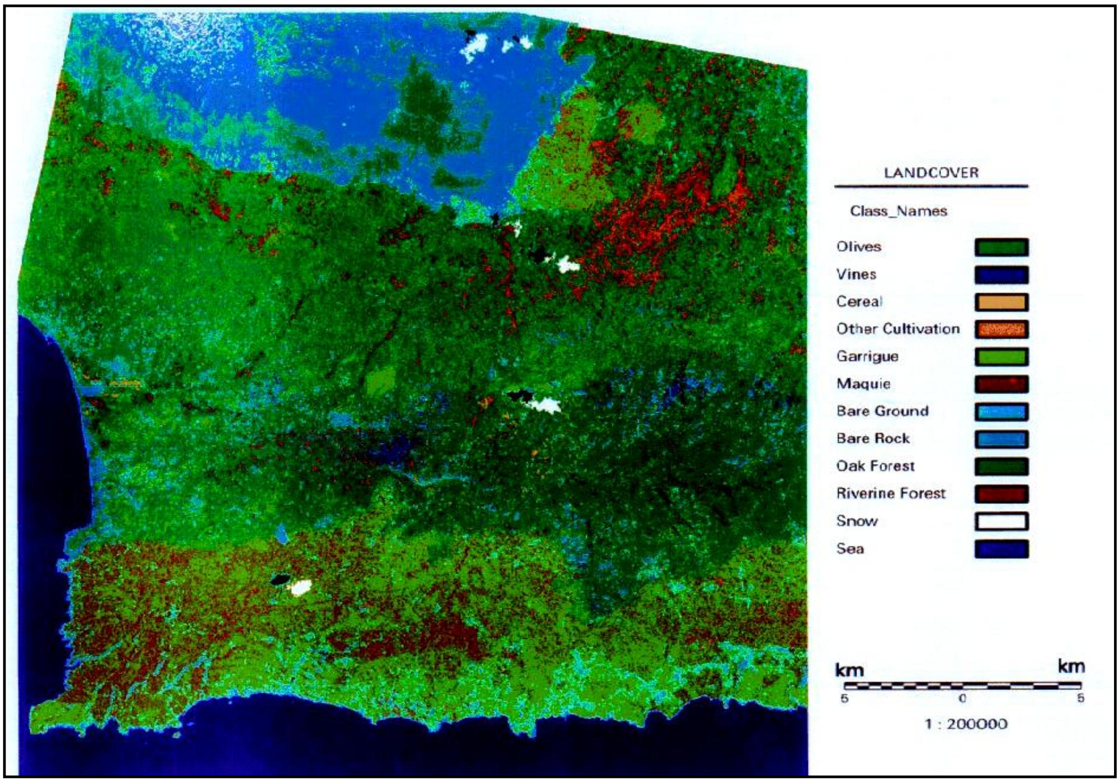


Figure 2.2.1: Land cover classification in Messara Valley

2.2 Patelis Catchment

Patelis catchment lies in the north-eastern part of Crete in the prefecture of Lasithi. The catchment covers an area of 123 km^2 comprising a north-south plain with steeply rising mountains on the east and the west side. The catchment receives a mean yearly rainfall of 650 mm. Around 90% of the total catchment area is cultivated. The main land use activities are grape vine cultivation (50%) and olive growing (20%). The remainder of the cultivated land (19%) is used for horticultural crops.

The main source of irrigation water is groundwater. The pumping stations that have been installed have allowed drip-irrigated cultivation of olive trees and vines.

Relief and Geology

The catchment comprises a north-south plain with steeply rising mountains on the east and west side. The mountains on the west side rise up to 900 m, on the east side up to 800 m. The valley extends at elevations between 200 and 50 m. The main outlet of the catchment is Patelis River in Siteia constriction at the north of the catchment. The mean elevation of Patelis riverbed is 460 m with a minimum elevation of 64 m. Patelis catchment has tectonic origin of trench type. By the slopes, two large fault systems extend almost from the north to the coast of the prefecture. The valley slopes consist of Neogene marly deposits and sandstone conglomeratic deposits. The west slope is mainly covered by clay, which is 1-1.5 m deep. The east slope is mainly covered by rocky conglomerate formations with an average depth of 2.5 m and layers of limestone and marly deposits. The west slope corresponds to a possible fault active during Middle Pleistocene. The valley consists of stream deposits of Patelis River, which have a rather large thickness (> 5m). They consist of sandstone and conglomerates.

Generally, the valley consists 50% of marly deposits, clays and conglomerates and 50% of Quaternary alluvial and silty deposits. Alluvial deposits consist of silty clay with conglomerates.

The geophysical map of the catchment with the rainfall gauges is depicted in figure 2.2.1. The geological map of the area is shown in figure 2.2.2.

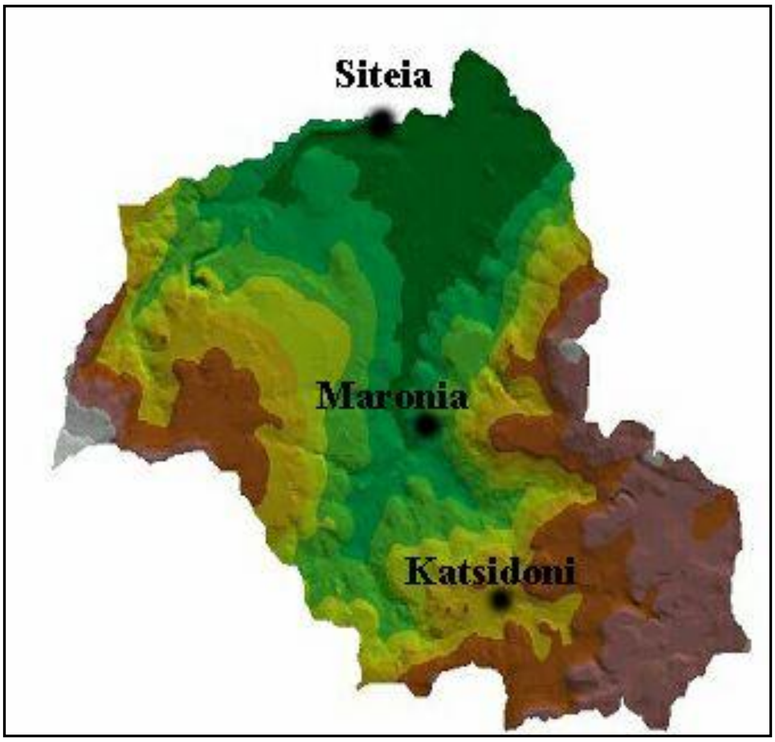


Figure 2.2.2: Geophysical map of Patelis catchment

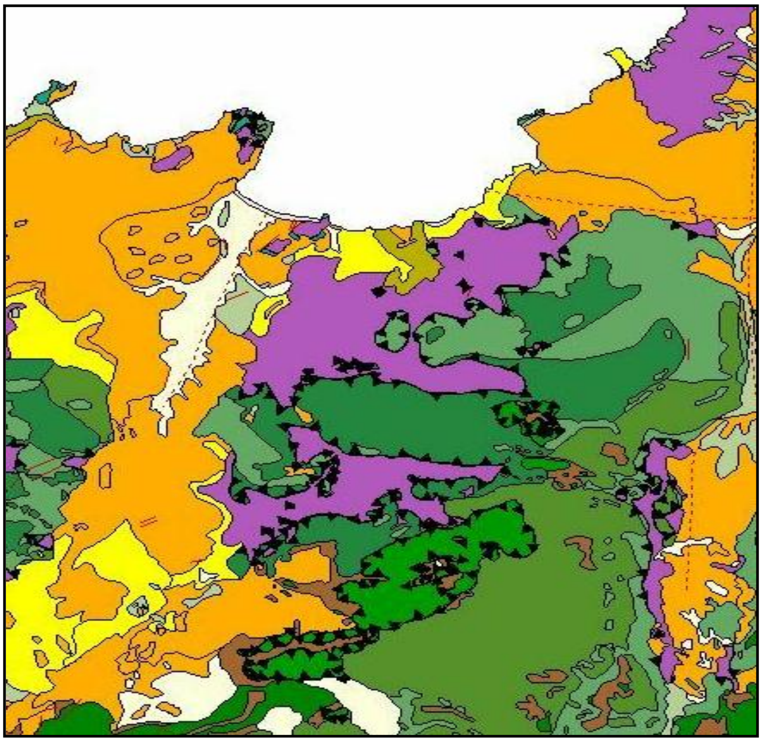


Figure 2.2.3: Geological map of Patelis catchment

Climate and Hydrology

The climate is sub-humid Mediterranean with mild moist winters and hot and dry summers. The catchment receives mean annual precipitation of 650 mm. The hydrological year may be divided into a wet and dry season. About 40% of precipitation occurs in the months of December and January while from June to August there is negligible rainfall. The average winter temperature is 13°C while for summer it is 25°C. The Department of Agriculture in Crete has monitored the valley's water resources for more than thirty years. There are daily measurements of rainfall from 3 stations. The mean annual rainfall for the different stations in the Patelis catchment is shown in figure 2.2.3. There is a dependence of rainfall and elevation. For the Patelis catchment the rainfall shows a linear trend with elevation with the fit being:

$P_i = 437.48 + 0.8827z_i$

P_i and z_i = rainfall (mm) and elevation (m) of a particular location in the catchment

The correlation coefficient R is 0.85 as shown in figure 2.2.4.

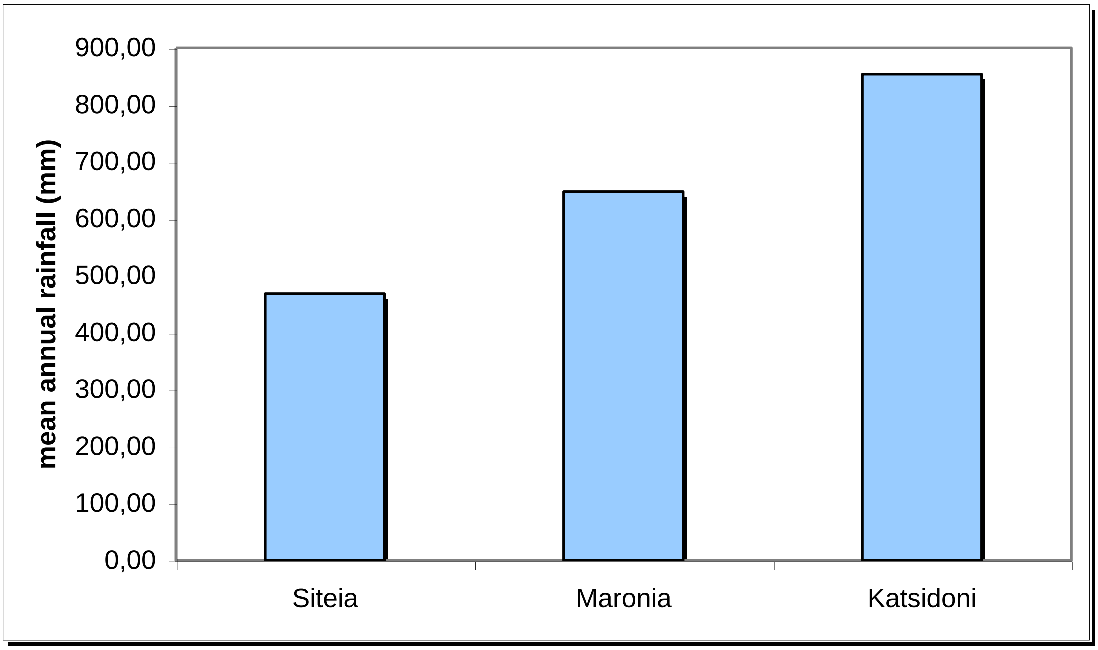


Figure 2.2.4: Mean annual rainfall for different station sin Patelis catchment

Rainfall ranges from 850 mm for Katsidoni station at an elevation of 480 m to 647 m for Maronia station at an elevation of 150 m and 470 m for Siteia station at an elevation of 115 m. Siteia station is a station that shows very low annual precipitation data compared to other stations in Crete, and Katsidoni station is at the upper end of stations that exhibit high annual precipitation.

