THE GOULANDRIS NATURAL HISTORY MUSEUM
GREEK BIOTOPE / WETLAND CENTRE

Drought Vulnerability Index (DVI) in Attica Region, Greece using climate models upon the climate scenarios A1B and A2

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Working Team

Greek Biotope/Wetland Centre (EKBY):
Papadimos Dimitris, Katsavouni Sotiria

Republic Hydrometeorological Service of Serbia, RHMSS:
Aleksandra Krzic, Vladimir Djurdjevic

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C O N T E N T S

PART B

L I S T O F T A B L E S

L I S T O F F I G U R E S

L I S T O F M A P S

INTRODUCTION

A special study entitled "Drought and Water shortage Management Plan" was commissioned within the preparation of the River Basin Management Plan of Attica Water District (Ministry of Environment 2013). Its main purpose was to: a) quantify the effects of drought and water shortage in the water district of Attica, b) to examine possible methodologies for predicting future incidents and c) to propose remedies for various levels of risk.

This essay aims to strengthen the effectiveness of the above "Drought and Water shortage Management Plan" of the Attica Water District, by enhancing the forecasting process of future drought incidents.

Specifically:

a) Time series of monthly rainfall were created, in each meteorological station of the study area, for the next 100 years (2010-2100) by using climate models upon the climate scenarios A1B and A2.
b) The same drought index (SPI-12) and drought vulnerability index (DVI), as well as the same characterization limits of these indices, were used in order the results to be compatible with those in the "Drought and Water shortage Management Plan".

Following the above procedure, the first step was to collect rainfall data of the meteorological stations located within Attica Prefecture and Water District and then to process and complete the rainfall data of each station. In order to ensure the drought index calculation accuracy, it was attempted that the duration of the historical time series data is above 30 years (1970-2010).

The next step was to calculate SPI-12 and DVI indices, for the historical time series data, following the same methodology as the "Drought and Water shortage Management Plan". In this context there was a cross check with the results of the "Drought and Water shortage Management Plan".

Finally, the SPI-12 and DVI indices were calculated based on time series of monthly rainfall data for future years and the future incidents of drought, their duration and intensity were identified.

PART A

CLIMATE VARIATION IN THE PERIOD 1970-2010

1. METHODOLOGICAL APPROACH

1.1. GATHERING - PROCESSING - COMPLETION OF METEOROLOGICAL DATA

The main criteria for the selection of the monitoring stations were: a) the available information covering the period (1970-2010), and (b) the geographical distribution, covering evenly as much of the study area as possible.

Sources of raw data were monthly log sheets of the meteorological observations of the Ministry of Environment, Energy and Climate Change (MEECC.) and the National Meteorological Service (NMS). The primary piece of information posted in monthly steps for rainfall and temperature was obtained using Excel and Hydrognomon software (www.hydroscope.gr).

The primary recordings of meteorological parameters were the following processing stages:

• Filling of gaps (based on monthly values), which are usually due to instrument damage or observers omissions.

• Time projection of monthly values in cases where the stations operated in shorter periods than those of interest.

Simple linear regression (Koutsoyiannis and Xanthopoulos 1999, Papamichail 2001, Cleaver 2006) was used for data projection. According to this method, the projected value Yi is estimated from the corresponding value Xi (independent) of an adjacent reference station for the period of lack of data by station Y, based on the linear relationship:

$$Y_i = aX_i + b$$

where
Yi: the value to complete
Xi: the value of the reference station,
i: the relevant month,
a and b: parameters are estimated so as to minimize the squared error of the estimate.

The degree of suitability of the method is determined by the coefficient of linear correlation (r) between the values of two stations whose values range in the interval (-1, 1). To be statistically significant, a correlation coefficient r must be in absolute value greater than the critical value: $r > 0.7$.
In this way, the correlation of monthly rainfall and temperature between stations was estimated.

1.2. METEOROLOGICAL DATA IN THE REGION OF ATTICA

Table 1 below presents the meteorological stations, the altitude, the managing body of the station and the meteorological parameters. In the study area of Attica, the available meteorological stations that were taken into account are given in Figure 1.

Table 1: Features of meteorological stations in the study area

α/α	Name station	Altitude (m)	Managing Body	Meteorological parameters
1	Tatoi	237,9	NMS	rainfall, temperature
2	Elefsina	30	NMS	rainfall, temperature
3	Elliniko	10	NMS	rainfall, temperature
4	Marathonas	-	NMS	rainfall, temperature
5	Nea Filadelfeia	136	NMS	rainfall, temperature
6	Piraeus	7	NMS	rainfall, temperature
7	Paiania	152	NMS	rainfall, temperature
8	Megara	-	NMS	rainfall, temperature
9	Spata	67,6	NMS	rainfall, temperature
10	Markopoulo	83,6	MEECC	rainfall, temperature
11	Peristeri	75,4	MEECC	rainfall
12	Vyronas	226,4	MEECC	rainfall, temperature
13	Chalandri	189,3	MEECC	rainfall
14	Piraeus	-	MEECC	rainfall
15	3^{rd} Cemetery Nikaias-Egaleo	67,2	MEECC	rainfall
16	Agios Ierotheos	-	MEECC	rainfall

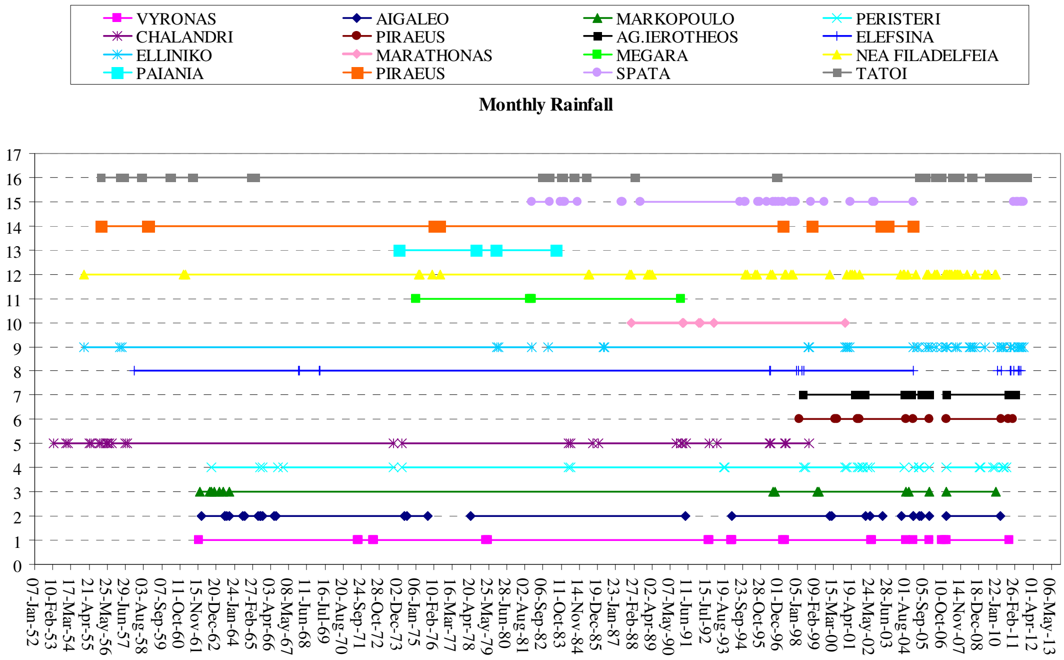


Figure 1: Period of data availability of monthly rainfall in the study area

From the above figure it is understood that in all stations presented several shortcomings either in individual months or into broader intervals covering different periods. In 6 of these stations, the observation period was too short and therefore chosen not to use their data (stations: Megara, Spata, Agios Ierotheos, Aigaleo, Paiania, Piraeus (MEECC). For the remaining 10 stations, to obtain complete time series of rainfall data, the available data were supplemented and projected to cover the period January 1970 – December 2010.

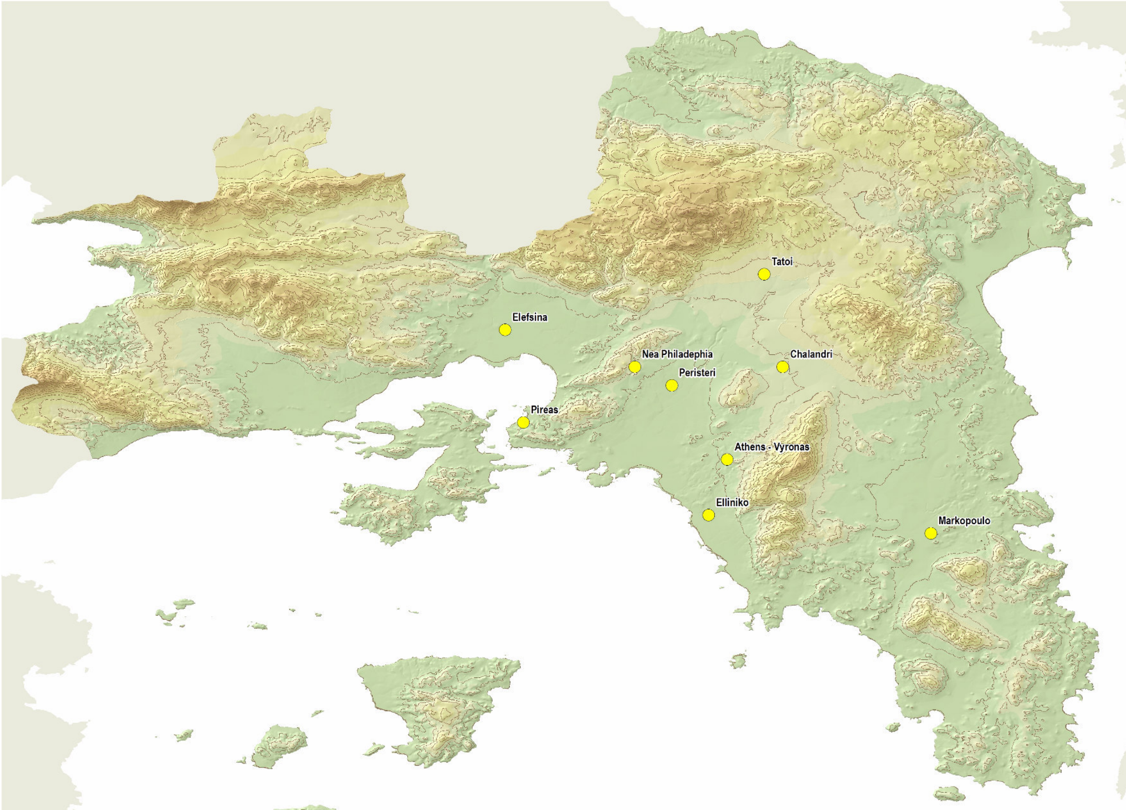


Figure 2: Meteorological stations in the region of Attica

The completion and projection of the data took place on a monthly scale. Initially estimated the correlation of monthly rainfall all stations between them. Correlation coefficients obtained from this analysis are given in table 2. The completion and projection of the data of each station was based on the data of an adjacent reference station with the greatest correlation.