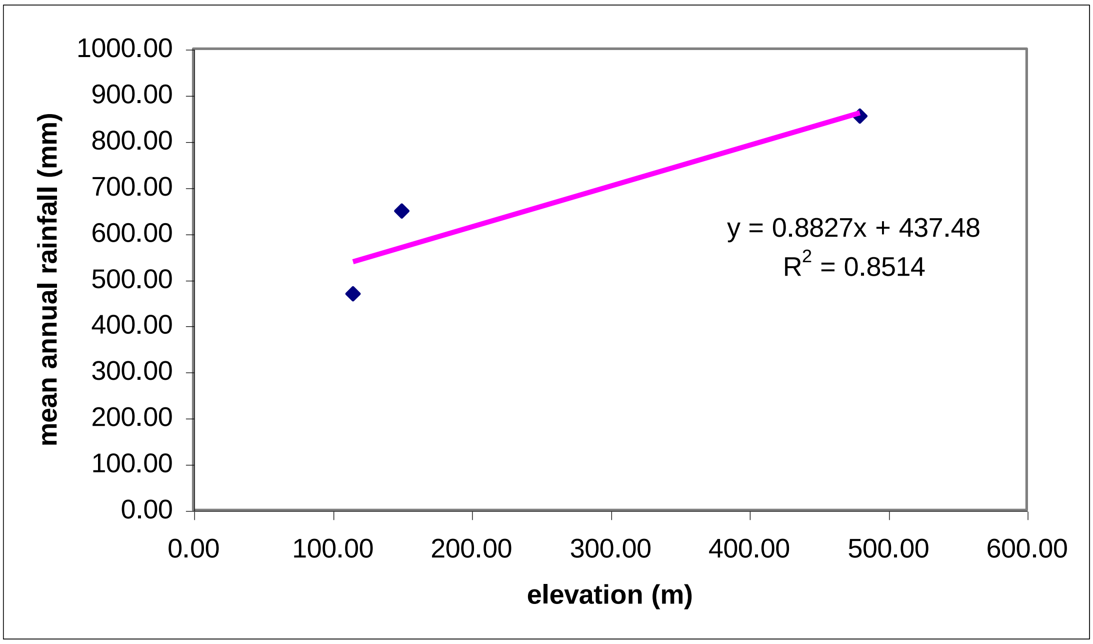


Figure 2.2.5: Rainfall for each of the three stations plotted against elevation. Also shown is the linear regression for the catchment

The mean annual and mean monthly rainfall for Pateli catchment is shown in figures 2.2.5 and 2.2.6 respectively.

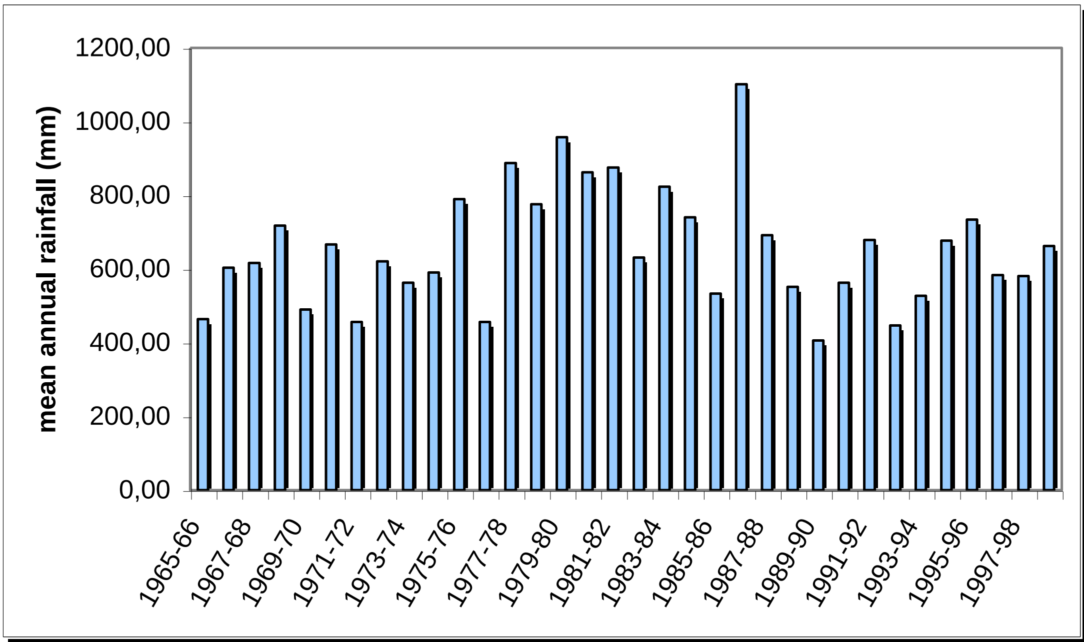


Figure 2.2.6: Mean annual rainfall for Patelis catchment

The hydrological year 1989-1990 was the driest year for the catchment while the wettest was the hydrological year 1986-1987.

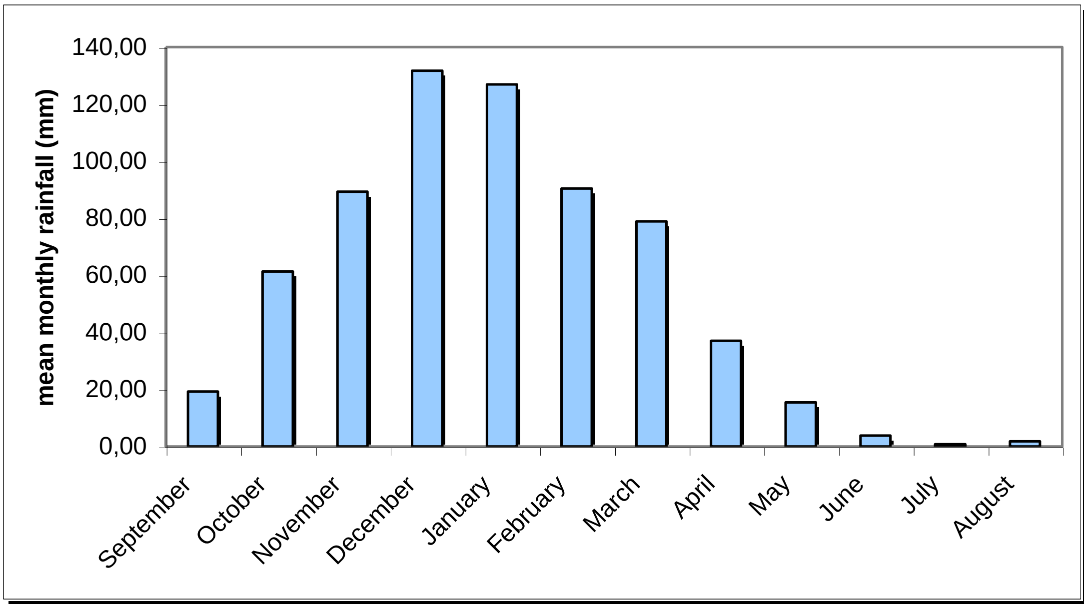


Figure 2.2.7: Mean monthly rainfall for Patelis catchment

Almost 40% of annual rainfall occur in December and January. The wet season lasts from November to March or April, while the dry season extends from June to September.

There is one station measuring temperature in the catchment of Patelis, namely Siteia station. Mean annual temperature for Siteia station is 18.67°C. The highest temperatures occur in July and August (25.7°C) while the lowest temperatures occur in January and February (12.2 to 12.3°C). Siteia station exhibits a high mean annual temperature compared to other stations in Crete. The monthly pattern of temperature for Siteia station is depicted in figure 1.1.3.22. The hot period extends from May to October and the cold period lasts from November to March or April. The average winter temperature is 13°C, while for the summer it is 25°C. The temperature range between the coldest and the hottest month of the year is 12.8°C.

Surface waters

There are no big rivers in the area of the catchment but there are seasonal streams originated from the relatively low mountains in the central part of the catchment and their outlet is the coastal area of Siteia bay. The most important stream of the area is Patelis, which is the main outlet of the catchment at Siteia constriction. Important affluents of the Patelis River are the streams Xiropotamos, Petrolakkos and Platani. The mean elevation of the riverbed is 469 m with a minimum elevation of 64 m. The length of the river path is around 14 km.

The mean annual runoff for Patelis River for the years 1967 to 1994 is shown in figure 2.2.7. Data for the hydrological years 1981 to 1983 are missing due to misplacement of the gauge. No flow is observed from May to September 1990, July to November 1991, July to November 1992, August to October 1993, July to September 1994 and July and August 1995.

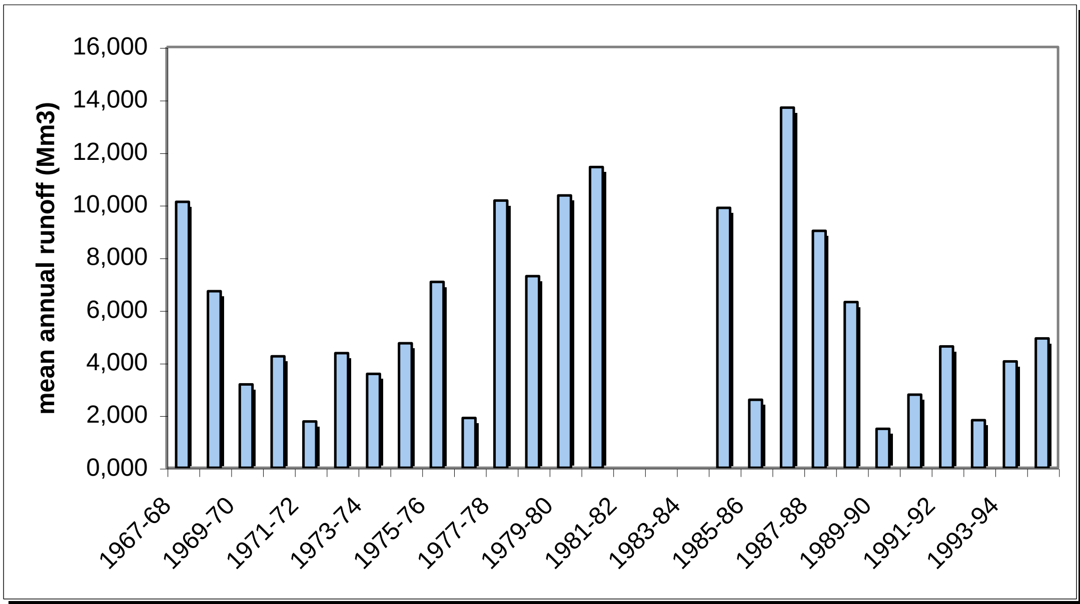


Figure 2.2.8: Mean annual runoff for Patelis

The hydrological year 1989-1990 was the year with the lowest rainfall and runoff, while the hydrological year 1986-1987 was the hydrological year with the highest rainfall and runoff.