Table 2: Linear correlation coefficients(r) among meteorological stations for monthly rainfall in the region of Attica

	Correlation coefficient (r)								
Meteorological stations	**Elefsina**	**Elliniko**	**Marathonas**	**Markopoulo**	**Peristeri**	**Tatoi**	**Nea Filadelfeia**	**Chalandri**	**Piraeus**
Vyronas	0,758	0,865	0,854	0,814	0,778	0,716	0,786	0,820	0,763
Elefsina		0,853	0,866	0,786	0,801	0,750	0,867	0,819	0,777
Elliniko			0,884	0,907	0,825	0,793	0,898	0,898	0,856
Marathonas				0,852	0,832	0,790	0,858	0,828	0,881
Markopoulo					0,785	0,788	0,843	0,882	0,783
Peristeri						0,754	0,878	0,846	0,760
Tatoi							0,831	0,843	0,672
Nea Filadelfeia								0,907	0,809
Chalandri									0,811

- *Gap filling of station Markopoulo*

  Data of the Elliniko station were used in order to supplement monthly rainfall values of Markopoulo station, due to their strong positive correlation.
- *Gap filling of station Elliniko*

  Data of the Markopoulo and Vyrona station were used in order to supplement monthly rainfall values of Elliniko station, due to their strong positive correlation.
- *Gap filling of station Vyronas*

  Data of the Elliniko station were used in order to supplement monthly rainfall values of Vyronas station, due to their strong positive correlation.
- *Gap filling of station Chalandri*

  Data of the Nea Filadelfeia and Elliniko station were used in order to supplement monthly rainfall values of Chalandri station, due to their strong positive correlation.
- *Gap filling of station Nea Filadelfeia*

  Data of the Chalandri and Elliniko station were used in order to supplement monthly rainfall values of Nea Filadelfeia station, due to their strong positive correlation.
- *Gap filling of station Elefsina*

  Data of the Nea Filadelfeia station were used in order to supplement monthly rainfall values of Elefsina station, due to their strong positive correlation.

- *Filling station Piraeus*

  Data of the Elliniko station were used in order to supplement monthly rainfall values of Piraeus station, due to their strong positive correlation.

- *Filling station Tatoi*

  Data of the Chalandri station were used in order to supplement monthly rainfall values of Tatoi station, due to their strong positive correlation.

- *Filling station Marathonas*

  Data of the Elliniko station were used in order to supplement monthly rainfall values of Marathona station, due to their strong positive correlation.

- *Filling station Peristeri*

  Data of the Nea Filadelfeia station were used in order to supplement monthly rainfall values of Peristeri station, due to their strong positive correlation.

In Figures 3-12 is shown graphically the variation of the annual rainfall of stations Vyronas, Elefsina, Elliniko, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Piraeus and the linear trend respectively.

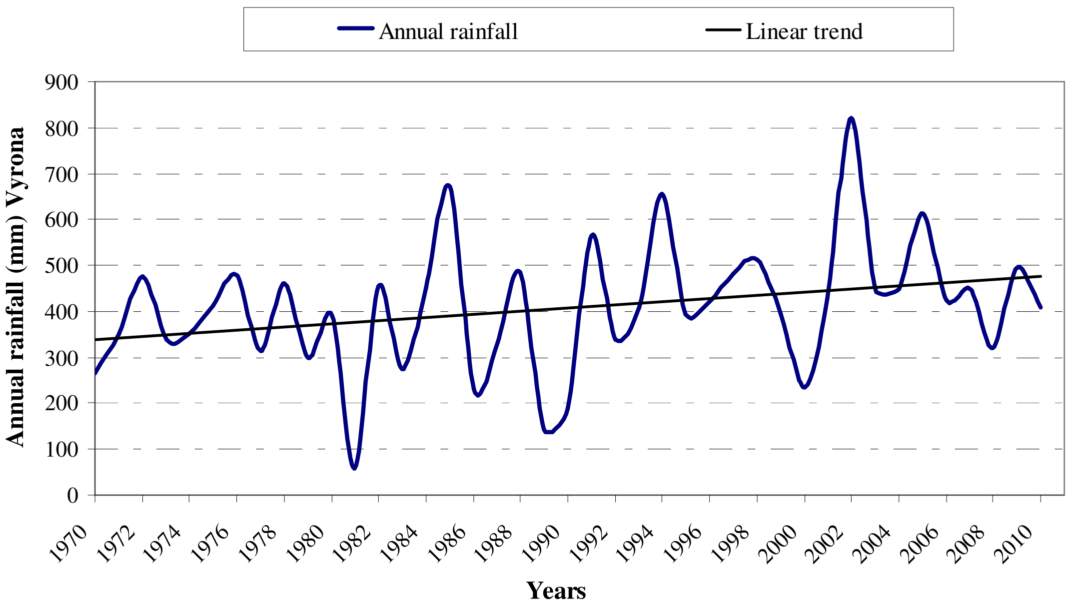


Figure 3: Annual rainfall and linear trend in the Vyronas station

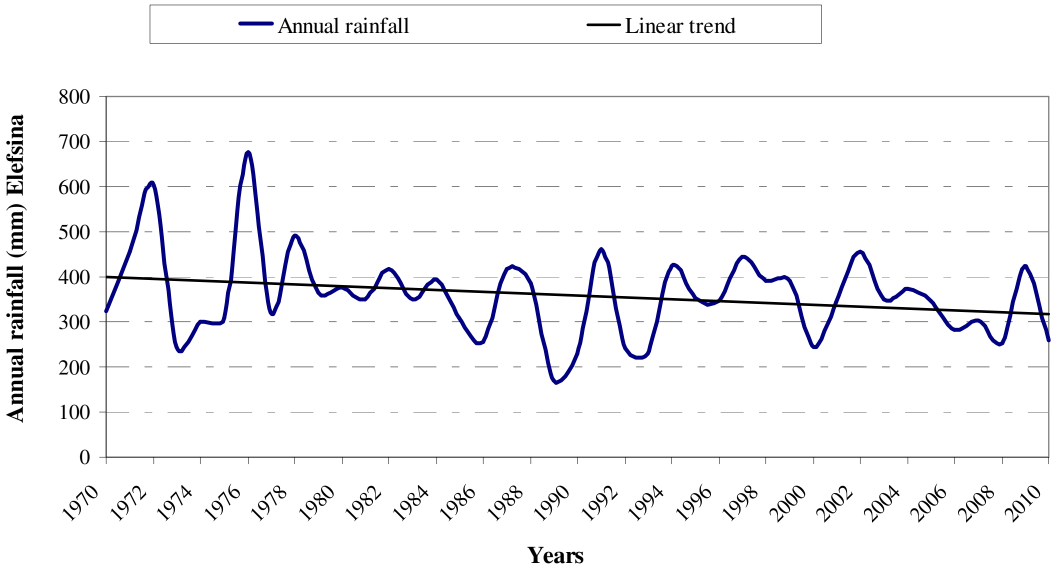


Figure 4: Annual rainfall and linear trend in the Elefsina station

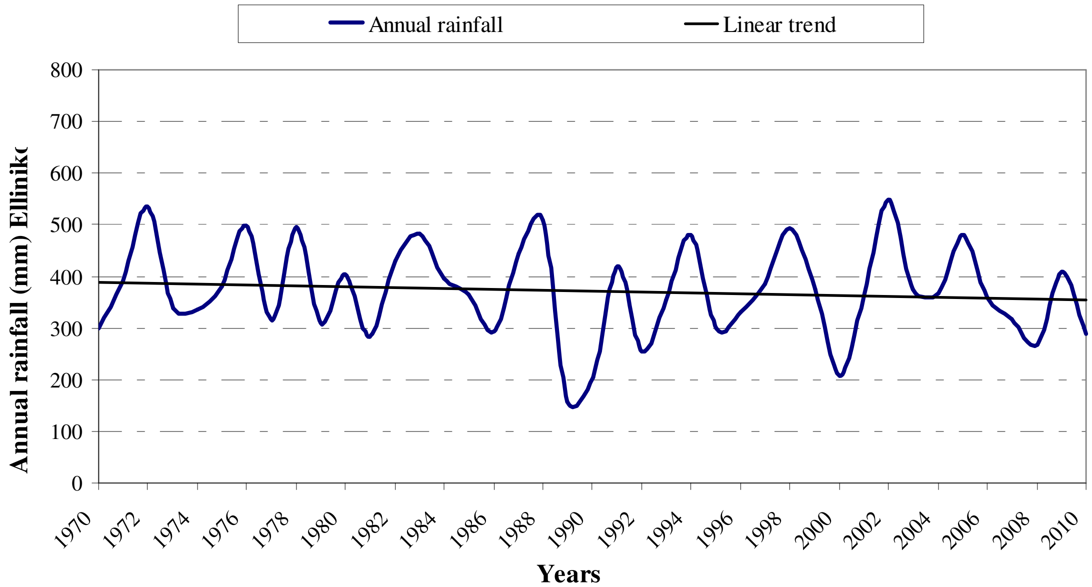


Figure 5: Annual rainfall and linear trend in the Elliniko station

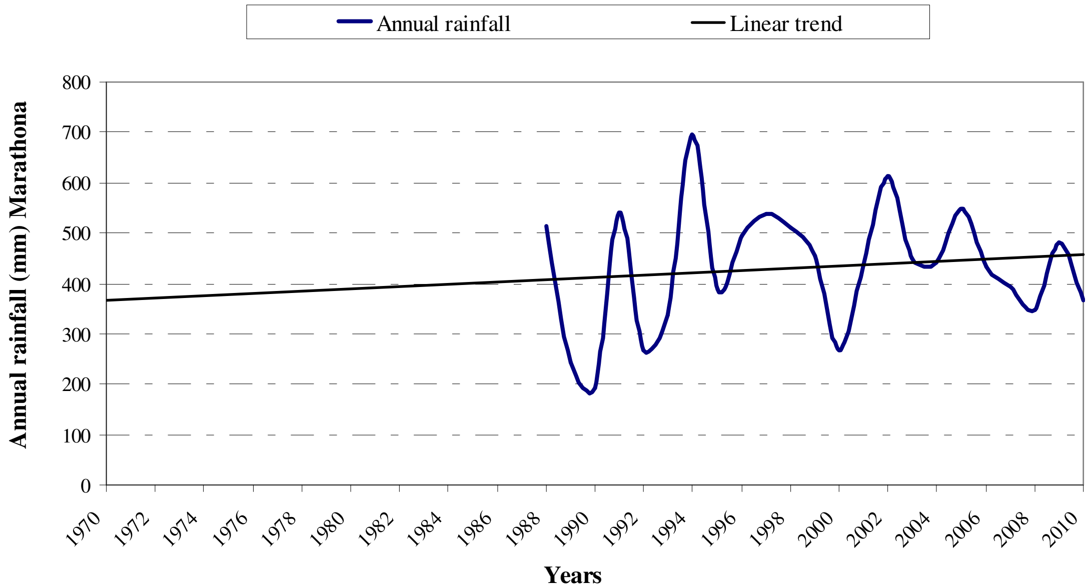


Figure 6: Annual rainfall and linear trend in the Marathonas station

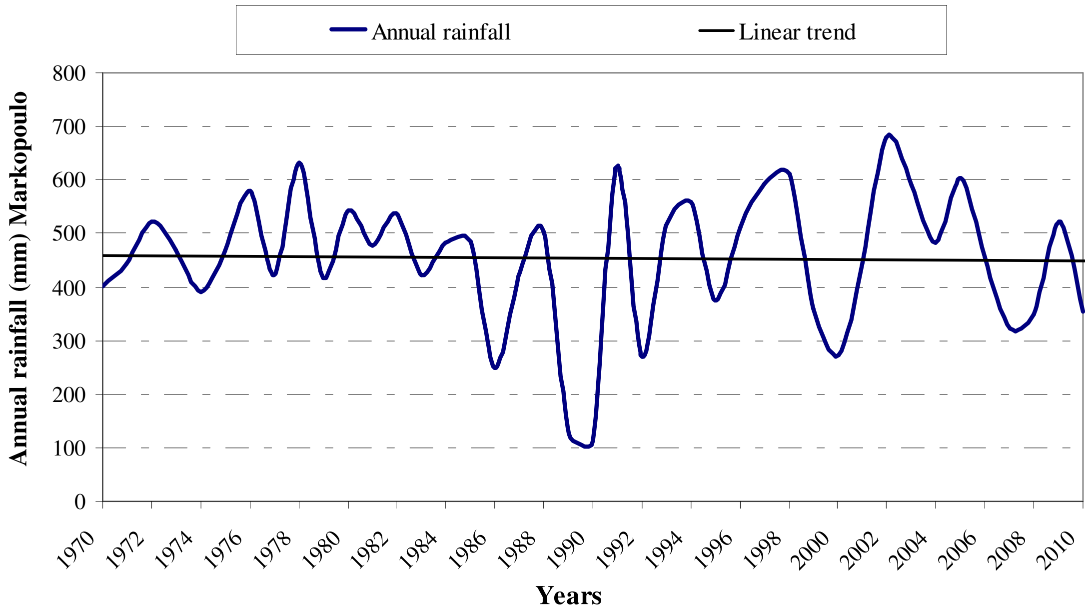


Figure 7: Annual rainfall and linear trend in the Markopoulo station

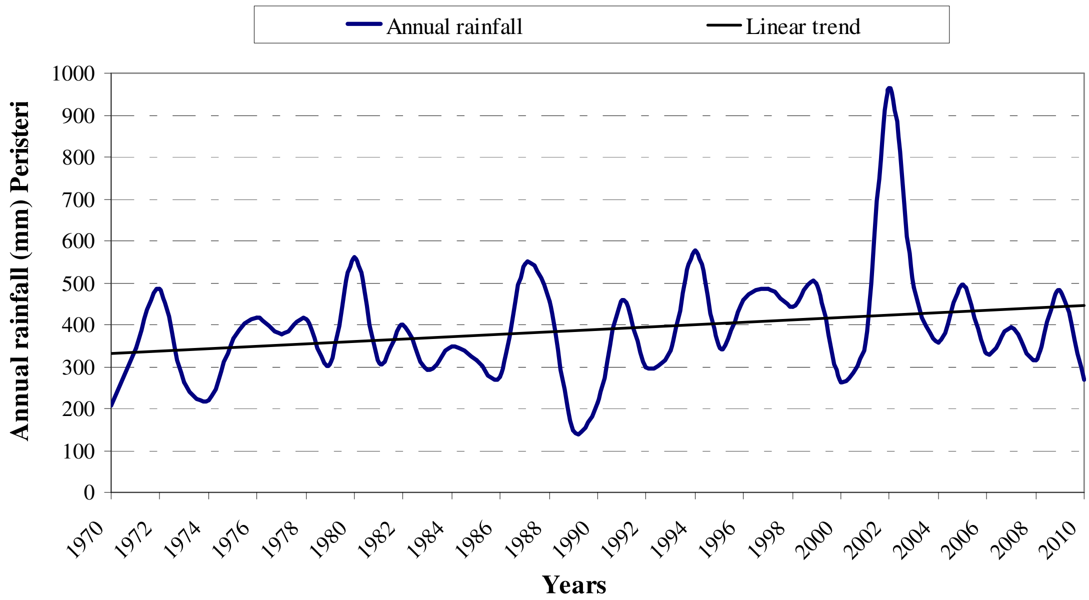


Figure 8: Annual rainfall and linear trend in the Peristeri station

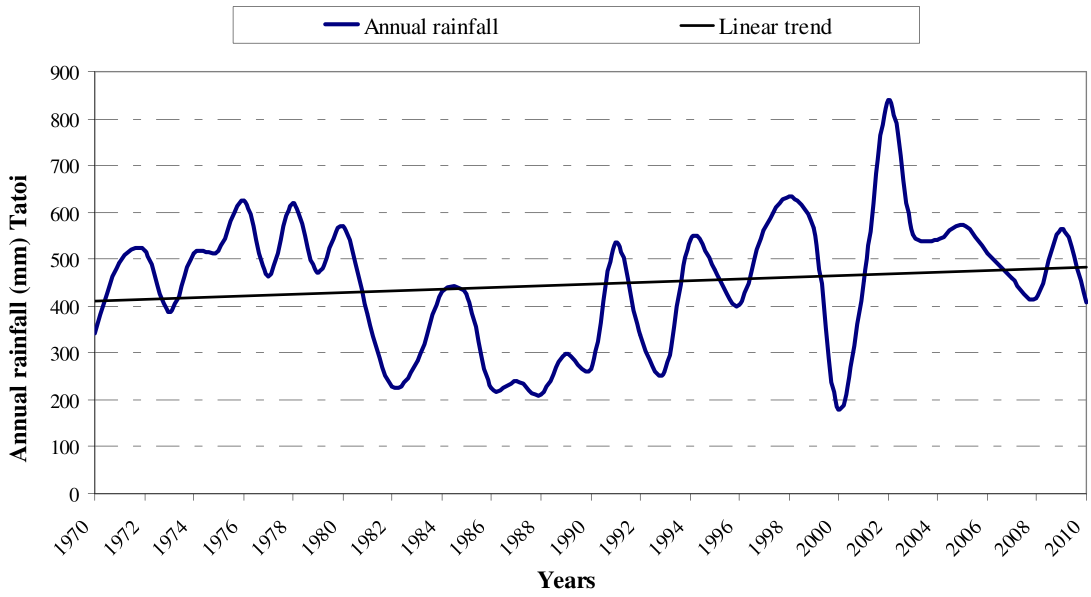


Figure 9: Annual rainfall and linear trend in the Tatoi station

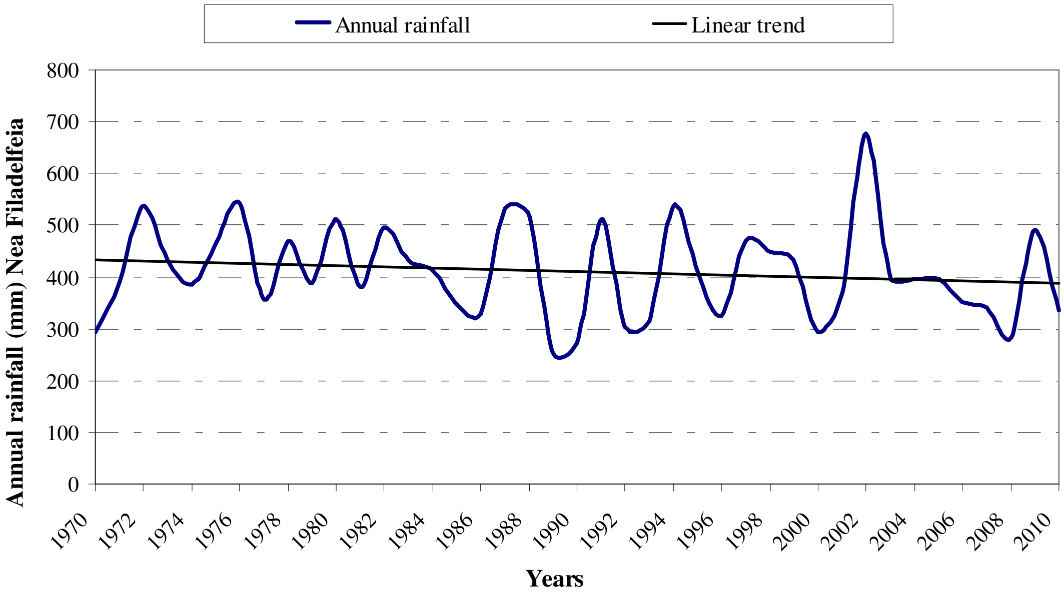


Figure 10: Annual rainfall and linear trend in the Nea Filadelfeia station

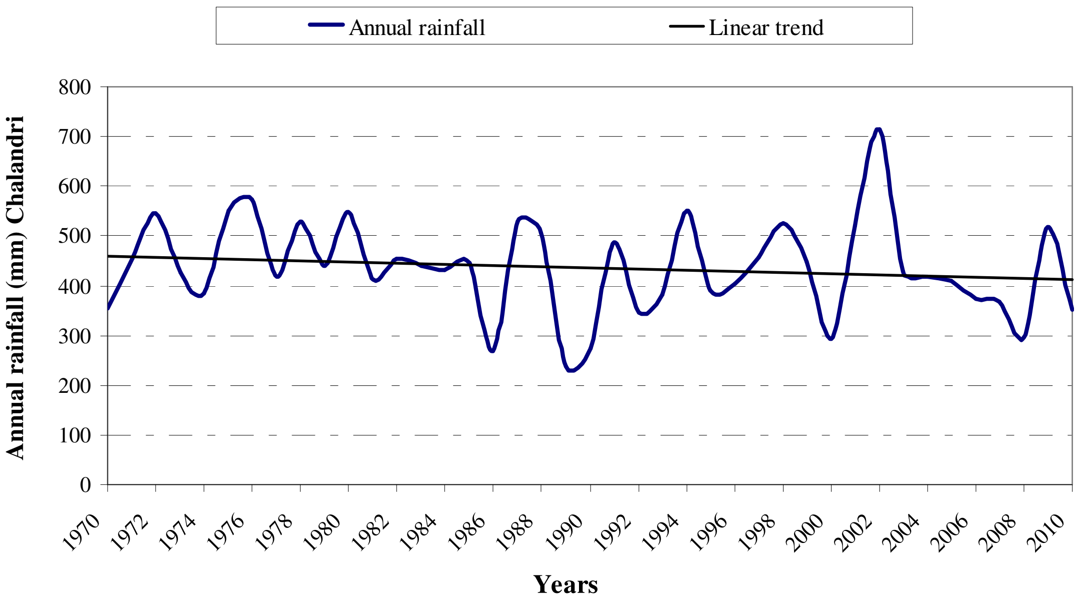


Figure 11: Annual rainfall and linear trend in the Chalandri station

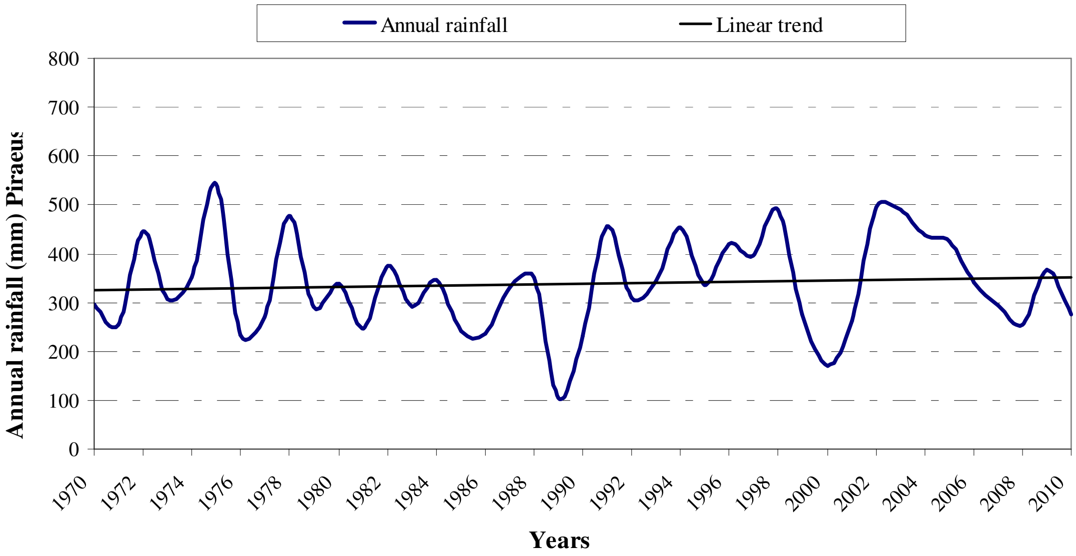


Figure 12: Annual rainfall and linear trend in the Piraeus station

The average annual rainfall of stations Vyrona, Elefsina, Elliniko, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Piraeus is 407,0 mm, 357,8 mm, 371,8 mm, 453,9 mm, 387,1 mm, 447,0 mm, 410,5 mm, 436,9 mm, 337,9 mm respectively, after the completion of missing values for the period January 1970 to December 2010, while the Marathon station amounted to 433,0 mm for the period January 1988 to December 2010.