The mean monthly runoff for Patelis River is shown in figure 2.2.8. High flows are observed in January and February, while low flows are experienced in July and August. The mean annual runoff for Patelis River is 6 Mm^3.

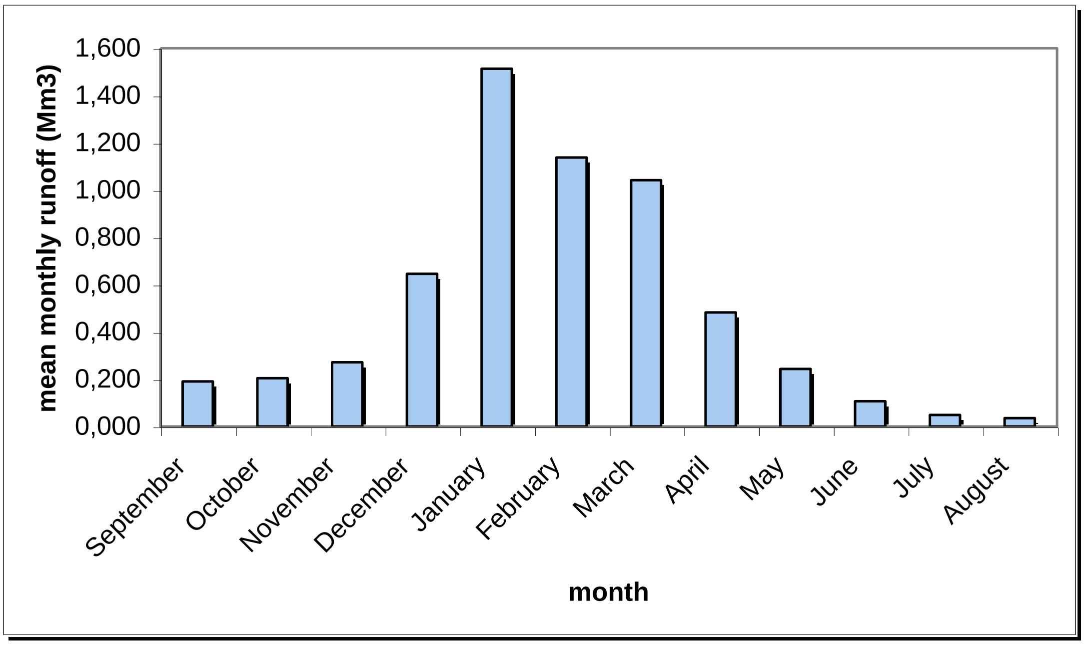


Figure 2.2.9: Mean monthly runoff of Patelis

The annual runoff coefficient for Patelis is shown in figure 2.2.9.

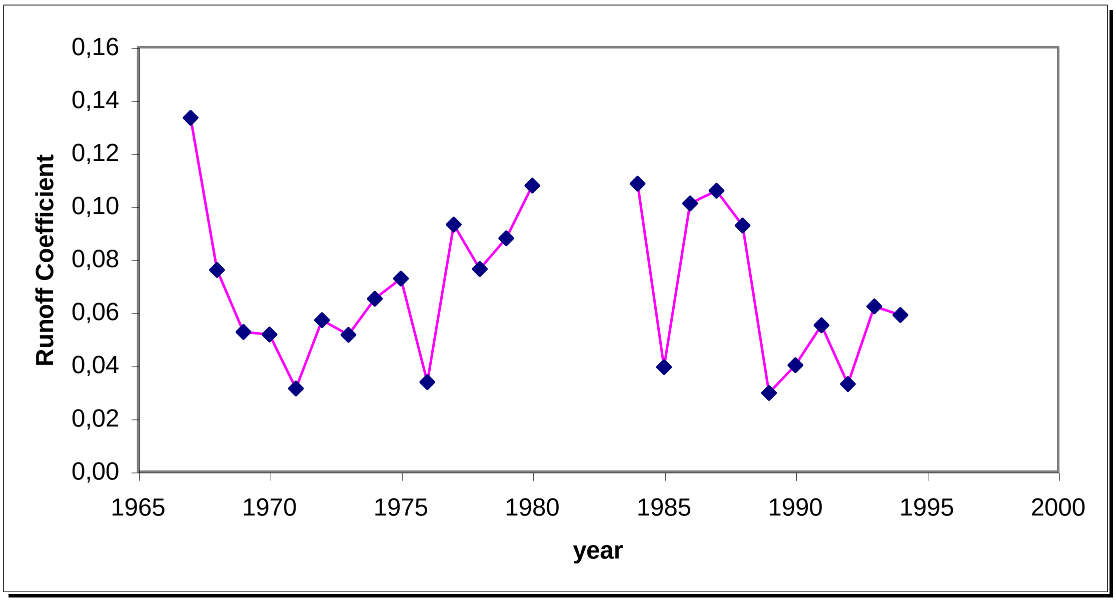


Figure 2.2.10: Annual runoff coefficient for Patelis

The mean annual runoff coefficient is 0.06 and the standard deviation 0.03. This value of runoff coefficient implies that pumping is taking place in the catchment. Figure 1.1.4.4 shows the mean annual runoff for the Patelis catchment compared with other stream in Lasithi prefecture. Water is abstracted from streams of the catchment for irrigation purposes.

Groundwater

The hydrogeological conditions of the catchment result from its geology. As mentioned above, the valley consists 50% of marly deposits, clays and conglomerates and 50% of Quaternary alluvial and silty deposits. Alluvial deposits consist of silty clay with conglomerates. Alluvial deposits exhibit high specific yield and are considered permeable formations, which form an unconfined aquifer. The east slope is less permeable due to the existence of silty clays and Neogene marly deposits. The valley is the receptor of discharge from the mountains. Groundwater levels are estimated at 50 m ASL. Surface and groundwater is used for irrigation purposes in the catchment area. Groundwater comes from pumping wells and springs.

In the area of the catchment the spring of Zou is located. This spring has a mean annual discharge of 51 L/s. The mean annual and monthly discharge of the spring is shown in figures 2.2.10 and 2.2.11 respectively.

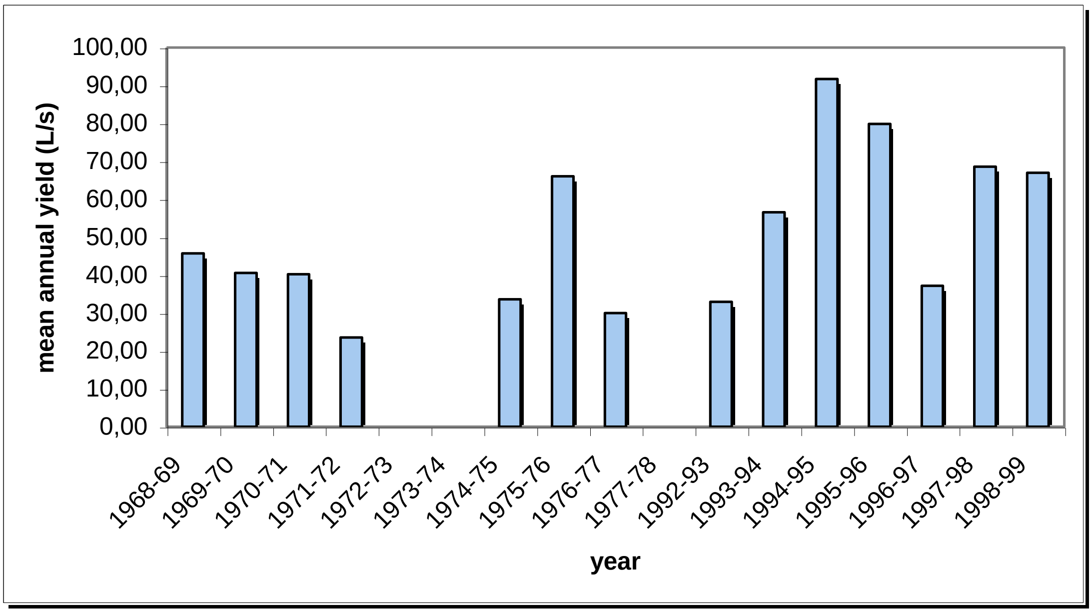


Figure 2.2.11: Mean annual discharge of Zou spring

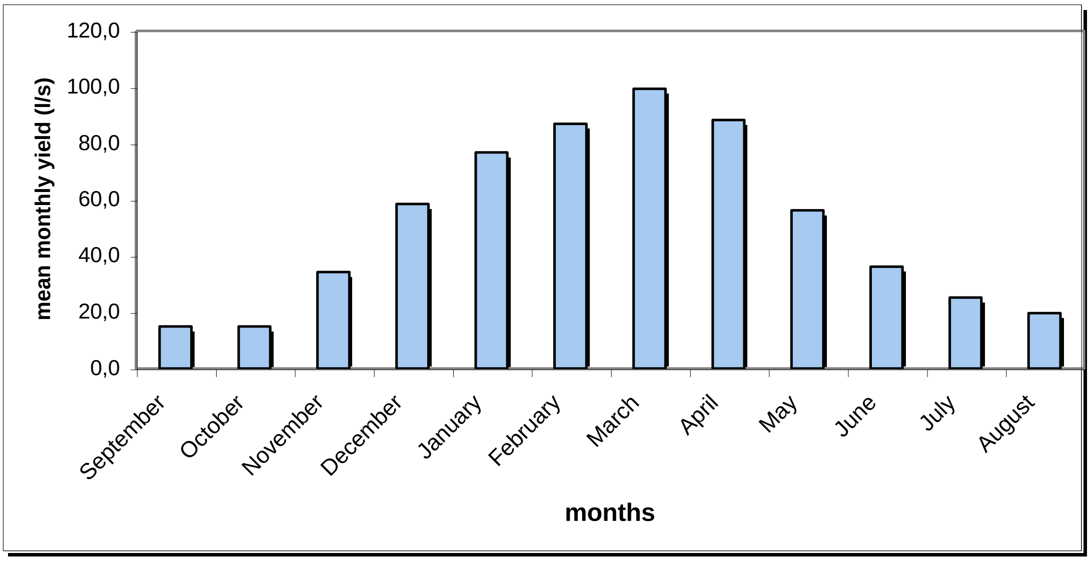


Figure 2.2.12: Mean monthly discharge of Zou spring

High yields are observed for February and March and low yields for August, September and November. A high percentage of the discharge of the spring ends up in the sea during winter time. From the spring of Zou 50m^3/h are abstracted for water supply of Siteia and Pistokefalo and another 33 m^3/h for irrigation.

There are about 35 registered pumping wells in the catchment. Around 25 of which are used for irrigation purposes, 10 are used for irrigation and water supply while some have not been exploited or have failed.

Agricultural situation

Around 90% of the catchment area is cultivated. Around 47% of the total tree crops are olives (cv Koroneiki), about 10% are vines (cv Sultanina), 6% are vegetables and 30% is fallow land and other crops.

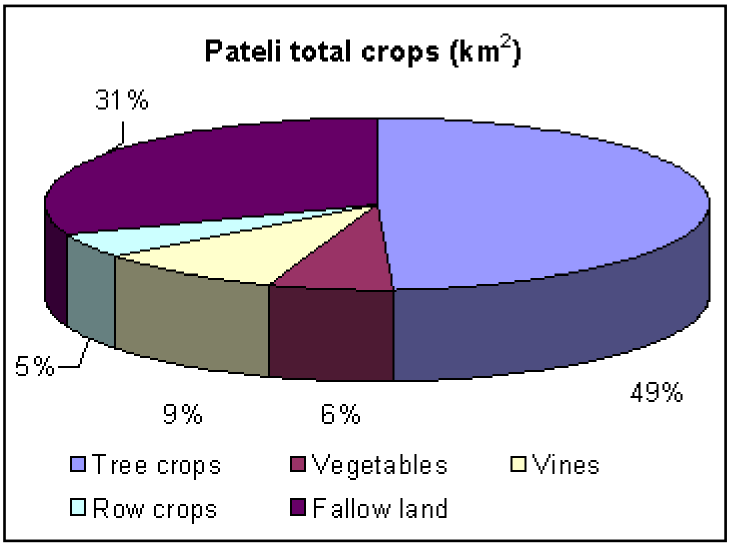


Figure 2.2.13: Crops cultivated in Platys catchment (HNSS, 1999)

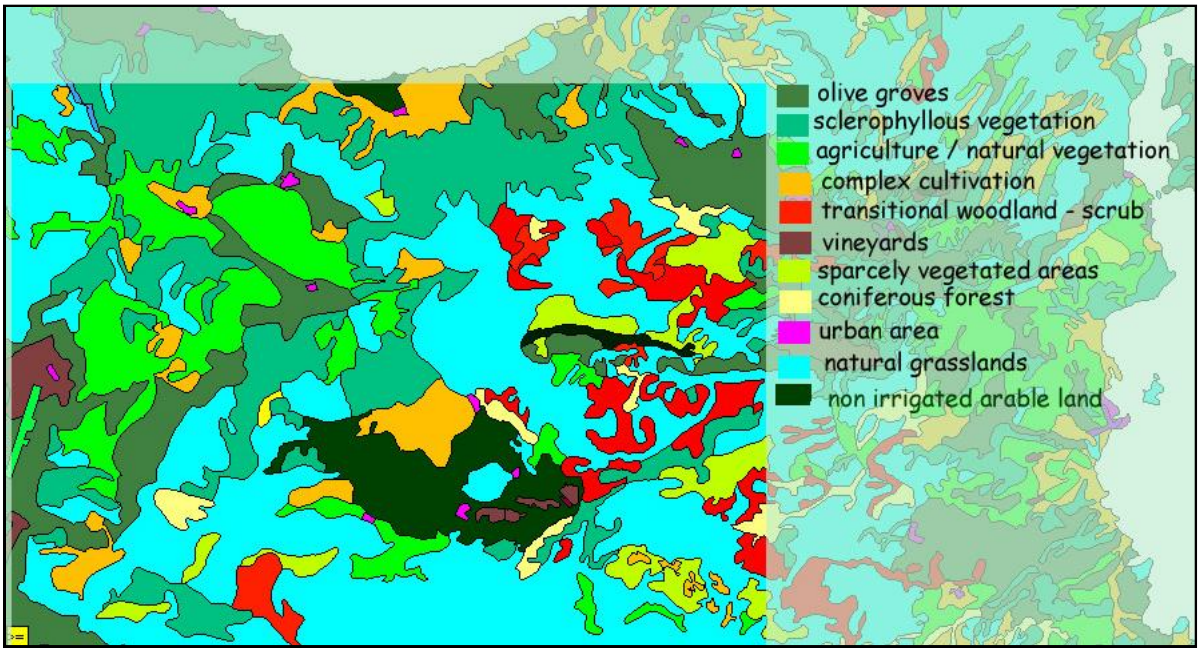


Figure 2.2.14: Land – use map of Patelis catchment (CORINE)

Irrigation systems and scheduling

Surface and groundwater is used for irrigation purposes from pumping wells, springs and stream runoff. Drip irrigation systems are used for olive orchards; micro-sprinklers for potatoes and furrow are used for the other vegetables. The time and amount of the water applied is empirically defined. The average water price is about 0.21 €/m^3. The price is increased compared to other catchments because the Local Board of Water Management (TOEB) has too many debts. When dept is paid the price of the water price will be reduced. The Local TOEB does not have water meters in all irrigated areas and thus it is not possible to know how much water the farmers in those areas use.

Crop water requirements

Reference evapotranspiration with Penman – Monteith method was estimated using data from Sitia weather station for the period 1971 – 1998.

Crop water requirements for the main crops in the catchment are presented on Table 2.2.1.

Fertilisers

Various forms of N-fertilizers (40%) and composite fertilizers (60%) applied empirically during winter without any analyses for the nutrient needs of the crops (about 5 Kg per tree). Fertigation is rarely used in the catchment.

Table 2.2.1: Crop water requirements in Patelis catchment

Crop	Crop water requirements ($m^3 x10^2/ha$)												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**SUM**
Olives	-	-	-	-	4.0	5.5	6.5	6.0	3.0	(1.0)*	-	-	**25.0 (26.0)***
Citrus	-	-	-	-	8.0	10.0	11.5	10.5	6.5	1.5	-	-	**48.0**
Vines (cv Soultanina)	-	-	-	-	6.5	8.0	(9.0)*	-	-	-	-	-	**14.5 (23.5)***
Watermelons, Melons	-	-	-	-	9.0	12.0	14.0	12.5	8.0	-	-	-	**55.5**
Potatoes (spring)	-	-	3.0	5.5	10.0	12.0	14.0	-	-				**44.5**
Potatoes (autumn)	-	-	-	-	-	-	13.0	11.5	7.0	2.0			**33.5**
Tomatoes (open)	-	-		2.5	7.5	12.0	14.0	12.5	-	-	-	-	**48.5**

* Additional irrigation due to low rainfall and/or high temperatures and/or extended crop

Taking into account the estimated crop water requirements, open field watermelons and melons are the most highly water demanding crops in Patelis catchment, followed by citrus and vegetables (open field tomatoes, spring potatoes).

Weed control, Irrigation systems and Fertilizer application

Weed control in olive orchards is done equally with herbicides, tillage and no tillage. In vines tillage (50%) and herbicides (50%) are used. Generally usage of chemicals is the most commonly used method in Patelis catchment.

In olive orchards weed control is done with herbicides (33%), tillage (33%) and no tillage (33%). In vines tillage (50%) and herbicides are used.

Surface and groundwater is used for irrigation purposes from pumping wells, springs and stream runoff. Drip irrigation systems are used for olive orchards; micro-sprinklers for potatoes and furrow are used for the other vegetables. The time and amount of the water applied is empirically defined. Sultanina is irrigated in winter and spring. Olives are irrigated after the irrigation period of Sultanina.

Various forms of N-fertilizers (40%0 and composite fertilizers (60%) are applied empirically during winter without any analyses for the nutrient needs of the crops (about 5 kg per tree).

2.3. Platys Catchment

Platys catchment lies in the southern part of Crete, in the prefecture of Rethymnon. The catchment covers an area of 203 km^2, comprising a north-south plain with mountains rising on the east and west side. The catchment receives around 850 mm of rainfall per year. Around 80% of the total Valley area is cultivated with olive groves. The main source of irrigation water is groundwater. Pumping stations that have been installed allow drip-irrigated cultivation of olive trees.

Relief and geology

Platys catchment comprises a north-south plain with mountains rising on the east and west side. Mountains on the west rise up to 1500 m while the plain stretches at an elevation of 250 to 50 m. The Platys River is the main stream of the catchment and its outlet at the south coast is located at Agia Galini constriction. An important affluent of the Platys River is Ligiotis.

Neogene and Preneogene formations comprise the basic geological setting of the area. In more detail: Formations that are classified in the Pindos Zone (a geostratigraphical classification regarding the evolution of the Preneogene rocks in Greece) crop out mostly on the area of interest. The basic formations of the Pindos Zone are upper Triassic limestones and radiolarites. They consist of pink finely bedded limestones underlying radiolarites and sandstones with sandstone limestones. Cretaceous thick bedded limestones consisting of pink limestones at the base, black-gray limestones in the middle of the stratigraphical sequence and a series of thin interchanging Palaeocene limestone and marl layers at the top of the sequence. Flysh of Eocene age comprises the most recent formation of the Pindos zone. It can be slightly metamorphic in places. Flysh is the most abundant formation in the area. Upper Miocene conglomerates, sandstones, sands with occasional lignites comprise the main Neogene outcrop in the Platys catchment. They crop out to the east, north east of the Platys River. The geological map of Platys catchment is depicted in figure 2.3.1.