In figures 13 to 22 the monthly average values of rainfall for stations Vyronas, Elefsina, Elliniko, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Piraeus respectively after their completion and for the above-mentioned period.

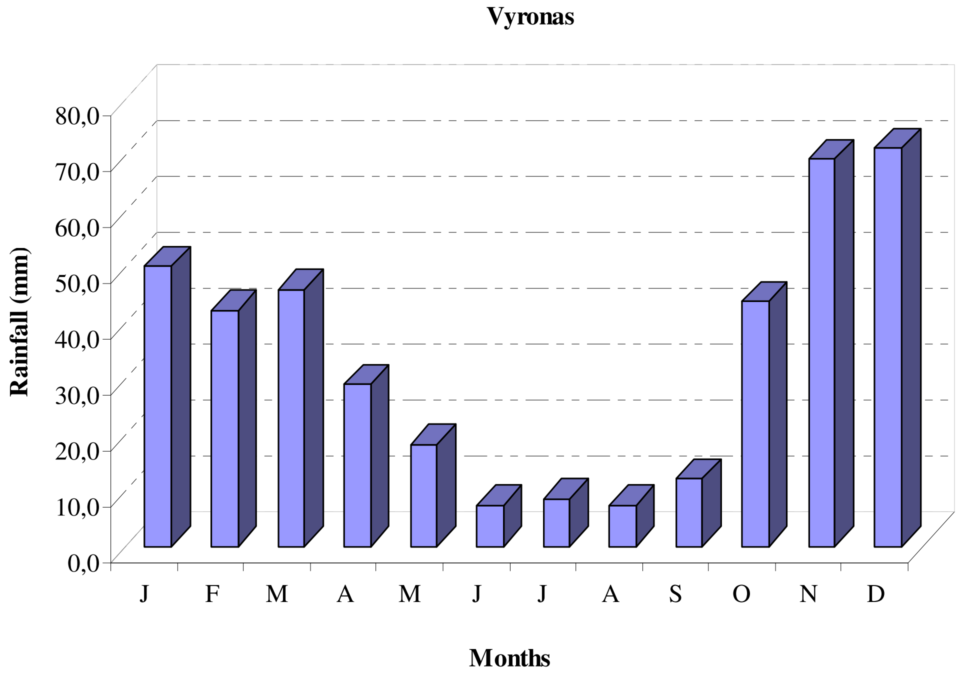


Figure 13: Average monthly rainfall in Vyronas station for the period 1970-2010

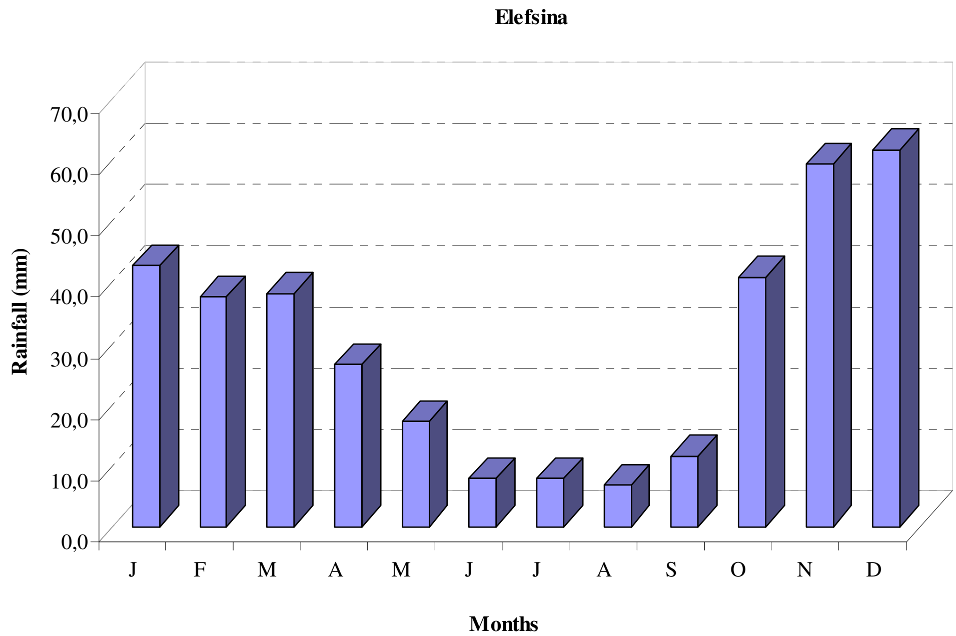


Figure 14: Average monthly rainfall in Elefsina station for the period 1970-2010

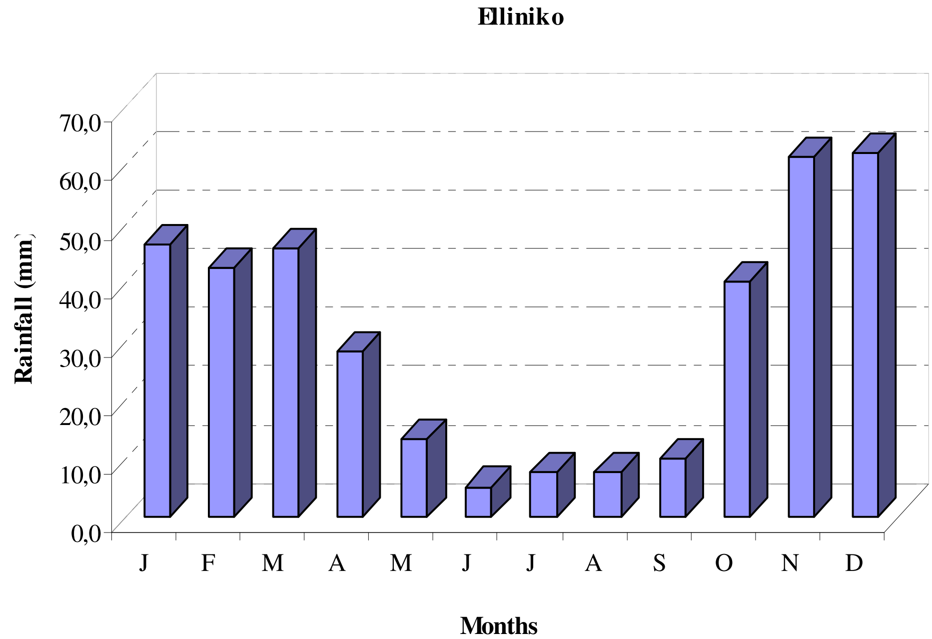


Figure 15: Average monthly rainfall in Elliniko station for the period 1970-2010

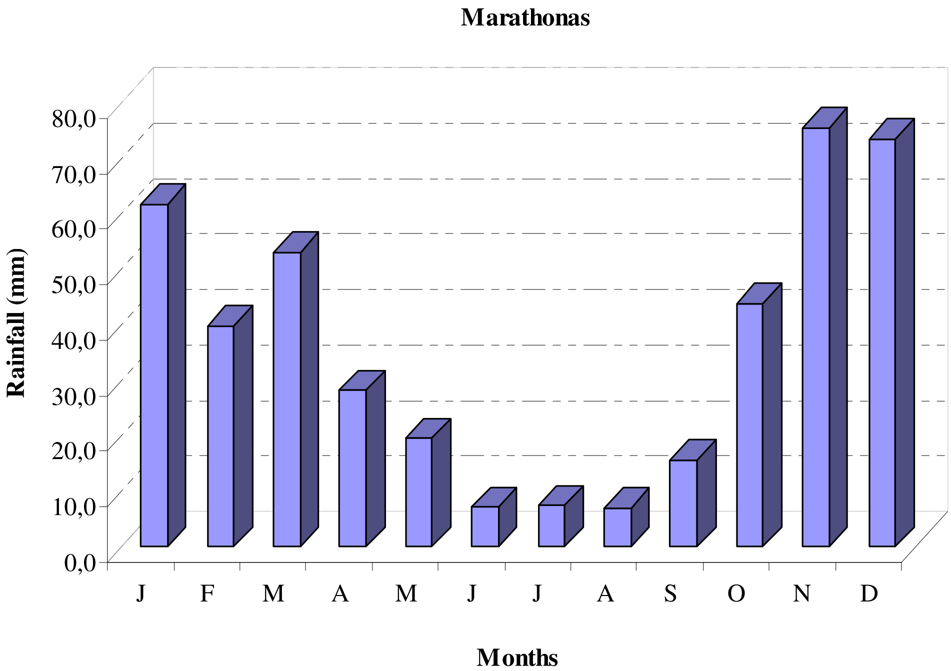


Figure 16: Average monthly rainfall in Marathonas station for the period 1970-2010

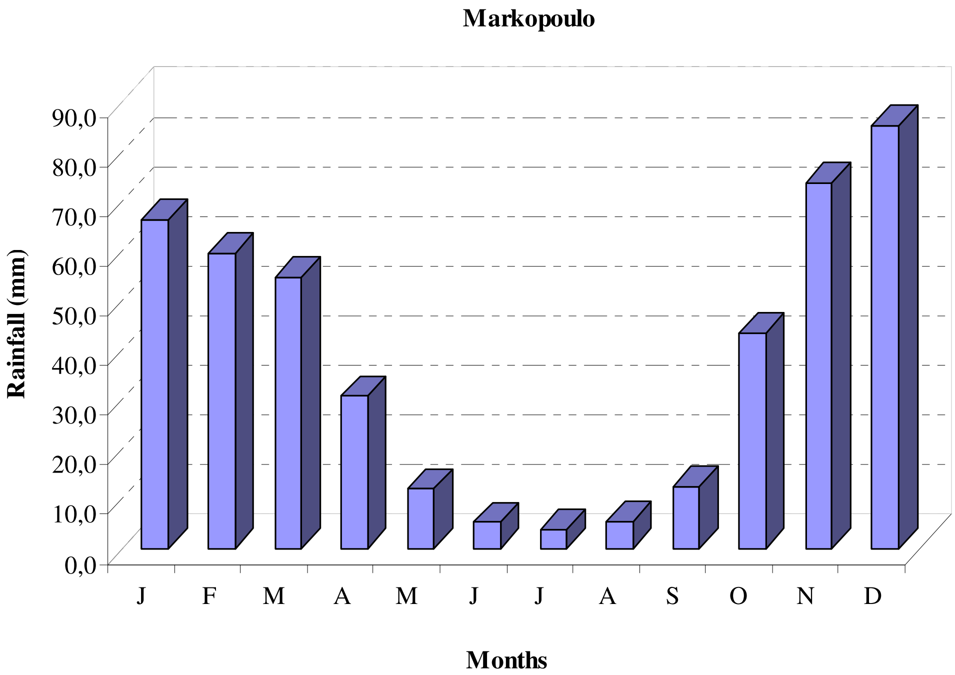


Figure 17: Average monthly rainfall in Markopoulo station for the period 1970-2010