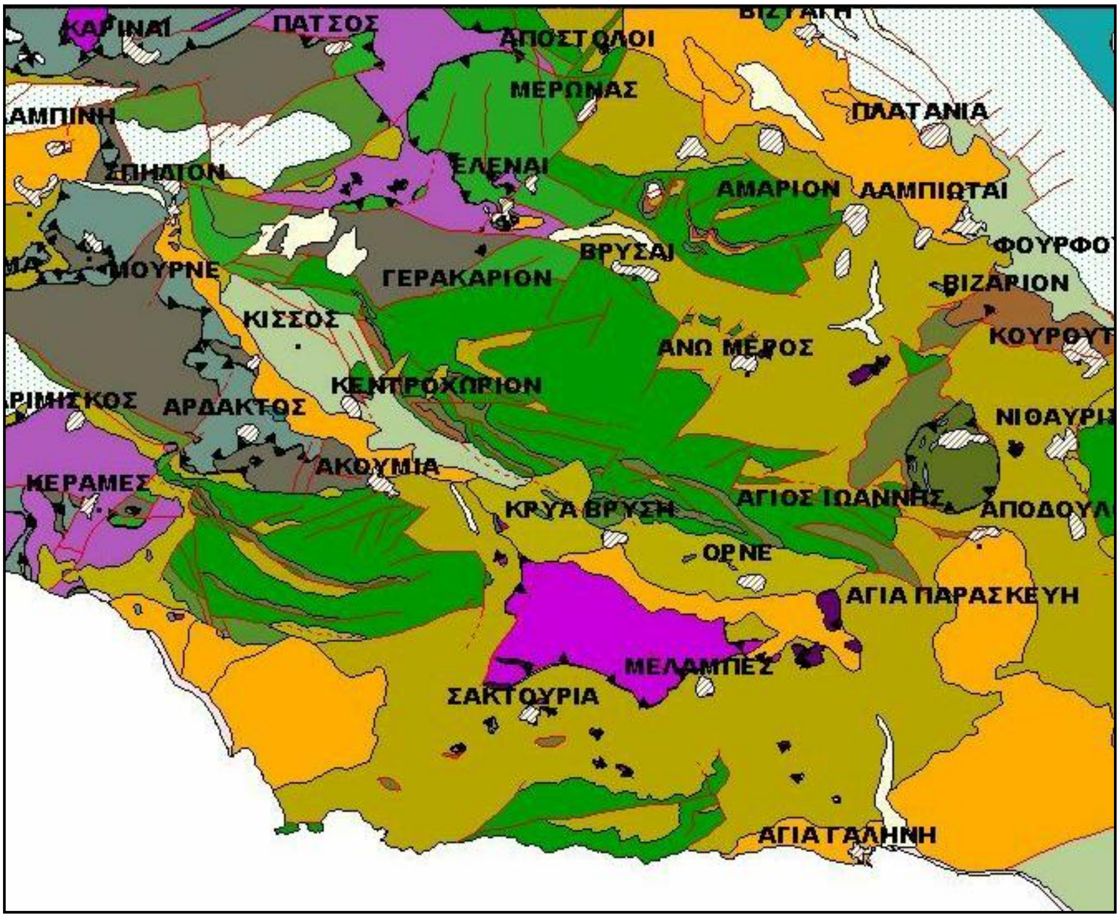


Figure 2.3.1: Geological map of Platys catchment

Climate and Water Resources

The climate is sub-humid Mediterranean with mild moist winters and hot and dry summers. The catchment shows a mean annual rainfall of 850 mm. Rainfall is measured by the Department of Ministry of Agriculture in Crete for around 30 years. There are four rainfall stations in the area. The location of these stations is shown in figure 2.3.2.

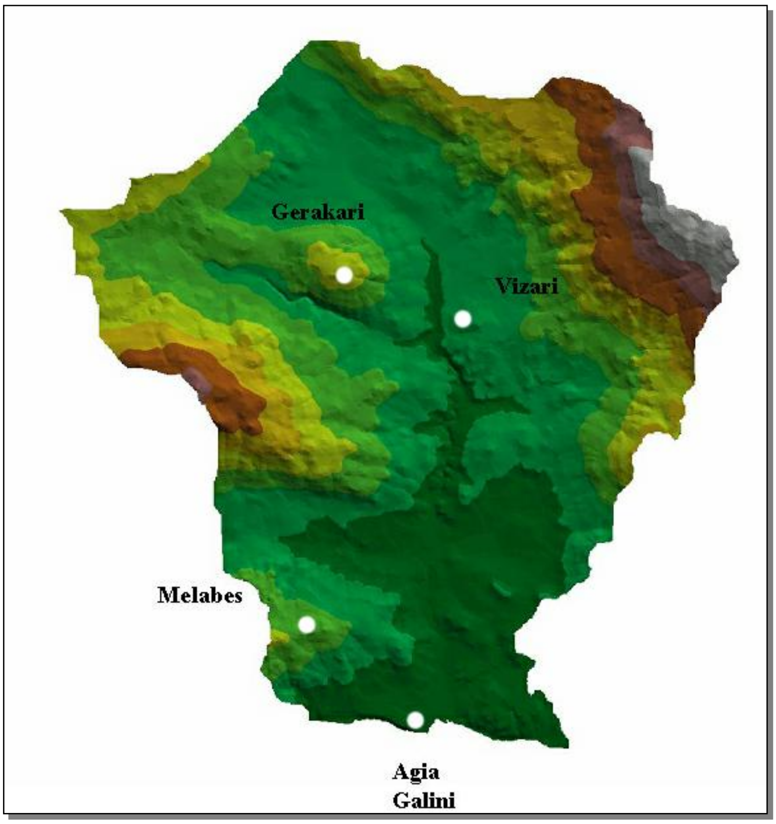


Figure 2.3.2: Geophysical map of Platys catchment with rainfall gauges

The mean annual rainfall for the four different stations in the catchment is depicted in figure 2.3.3. Gerakari station shows the highest mean annual rainfall, as it is located at high elevation. Rainfall ranges from 1300 mm at Gerakari station at an elevation of 580 m, to 754 mm at Vizari station at an elevation of 310 m, and 574 mm for Agia Galini station at an elevation of 20 m. Agia Galini station shows very low annual precipitation compared to other stations in Crete and the lowest in Rethymnon prefecture and Gerakari station is at the upper end of stations that exhibit high annual precipitation and the second highest in Rethymnon prefecture.

As shown in figure 2.3.4, rainfall increases with elevation but there is no linear dependence between rainfall and elevation. Melabes station, which is located at an elevation of 560 m ASL, shows lower precipitation than Vizari station located at an elevation of 310 m. This is most probably due to the location of Melabes near the coast while Vizari lies in the mainland close to the mountains. For Agia Galini, Vizari and Gerakari stations show a linear dependence of rainfall with elevation is observed with the fit being:

$P_i = 491.57 + 1.2991z_i$

P_i and z_i = rainfall (mm) and elevation (m) of a particular location in the catchment

The correlation coefficient R is 0.927 as shown in figure 2.3.5.

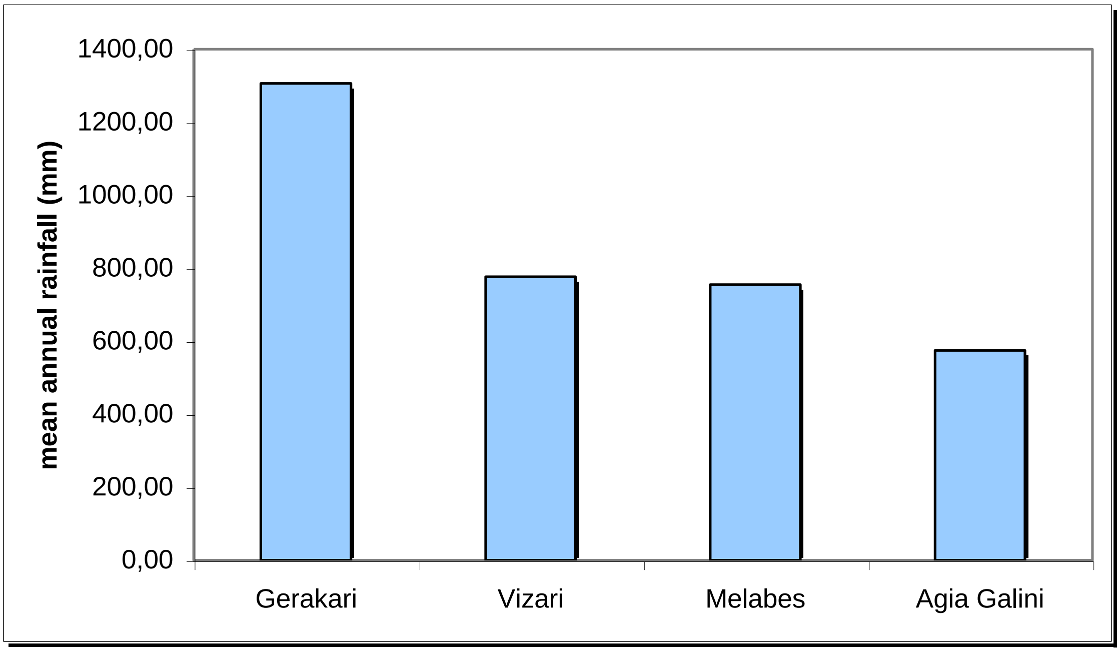


Figure 2.3.3: Mean annual rainfall for the different stations in Platys catchment