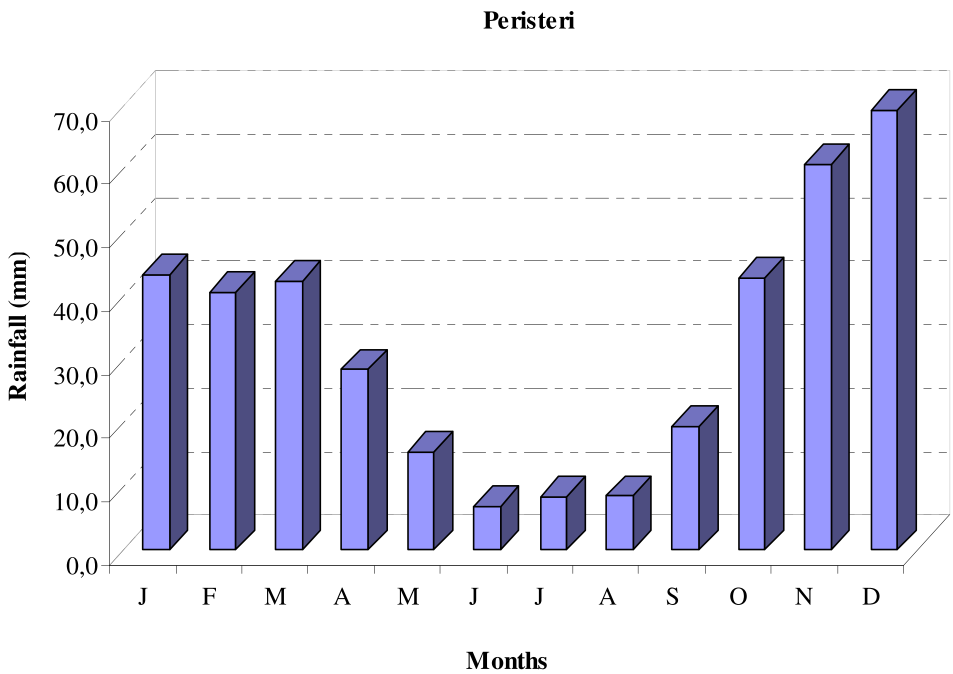


Figure 18: Average monthly rainfall in Peristeri station for the period 1970-2010

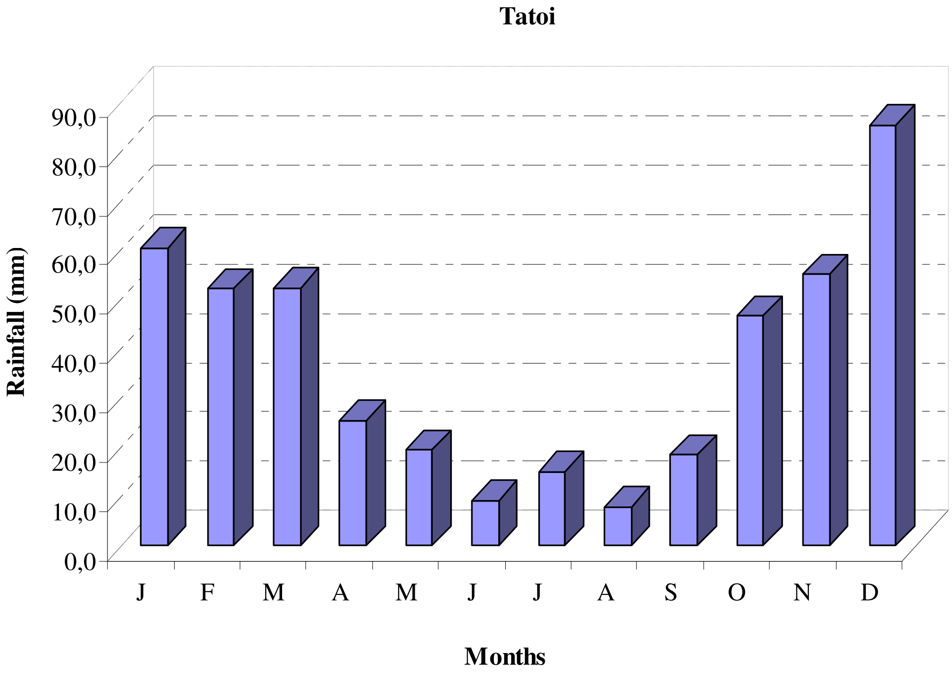


Figure 19: Average monthly rainfall in Tatoi station for the period 1970-2010

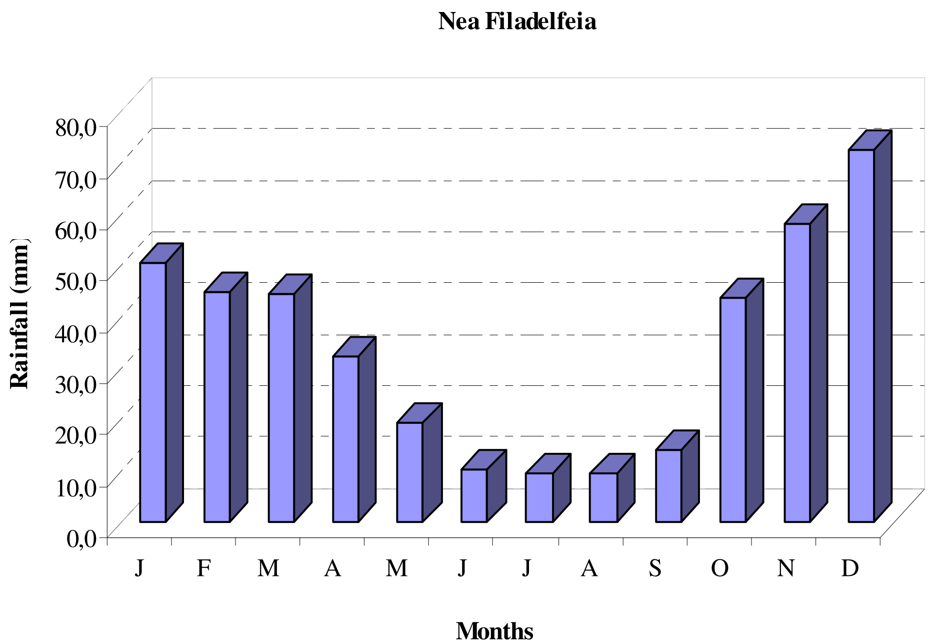


Figure 20: Average monthly rainfall in Nea Filadelfeia station for the period 1970-2010

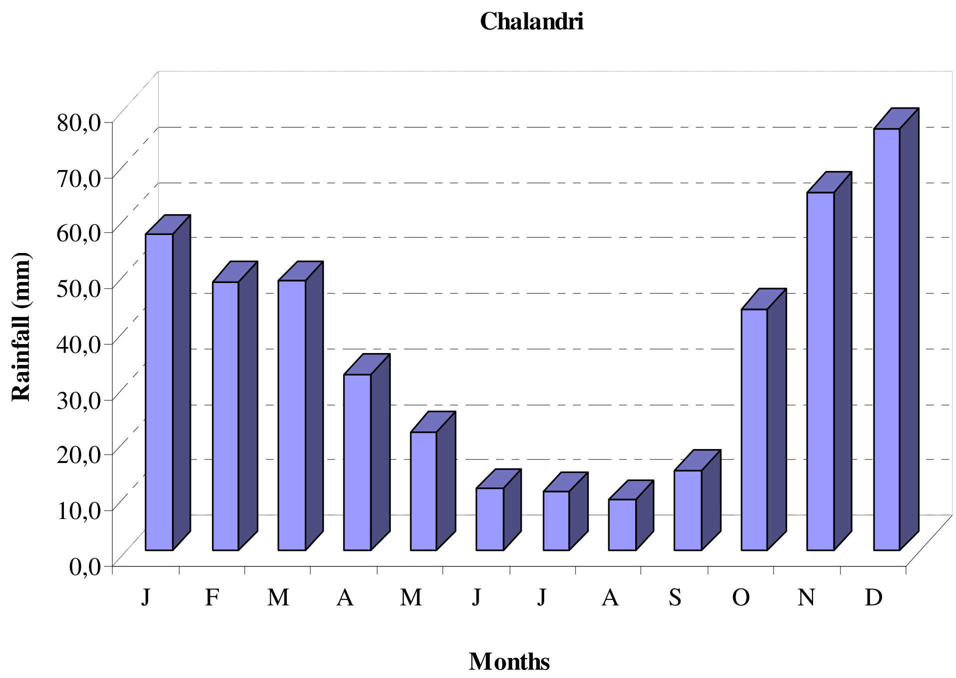


Figure 21: Average monthly rainfall in Chalandri station for the period 1970-2010

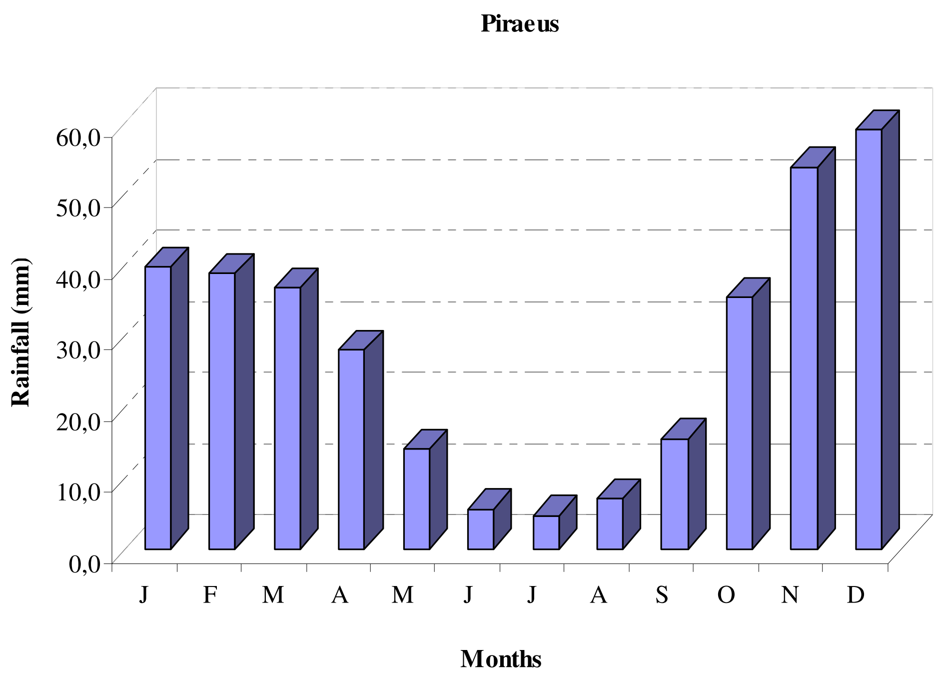


Figure 22: Average monthly rainfall in Piraeus station for the period 1970-2010

From the above figures, it appears that the maximum rainfall occurs during the month of December for all of the meteorological stations except the Marathon station where the maximum is observed in the month of November. Regarding the minimum of rainfall observed during the month of June for the stations at Vironas, Elliniko, Peristeri, Tatoi, during the month of July for the stations at Markopoulo and Pireus and the month of August for stations at Elefsina, Marathona, Nea Filadelfeia and Chalandri.

2. DROUGHT INDEX SPI (Standardized Precipitation Index)

The drought index SPI was developed by McKee et al (1993) and it is based on rainfall observations for a given period. The longer this period, the more reliable are the results. According to McKee et al. (1993) the period must be at least 30 years.

The calculation of the SPI is obtained by subtracting the average price of the period investigated from the rainfall, and dividing the result by the standard deviation. However, because the rainfall has no normal distribution there is a setting that allows SPI to have normal distribution. Therefore, the average value of the SPI for a time period and for a specific region is 0 and the standard deviation is 1. The normalization of the SPI index has the advantage that wetter and drier portions can be represented in the same way.

The nature of the SPI allows the identification of a rare incident of drought or an extremely wet episode that can occur in any area and at any time, provided that there are sufficient data.

The SPI can be calculated for different time scales. The McKee et al (1993) calculated the SPI for 3-, 6-, 12-, 24- and 48- month intervals. The small time scales are sufficient to assess and characterize the agricultural and the meteorological drought while for the hydrological drought larger scales are required. It has been shown that the 3- or 6-months SPI is related to soil moisture (Sims et al., 2002; Ji and Peters, 2003), which is crucial for vegetation and agriculture and thus the agricultural as well as the meteorological drought is controlled (McKee et al. 1993; Hayes et al. 1999), while the 12- months SPI is related to water resources (reservoirs, rivers, groundwater) and therefore the hydrological drought is controlled (Szalai et al. 2000; Hayes et al. 1999).

The SPI is a dimensionless index; where positive values indicate rainfall higher than 50 % of the observations and respectively, negative values indicate rainfall lower than 50 % of the observations. This normalization of SPI has the advantage that wetter and drier incidents can be represented in the same way.