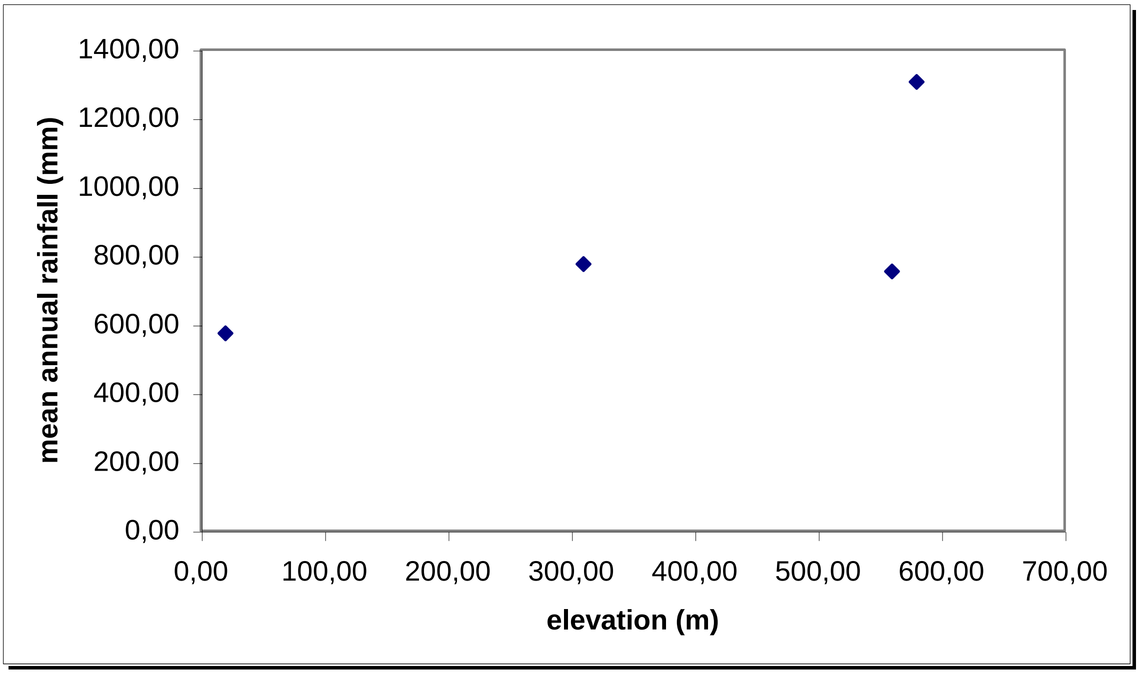


Figure 2.3.4: Rainfall distribution with elevation

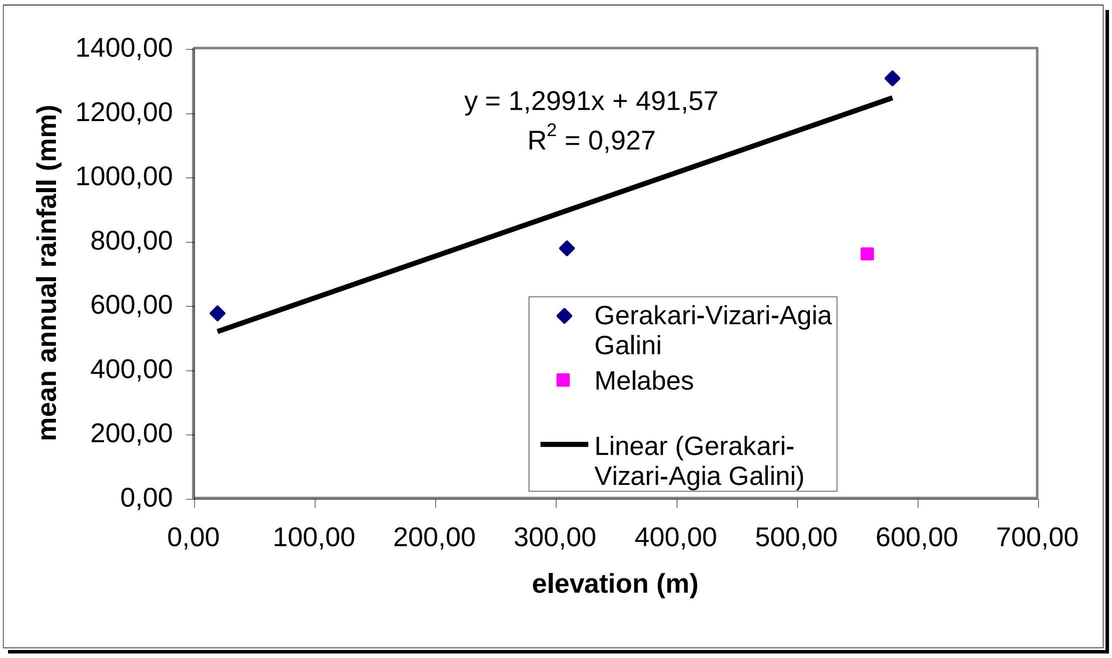


Figure 2.3.5: Linear dependence of rainfall with elevation

The mean annual rainfall for the catchment is shown in figure 2.3.6.

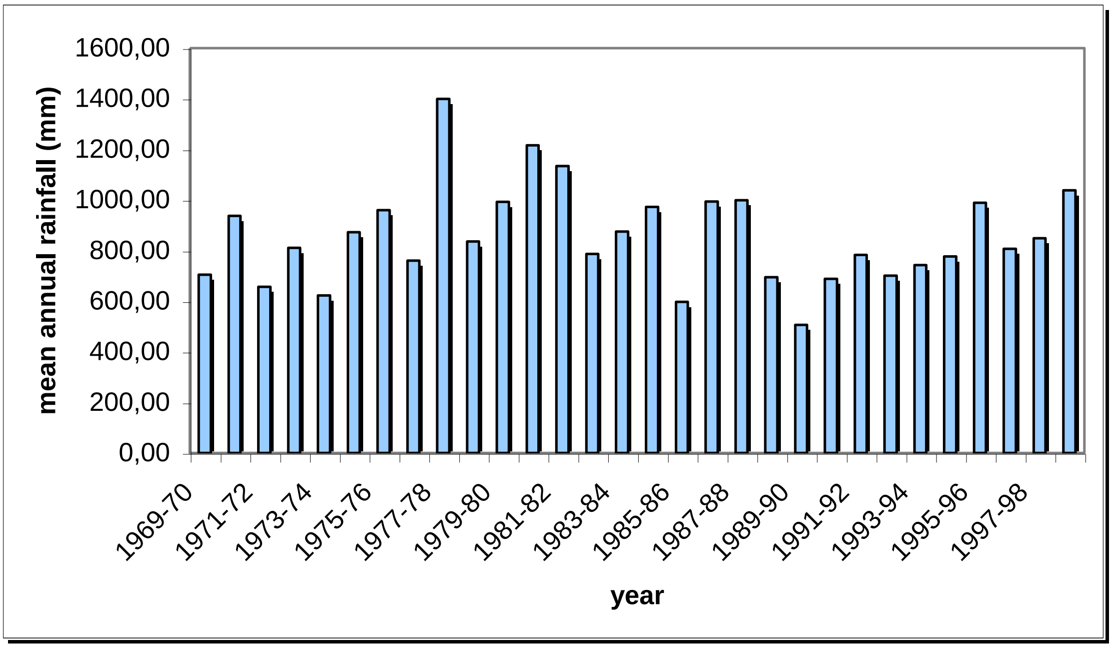


Figure 2.3.6: Mean annual rainfall for Platys catchment

As it is shown in figure 2.3.6, the driest year was the hydrological year 1989-1990 and the wettest year was the hydrological year 1977-1978. Figure 2.3.7 depicts the seasonal pattern of rainfall for the catchment. Around 40% of mean annual precipitation occurs in December and January. December seems to be the wettest month, while July and August are usually the driest months. The wet season lasts from October or November to March and the dry season extends from May to September.

Surface waters

Platys River is the main stream of the catchment and its outlet is at the south coast at Agia Galini constriction. An important affluent of the Platys River is Ligiotis. The mean annual runoff for Platys River is depicted in figure 2.3.7. The river shows mean annual runoff of 50.7 Mm^3.

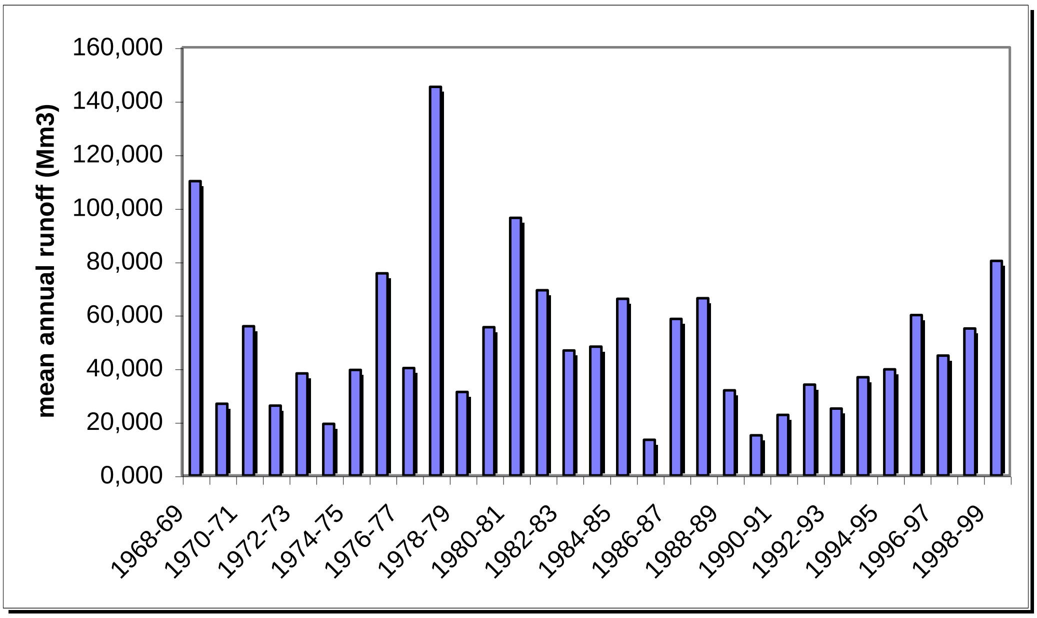


Figure 2.3.7: Mean annual runoff of Platys

The highest mean annual runoff is observed at the hydrological year 1977-1978 and the lowest at 1985-1986.

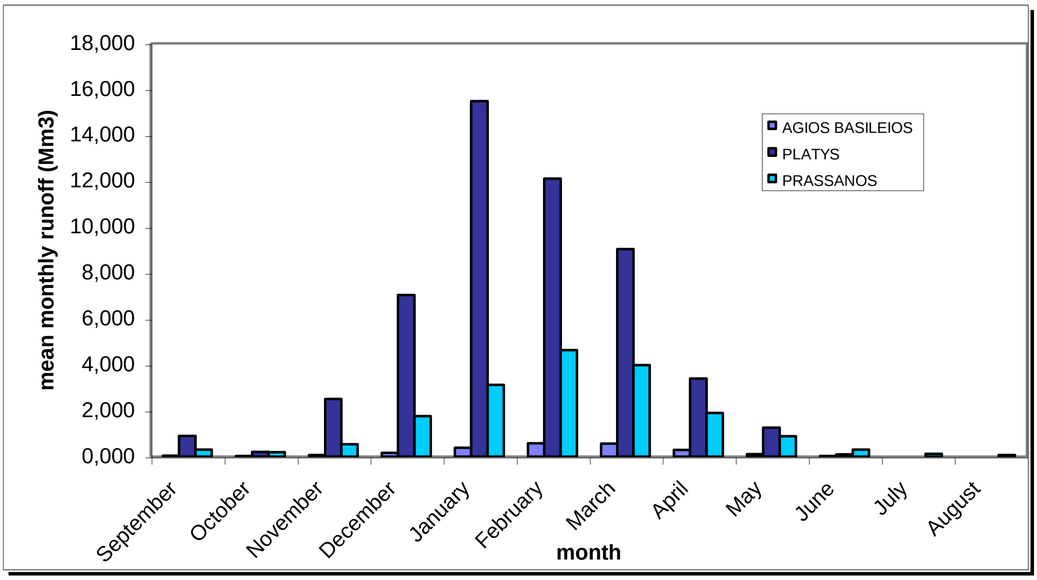


Figure 2.3.8: Mean monthly runoff for different streams in Rethymnon

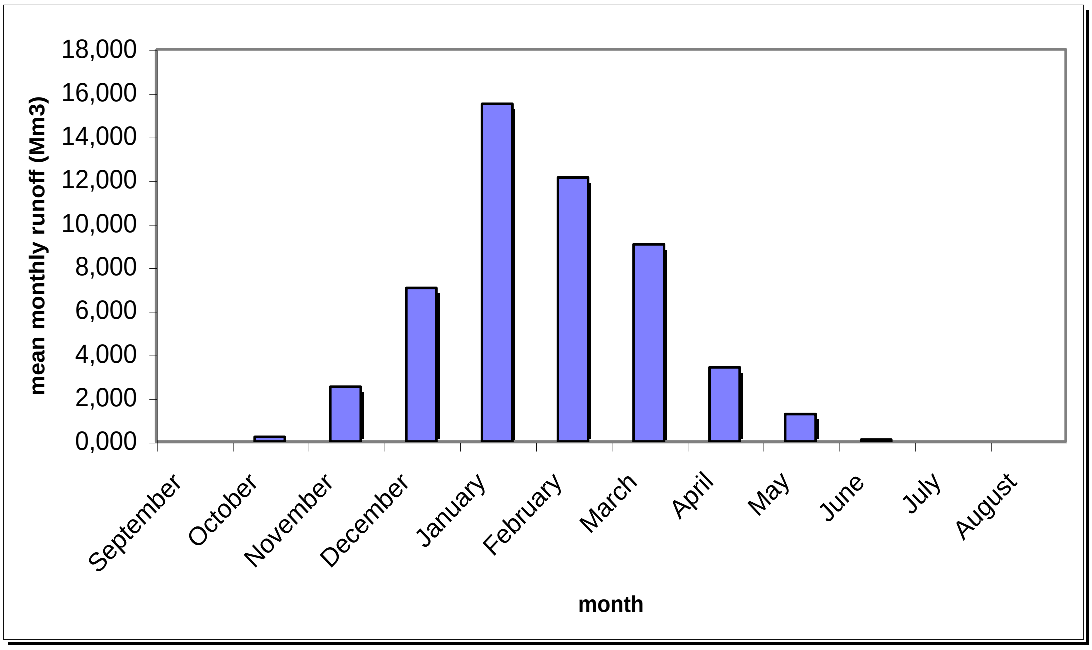


Figure 2.3.9: Mean monthly runoff of Platys

As shown in figure 2.3.9, the highest flow is observed in January and February while low flows or no flow are observed from June to October. The river was dry for all hydrological years in July, August and September and in October of 1969, 1971 and 1973 to 1998. For many hydrological years no flow was observed in June and even in November. The mean annual and mean monthly runoff coefficients are shown in figure 2.3.10 and 2.3.11 respectively. The mean runoff coefficient is 0.26, a relatively high value, which shows that not much pumping is taking place.