The characterization of drought incidents, based on the SPI grading scale given by McKee et al. (1993), are given in Table 3 (Apostolou 2010). The table also contains the corresponding probabilities of each category's occurrence. The criteria for an incident of drought at any time scale were also set. An episode of drought begins when the SPI index gets a negative value, continues with negative values and becomes intense when the SPI index gets a negative value less than or equal to -1.5. The episode ends when the SPI index gets a positive value. So each drought incident has a duration, which is determined by a start, an end and intensity for each month that the incident continues.

Table 3. Drought classification based on the index SPI and corresponding occurrence probabilities

SPI Value	Category	Probability %
SPI ≥ + 2.00	Extremely wet	2.3
1.50 ≤ SPI ≤ 1.99	Severely wet	4.4
1.00 ≤ SPI ≤ 1.49	Moderately wet	9.2
0.00 ≤ SPI ≤ 0.99	Near normal	34.1
- 0.99 ≤ SPI ≤ 0.00	Near normal	34.1
- 1.49 ≤ SPI ≤ - 1.00	Moderately dry	9.2
- 1.99 ≤ SPI ≤ - 1.50	Severely dry	4.4
SPI ≤ - 2.00	Extremely dry	2.3

Source: Apostolou (2010)

2.1. CALCULATION OF SPI INDEX

In the "Drought and Water Shortage Management Plan" drawn up for the Basin Management Plan of Attica, SPI indicator was used for 12 months period (SPI12). For the calculation of SPI12 monthly rainfall data were used, collected from 11 meteorological stations of the specific region through the period from 1980 to 2010. The stations and the time periods studied are presented at Table 4.

In the context of OrientGate project, the same stations were used except the Asteroskopeio and the Marathon dam's stations. Additionally, the duration of the studied time-series of the monthly rainfall values of each station, was chosen to be grater than 30 years (1970 – 2010), to ensure the reliability of the results (Table 4) regarding the calculation of the drought indicator.

Table 4: Meteorological stations and corresponding time intervals studied in the context of "Drought - Water shortage Management Plan" and project OrientGate

a/a	Meteorological station	Drought – Water shortage Management Plan		OrientGate	
		Period			
		from	to	from	to
1	Asteroskopio	1980 – 81	2008 – 09		
2	Vyronas	1980 – 81	2009 – 10	1970 – 71	2009 – 10
3	Elefsina	1980 – 81	2000 – 01	1970 – 71	2009 – 10
4	Elliniko	1980 – 81	2005 – 06	1970 – 71	2009 – 10
5	Marathonas	1980 – 81	2000 – 01	1988-1989	2009-2010
6	Markopoulo	1980 – 81	2008 – 09	1970 – 71	2009 – 10
7	Peristeri	1980 – 81	2009 – 10	1970 – 71	2009 – 10
8	Tatoi	1980 – 81	2000 – 01	1970 – 71	2009 – 10
9	Filadelfeia	1980 – 81	2005 – 06	1970 – 71	2009 – 10
10	Dam of Marathona	1980 – 81	2000 – 01		
11	Chalandri	1980 – 81	2000 – 01	1970 – 71	2009 – 10
12	Piraeus			1970 – 71	2009 – 10

For the detailed calculation of SPI-12 index, it was followed the methodology developed by McKee et al. (1993) as described in «Drought-Water shortage Management Plan» (MEECC 2013). In accordance with the above, the SPI index is calculated from the relationship:

$$z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0 < H(x) < 0.5$$

$$z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0.5 < H(x) < 1.0$$

where:

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \qquad \text{for } 0 < H(x) < 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \qquad \text{for } 0.5 < H(x) < 1.0$$

and

$c_0 = 2.515517$ $c_1 = 0.802853$ $c_2 = 0.010328$

$d_1 = 1.432788$ $d_2 = 0.189269$ $d_3 = 0.001308$

$H(x) = q + (1 - q)G(x)$

and

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}-1} e^{-t}\, dt$$

where q is the possibility of zero-rainfall. If m is the amount of the zero-rainfall occasions during the time-series, then q can be calculated from the equation $q=m/n$. Other approaches for handling the zero-rainfall occasions is by replacing them with a very small quantity (i.e. 1 mm) (Loukas and Vasiliades 2004)

These relations were used through Excel software and SPI-12 index values were calculated for all the stations. In Annex I, SPI-12 values are graphically presented for the time period between 1970 and 2010.

In Figure 23 the drought events, intensity and duration are given, as calculated for each station for the historical period (1970 – 2010).

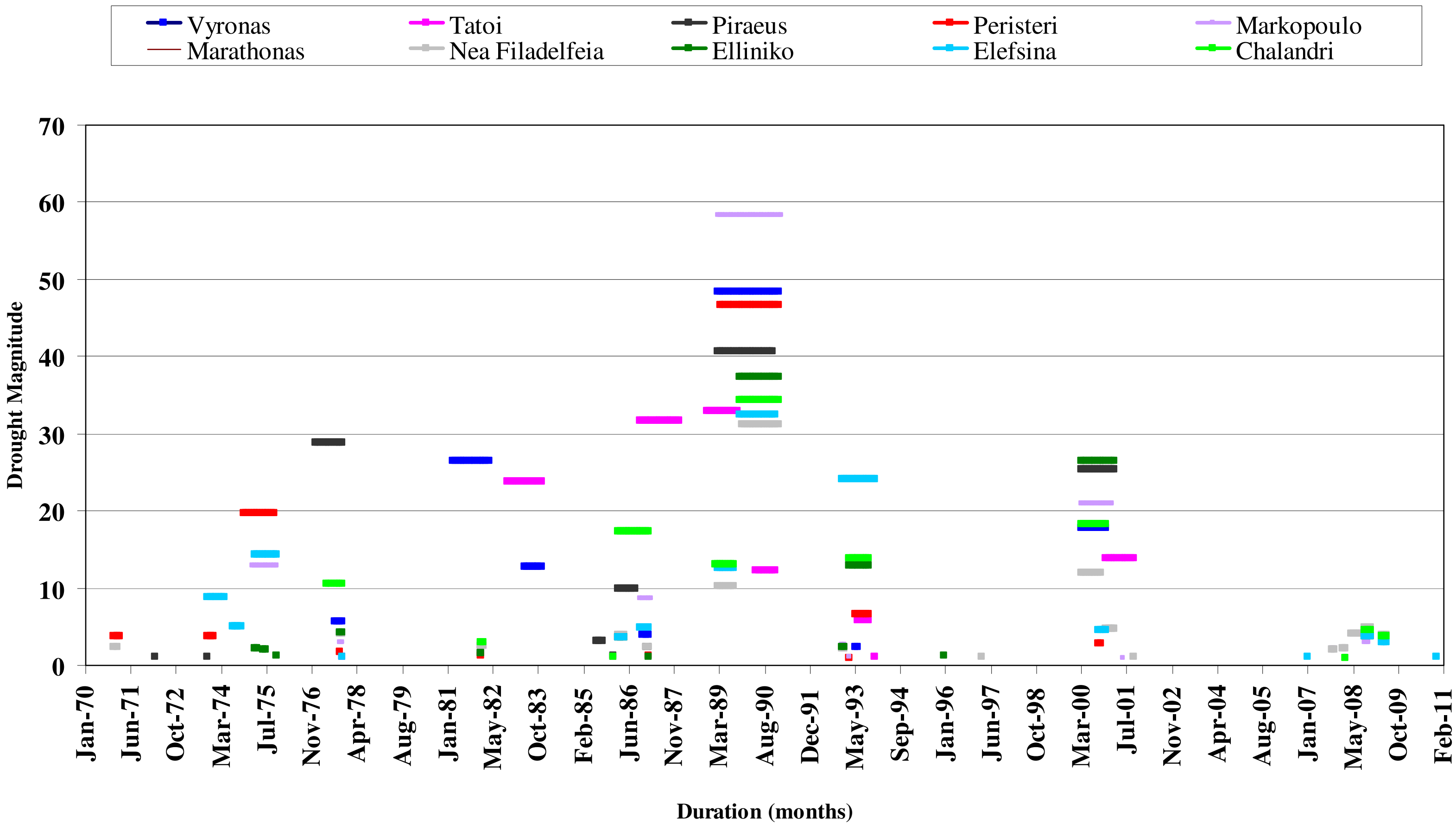


Figure 23: Drought events, intensity and duration in the meteorological stations of Attica for the historical period (1970 - 2010)

3. DROUGHT VULNERABILITY INDEX (DVI)

Within the "Drought and Water Shortage Management Plan" project, for the further valuation of the drought vulnerability in the regions subjected in the Basin Management Plan of Attica and the determination of the high risk zones, the Drought Vulnerability Index (DVI) was developed and used (MEECC 2013). According to the writers: "… this indicator aims to the overlaying of all the drought characteristics (duration, intensity, occurrence frequency), as they are analyzed and calculated with the SPI-12 indicator".

In this current study, indicator DVI and its calculation method have been used, as well as the characterization boundaries of the drought vulnerability. According to the methodology, described in the "Drought and Water Shortage Management Plan" (MEECC 2013), DVI indicator is calculated with the following equation:

DVIi = 0.25 * Score (drought events) + 0.25 * Score (drought events with duration > 24 months) + 0.25 * Score (DM_max) + 0.25 * Score (Duration_max)

where:

DVIi: Drought Vulnerability Index for station i

- drought events: Number of drought events observed in the investigation period
- drought events with duration > 24 months: Number of drought events with duration longer than 24 months observed in the investigation period
- DM_max: Maximum size of drought event in the investigation period
- Duraton_max: Maximum duration of drought events in the investigation period

The above parameters were calculated for each station (i) based on the index SPI-12, and on the classification in 4 classes where the score receives values from 1-4 (1: low Vulnerability, 4: high Vulnerability) (Table 5).

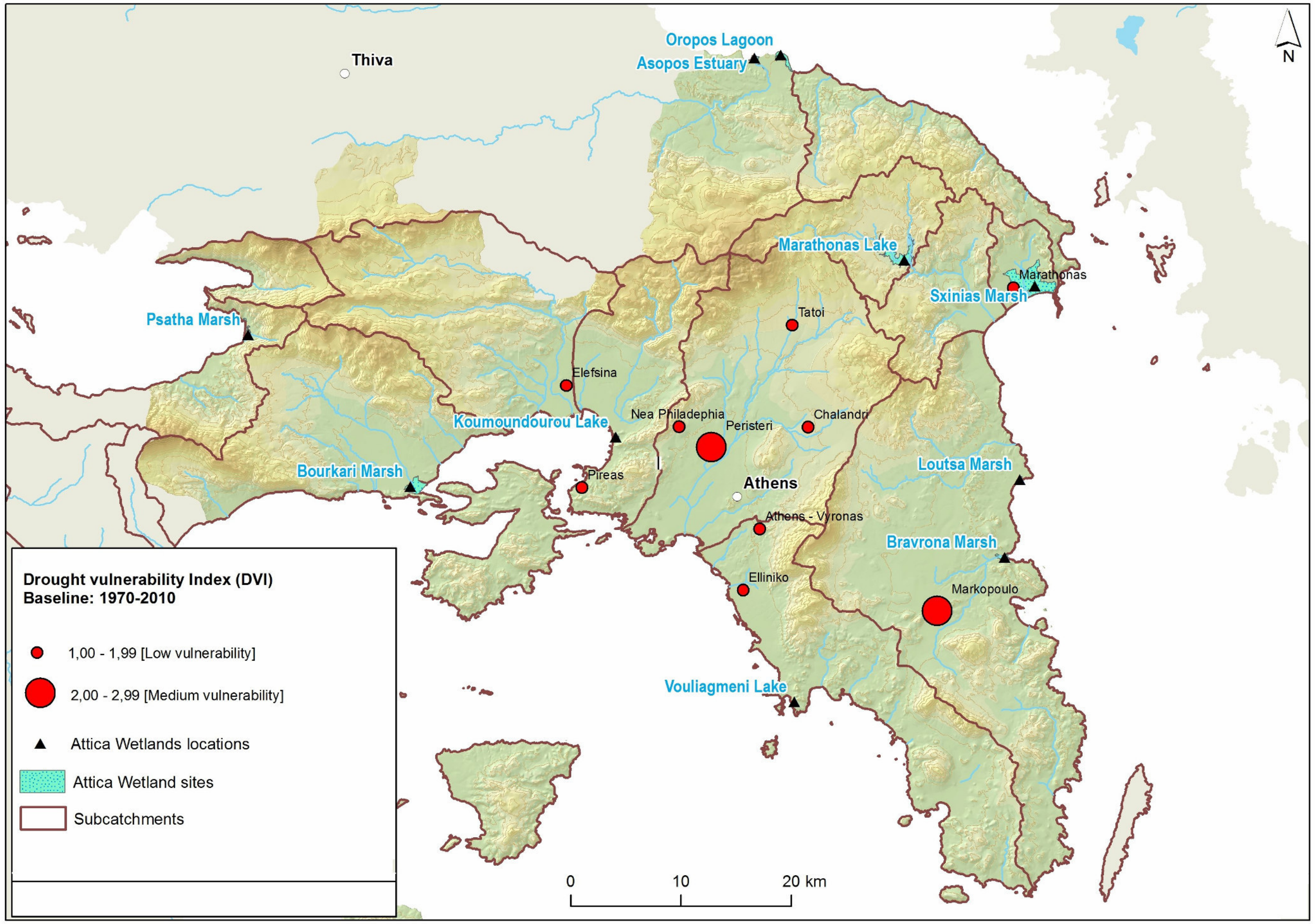
Table 5. Classification of parameters for calculating the DVI into classes and Score

Drought incidents	Drought events with duration>24 months	Maximum size of drought	Maximum duration of drought event	Score
0-10	0-4	0 – 30	0 – 20	1
11-20	5-6	31 – 40	21 – 30	2
21-30	7-8	41 – 50	31 – 40	3
>31	>9	> = 51	>=41	4

Based on the SPI index:

- As starting time of a drought event is set the moment (month in the current analysis) when SPI-12 takes a negative value, and reaches subsequently the -1 value for the following months, without getting any positive value in the meantime.
- As ending time of the event, the month is set when the first positive value is observed.
- In the case that the SPI-12 Index is negatively valued, for several consequent months without reaching -1 value (negative values lower than -1), then this event is not considered as drought event, but simply a dryer period than the average.
- The size of a drought event DM (Drought Magnitude), is defined as the absolute value of the sum of the time-series SPI-12, during the months that the drought event lasted.

The DVI index was calculated for each meteorological station, for the historic period 1970 – 2010. The optical imaging is shown in the Maps 1.



Map 1: Drought Vulnerability Index (DVI) in the meteorological stations of Attica for the historical period 1970 – 2010

PART B

ESTIMATION OF CLIMATE VARIATION IN THE PERIOD 2010-2100

4. RAINFALL TIME-SERIES OF CLIMATE CHANGE SCENARIOS A1B & A2

The forecasting climate model (Kržič et al. 2011) was applied to the climate change scenarios A1B and A2 in the 10 meteorological stations of the study area for the period 2010-2100. The characteristics of scenarios A1B and A2 are summarised as follows:

Scenario A1B: Rapid economic growth. Particularly strong consumption of energy, but also spread of new and efficient technologies. Use of both fossil fuels and alternative energy sources. Small changes in land uses. Rapid rise in global population by 2050 and gradual decline thereafter. Large increase in CO2 concentration in the atmosphere, to 720 ppm by 2100.

Scenario A2: Moderate increase in global average per capita income. Particularly strong energy consumption. Rapid rise in global population. Slow and fragmented technological change, and modest to major changes in land uses. Rapid rise in CO2 concentration in the atmosphere, to 850 ppm by 2100.

4.1. Climate scenario A1B

Figures 24 to 33 show the variation and the linear trend of annual rainfall in the stations Vyronas, Elefsina, Elliniko, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Piraeus for the period 2010-2100.

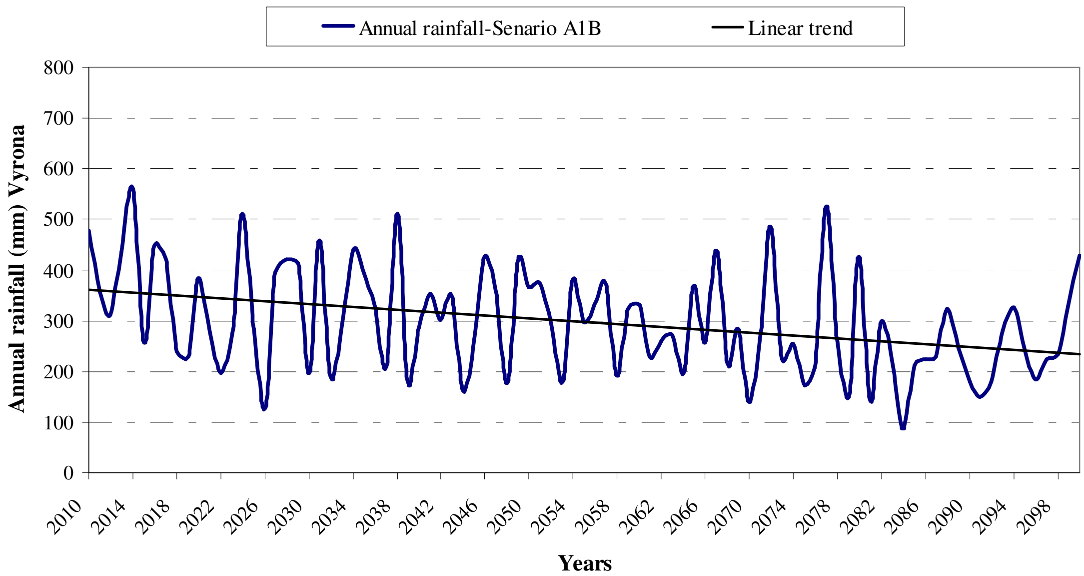


Figure 24. Annual rainfall and linear trend in the Vyronas station for the scenario A1B

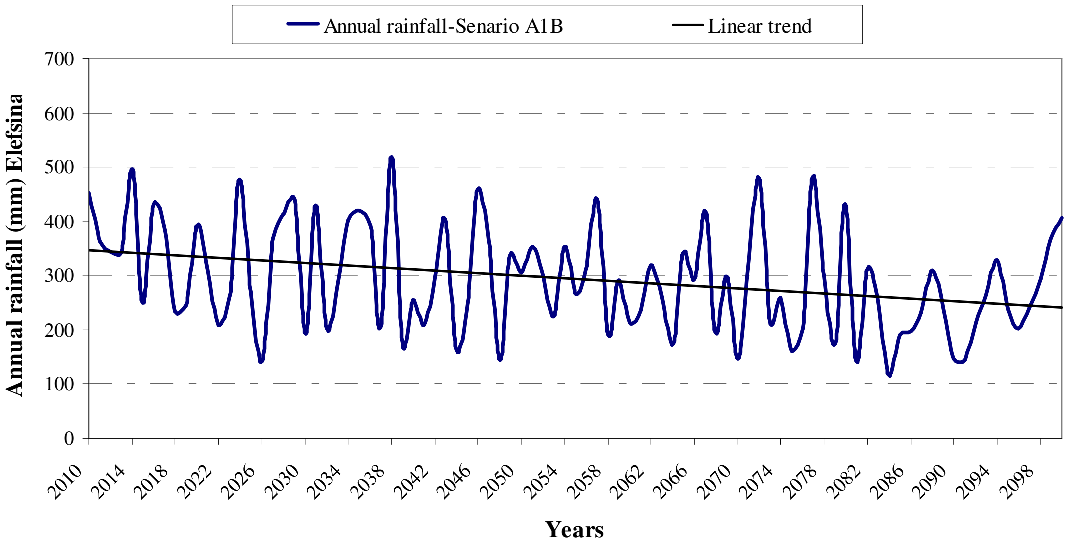


Figure 25. Annual rainfall and linear trend in the Elefsina station for the scenario A1B

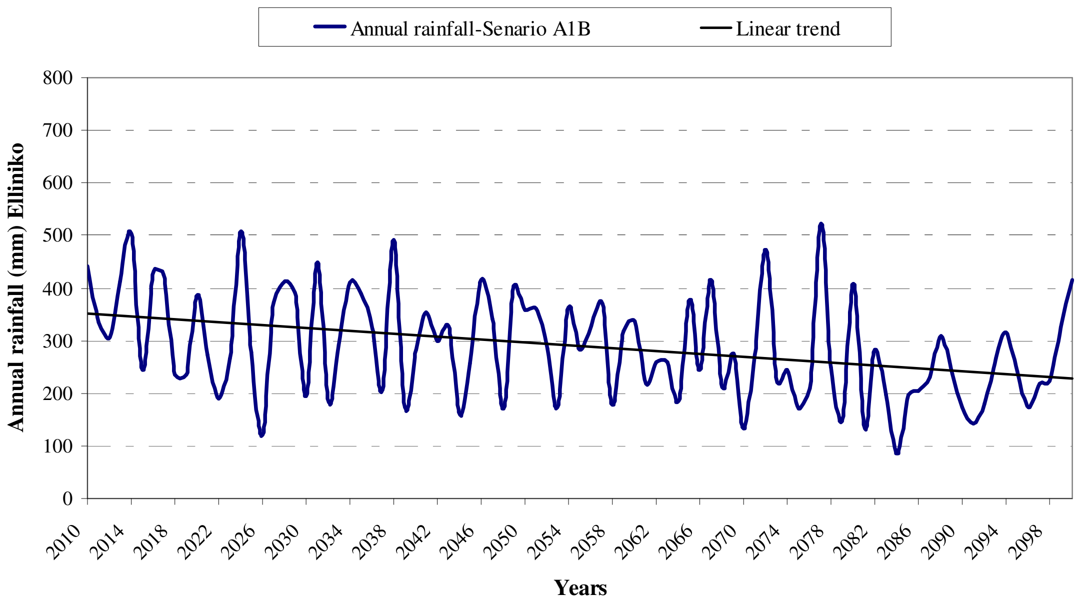


Figure 26. Annual rainfall and linear trend in the Elliniko station for the scenario A1B

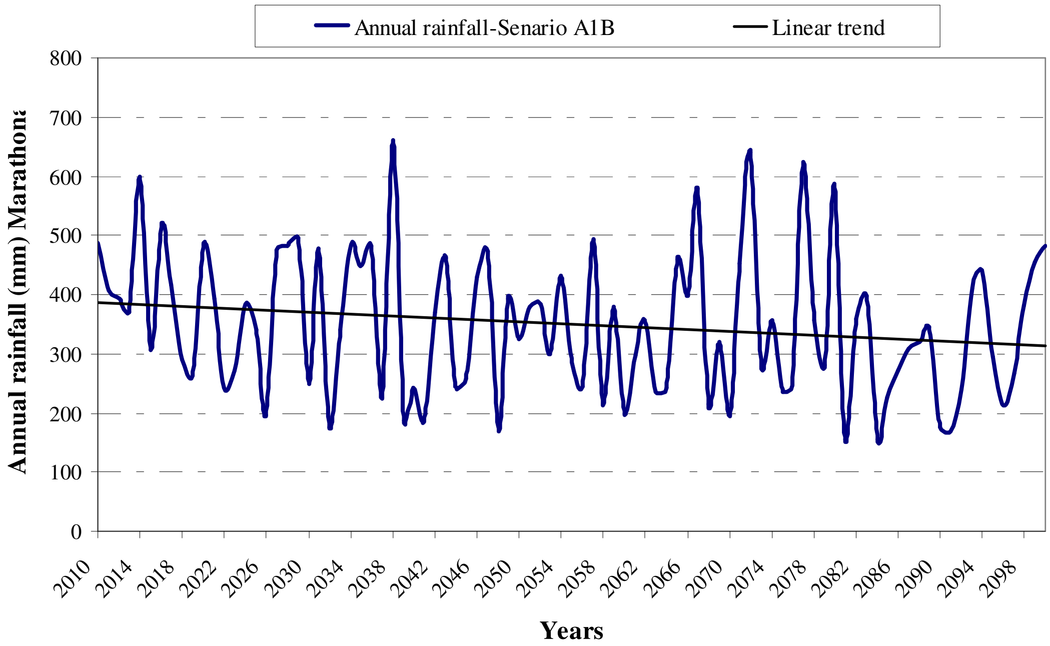


Figure 27. Annual rainfall and linear trend in the Marathonas station for the scenario A1B