Groundwater

The main source of irrigation water in the valley is groundwater. ~~Drip irrigation systems are used for olive orchards of cv Koroneiki. The cv Throumbolia is non-irrigated. Vines are also non-irrigated.~~ Around 20 pumping wells have been registered in the area. Most of them are used for water supply and irrigation purposes, while some are used for research and some are either not in use any more, or have failed. It is estimated that not much groundwater is pumped form the aquifer. This is also suggested by the relatively high value of runoff coefficient.

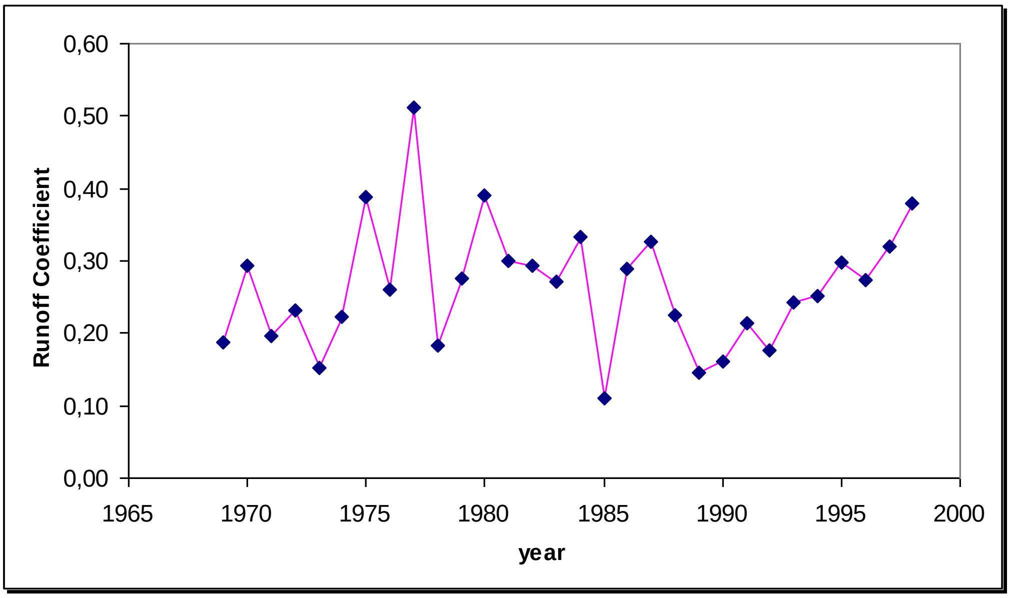


Figure 2.3.10: Runoff coefficient for Platys

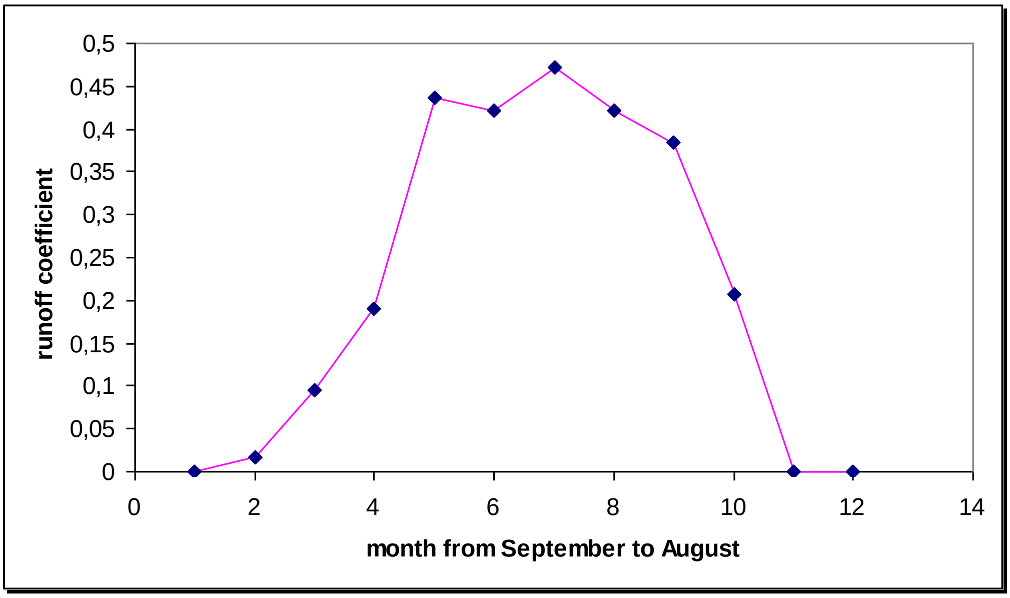


Figure 2.3.11: Mean monthly runoff coefficient for Platys

Agricultural situation

Around 80% of the total catchment area is cultivated but fallow land covers the biggest part of the cultivated area due to animal breeding and to difficult (or even impossible) access to irrigation water. 95% of the total tree crops are olives (80% cv Throumbolia, 15% cv Koroneiki, 3-4% cv Mastoidis).

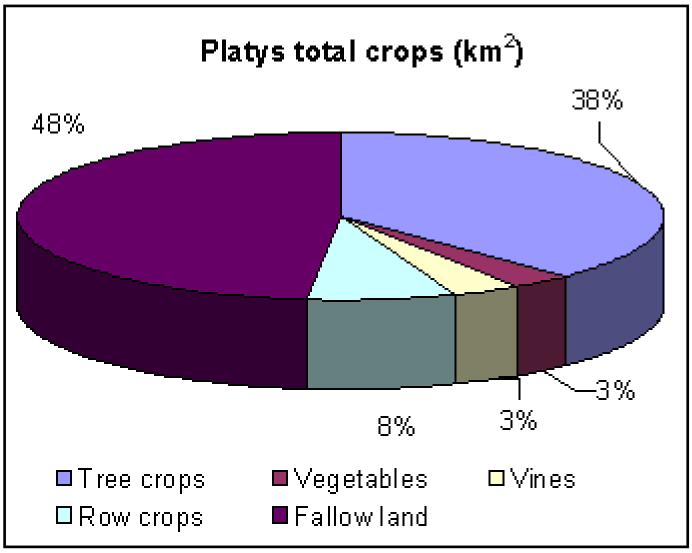


Figure 2.3.12: Crops cultivated in Platys catchment (HNSS 1999)

Irrigation systems and scheduling

The main source of irrigation water is groundwater. Drip irrigation systems are used for olive orchards of cv Koroneiki. The cv Throumbolia is non-irrigated. Vines are also non-irrigated. The amount of water applied is empirically defined. The average water price is approximately 0.06 €/m3.

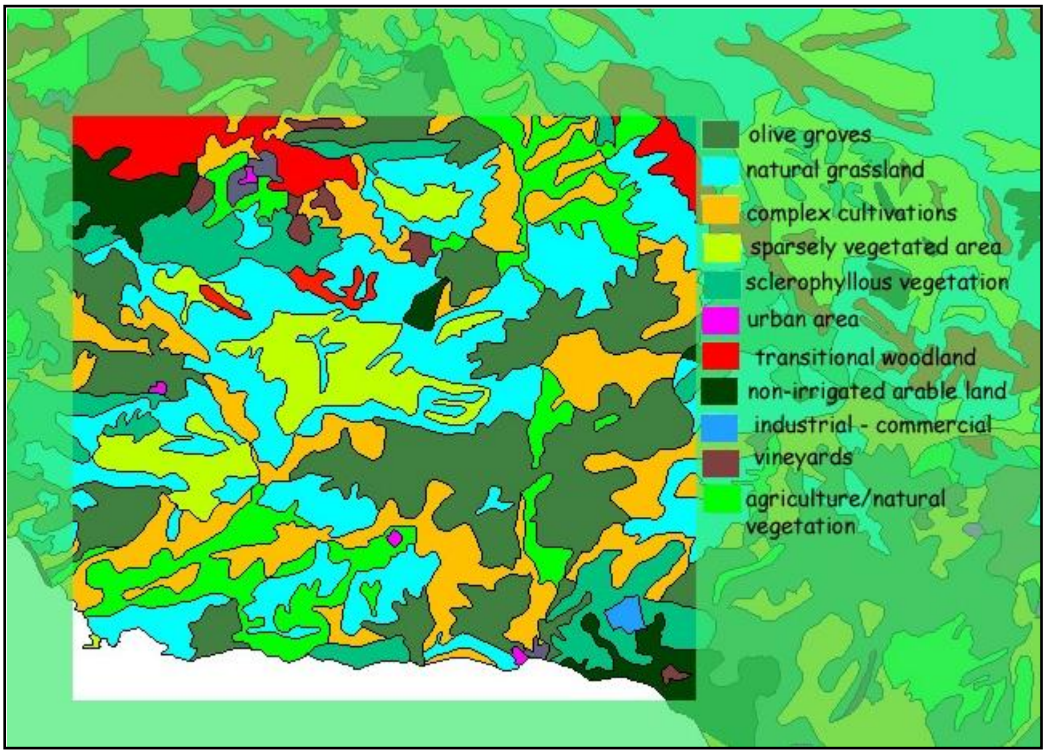


Figure 2.3.13: Land use map of Platys catchment (CORINE)

Crop water requirements

Data from Vizari station were used to estimate reference evapotranspiration with Penman – Monteith method, for the period 1971 – 2001. Missing data were filled from Gerakari and Leukogia stations. Crop water requirements for the main crops in the catchment are presented on Table 2.3.1.

Table 2.3.1: Crop water requirements in Platys catchment

Crop	Crop water requirements (m^3x10^2/ha)												
	J	F	M	A	M	J	J	A	S	O	N	D	**SUM**
Olives	-	-	-	-	3.0	6.0	7.5	6.5	3.5	(1.0)*	-	-	**26.5 (27.5)***
Vines for wine	-	-	-	-	-	8.5	11.0	-	-	-	-	-	**19.5**
Cherries	-	-	-	4.5	8.5	13.0	16.0	-	-	-	-	-	**42.0**
Potatoes (summer)	-	-	-	-	-	13.0	16.0	14.5	9.0	2.0	-	-	**54.5**
Artichokes	-	-	-	-	-	-	-	3.0	3.5	1.5	-	-	**8.0**
Tomatoes (open)	-	-	-	1.5	6.5	13.0	16.0	14.5	-	-	-	-	**51.5**

* Additional irrigation due to low rainfall and/or high temperatures

Taking into account the estimated crop water requirements, open field vegetables (summer potatoes and tomatoes) are the most highly water demanding crops in Platys catchment, followed by cherry trees.

Fertilisers

Various forms of N-fertilizers are applied empirically without any analyses for the nutrient needs of the crops (about 4 kg per tree for olive trees). Fertigation is rarely used in the catchment.

Weed control

Weed control is performed mostly with herbicides (40%) and tillage is used only in olives cv Koroneiki or supplementary to chemicals. 15% of the farmers use weed cutting.

~~The main source of irrigation water is groundwater. Drip irrigation systems are used for olive orchards of cv Koroneiki. The cv Throumbolia is non-irrigated. Vines are also non-irrigated. The amount of water applied is empirically defined.~~

~~Various forms of N-fertilizers are applied empirically without any analyses for the nutrient needs of the crops (about 4 kg per tree for olive trees).~~

~~Weed control is performed mostly with herbicides (80%) and tillage is used only in cv Koroneiki.~~

2.4 Kissamos catchment

The Kissamos catchment lies in the northwestern part of Crete in Chania prefecture. It constitutes one of the most important agricultural regions on the island. Of the total crops cultivated, 65% are olives (cv Koroneiki), 20% are vegetables, 5% are vines and 10% are other cultivars. Irrigation systems are mostly used for olive orchards. The amount of water applied is empirically defined. Various forms of N-fertilizers are applied empirically without any soil or leaf analyses for the nutrient needs of the crops. Weed control is performed mostly by tillage (70%), while herbicides are used by 20% only.

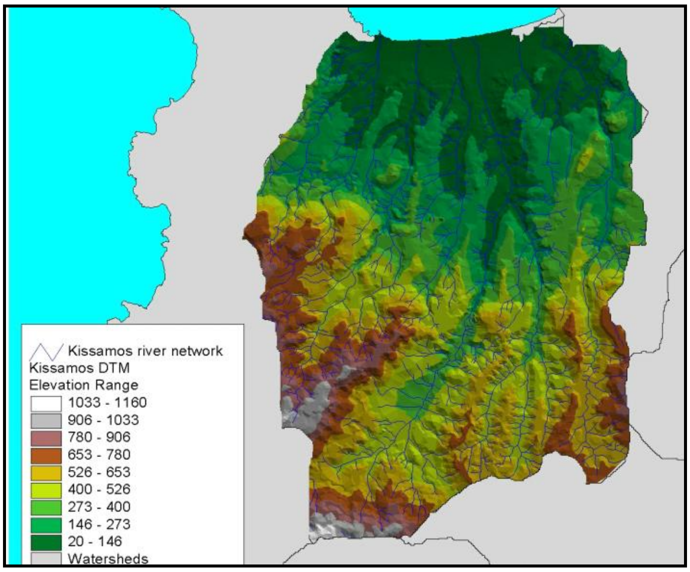


Figure 2.4.1: Kissamos catchment

The basic geological setting of the area is formed by Neogene formations overlying Palaeozoic formations, mainly phyllites and quartzites**.** The Neogene formations of Miocene up to Pleistocene age consist of conglomerates, white-gray marls and marly limestones on the top of the stratigraphical sequence. The upper Palaeozoic phyllites and quartzites crop out to the south of the area where the terrain becomes more mountainous.

The total permanent population of the area is about 5,000 inhabitants. The climate is sub-humid Mediterranean with mild winters and dry summers (aridity index=0.58). The mean annual temperature is estimated at 18+/-2 ^{0}C. The mean winter temperature is 13^{0}C and the mean summer temperature 24^{0}C. The mean annual precipitation is 745 mm, while the average monthly precipitation from April to September is 12.7 mm and from October to March 111.5 mm. The lowest annual rainfall observed was 350 mm and the maximum was 1100 mm in 30 years of record. Evapotranspiration varies from 1190 to 1420 mm/a.

Cultivated crops and cultivated land

Of the total crops cultivated, about 80% are olives (cv Koroneiki)(98% of the tree crops), 8% are vegetables, 3% are vines and 10% are fallow land and other cultivars.

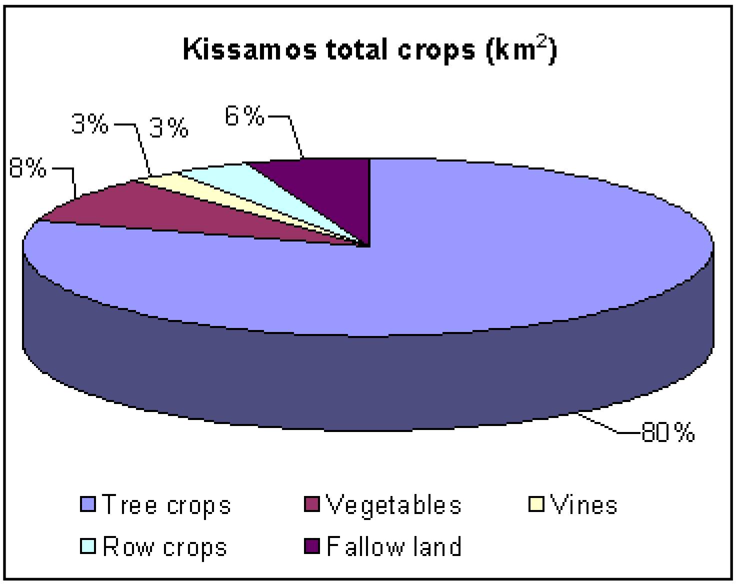


Figure 2.4.2: Crops cultivated in Kissamos catchment (HNSS 1999)

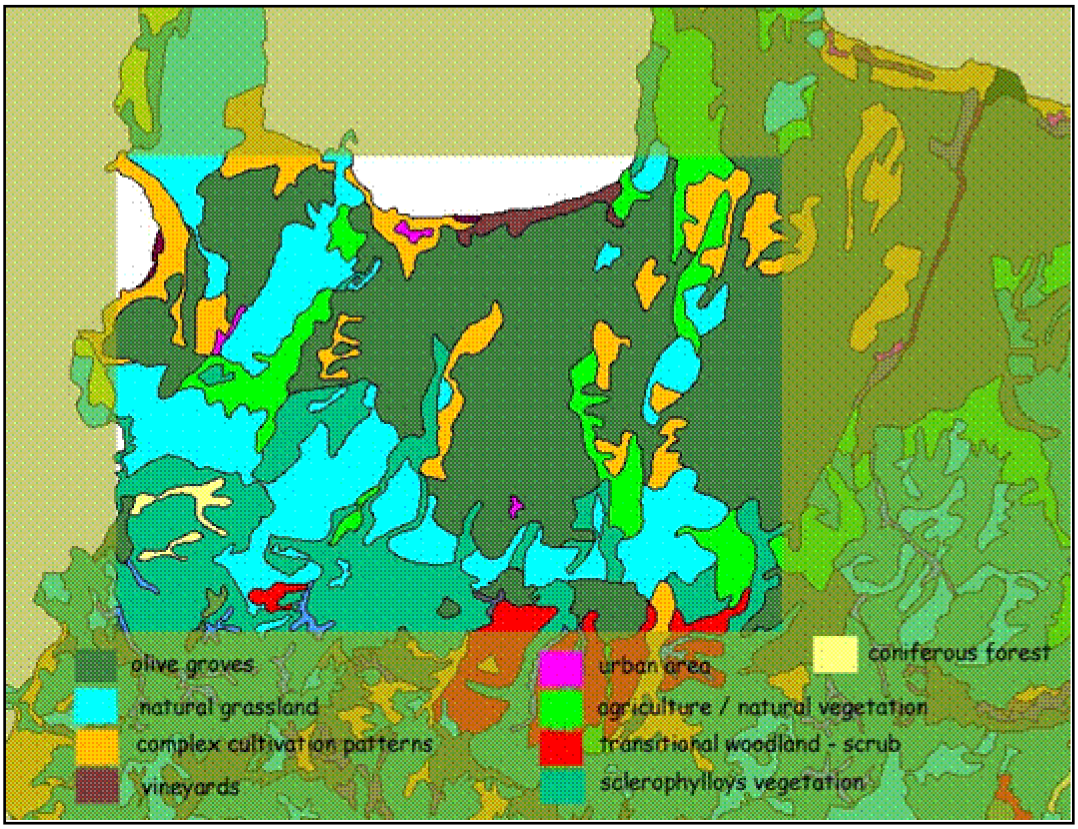


Figure 2.4.3: Land use map of Kissamos catchment (Corine)

Irrigation systems and scheduling

The amount of water applied is empirically defined. Approximately 2 Mm^3 of water is used for irrigation in Kissamos area. The average water price is approximately 0.08 €/m^3. The main irrigation system is drip irrigation.

Crop water requirements

Data from Drapanias station were used to estimate reference evapotranspiration for the period 1965 – 1992 with Penman – Monteith method. Missing data were filled from a station nearby (Zimbragou). Crop water requirements for the main crops in the catchment are presented on Table 2.4.1.

Table 2.4.1 Crop water requirements in Kissamos catchment

Crop	Crop water requirements (m^3x10^2/ha)												
	J	F	M	A	M	J	J	A	S	O	N	D	SUM
Olives	-	-	-	-	3.0	5.5	6.5	5.5	3.0	(1.0)*	-	-	**23.5 (24.5)***
Citrus	-	-	-	-	6.5	9.0	10.0	9.0	5.5	1.0	-	-	**41.0**
Table vines	-	-	-	-	-	7.5	8.0	7.5	4.5	-	-	-	**27.5**
Vines for wine	-	-	-	-	-	7.5	8.0	-	-	-	-	-	**15.5**
Greenhouse tomato (Oct – May)	2.0	2.0	3.0	5.0	9.0	-	-	-	-	2.5	2.5	2.0	**28.0**
Greenhouse cucumber (Aug – Dec)	-	-	-	-	-	-	-	3.5	7.5	7.5	5.5	4.5	**28.5**
Greenhouse cucumber (March – Jun)	-	-	3.0	6.0	8.0	8.5	-	-	-	-	-	-	**25.5**
Watermelons	-	-	-	-	8.0	10.5	12.0	10.5	-	-	-	-	**41.0**
Potatoes (spring)	-	-	2.5	3.5	8.0	5.0**		-	-	-	-	-	**19.0**
Onions	-	-	1.5	3.0	7.0	5.0**	-	-	-	-	-	-	**16.5**
Tomatoes (open field)	-	-	-	2.0	6.0	10.5	12.0	10.5	-	-	-	-	**41.0**

* Additional irrigation due to low rainfall and/or high temperatures

** Irrigation lasts until mid June

Taking into account the estimated crop water requirements, open field vegetables (tomatoes and watermelons) are the most highly water demanding crops in Kissamos catchment along with citrus, followed by table vines which though, do not account for a large area in the catchment.

Fertilisers

Various forms of N-fertilizers applied empirically without any soil or leaf analyses for the nutrient needs of the crops.

Weed control

Tillage and chemicals are equally used in weed control in Kissamos catchment.

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