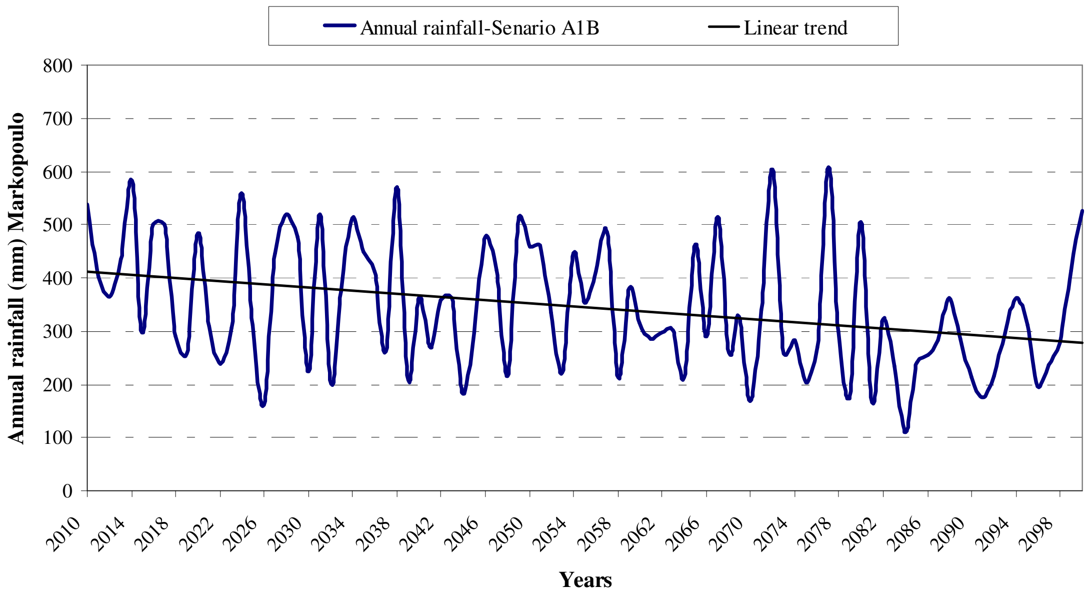


Figure 28. Annual rainfall and linear trend in the Markopoulos station for the scenario A1B

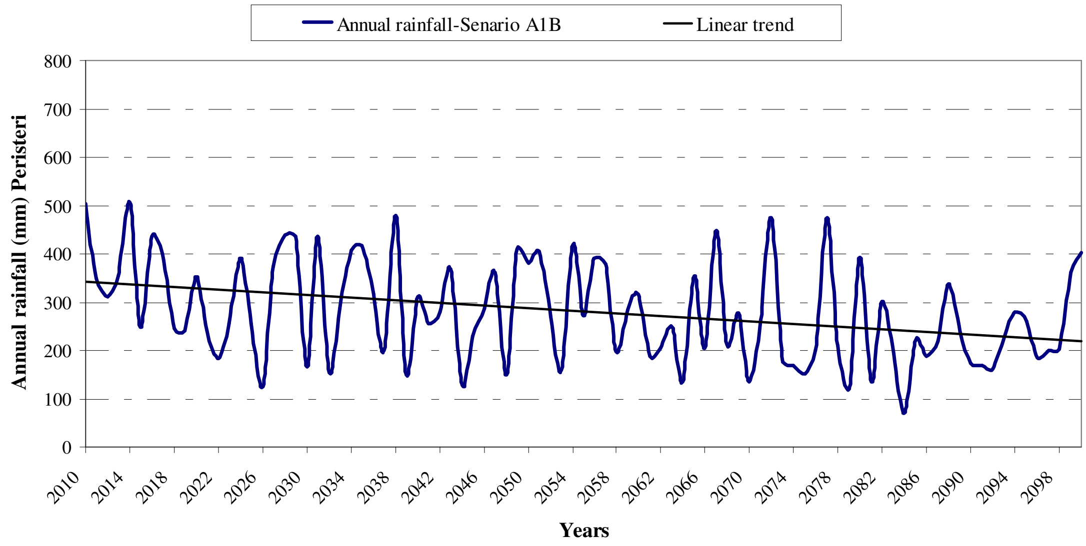


Figure 29. Annual rainfall and linear trend in the Peristeri station for the scenario A1B

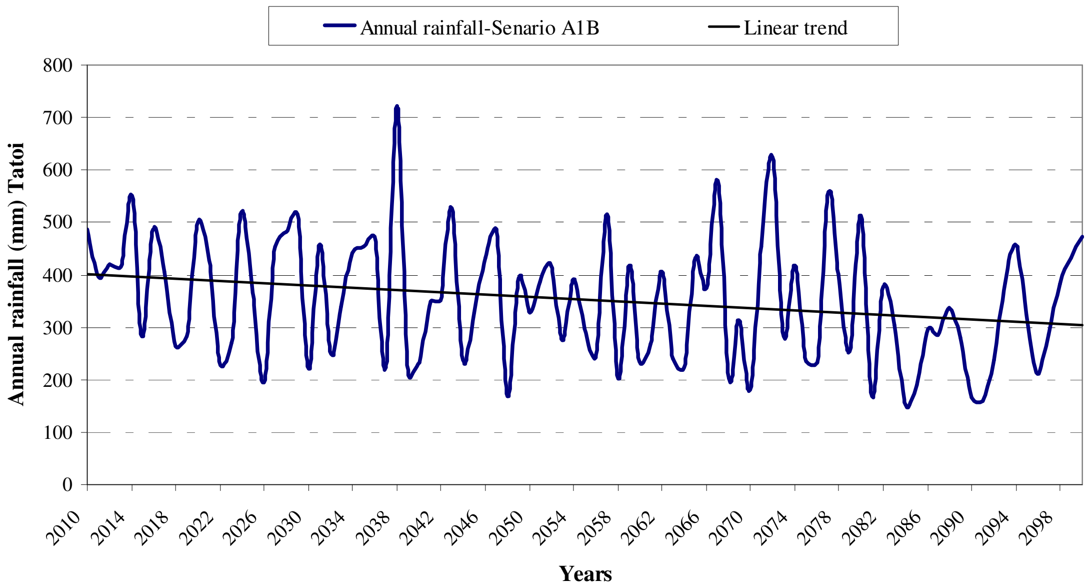


Figure 30. Annual rainfall and linear trend in the Tatoi station for the scenario A1B

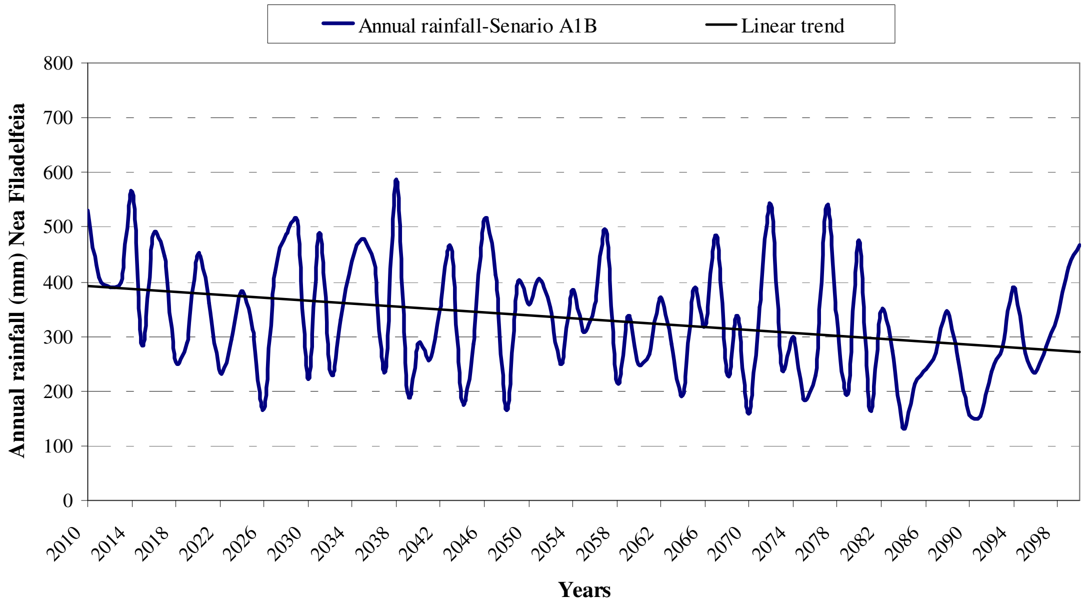


Figure 31. Annual rainfall and linear trend in the Nea Filadelfeia station for the scenario A1B

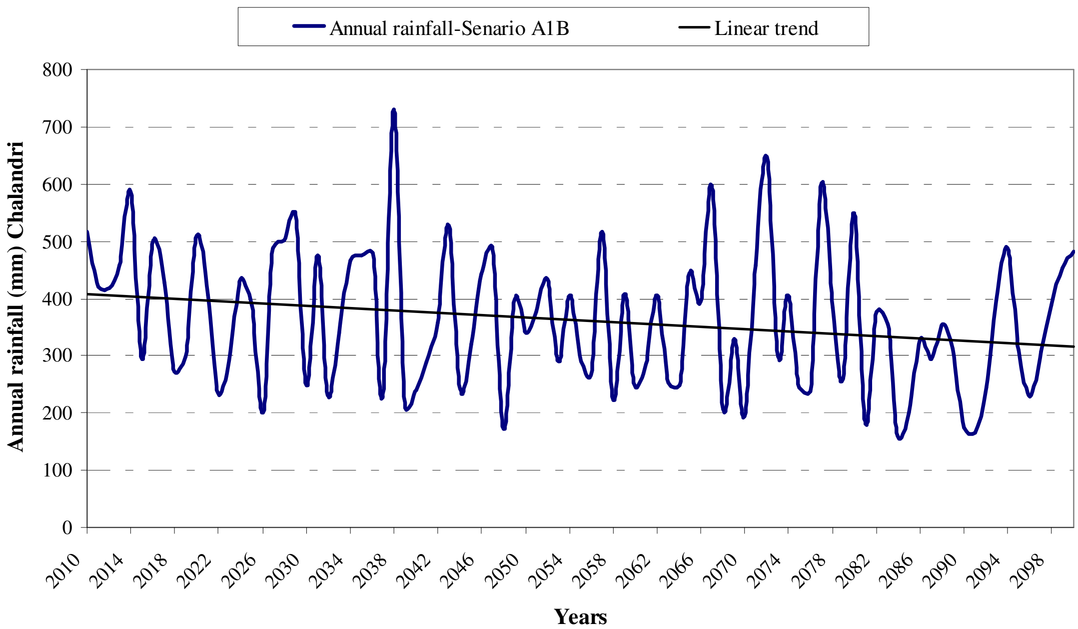


Figure 32. Annual rainfall and linear trend in the Chalandri station for the scenario A1B

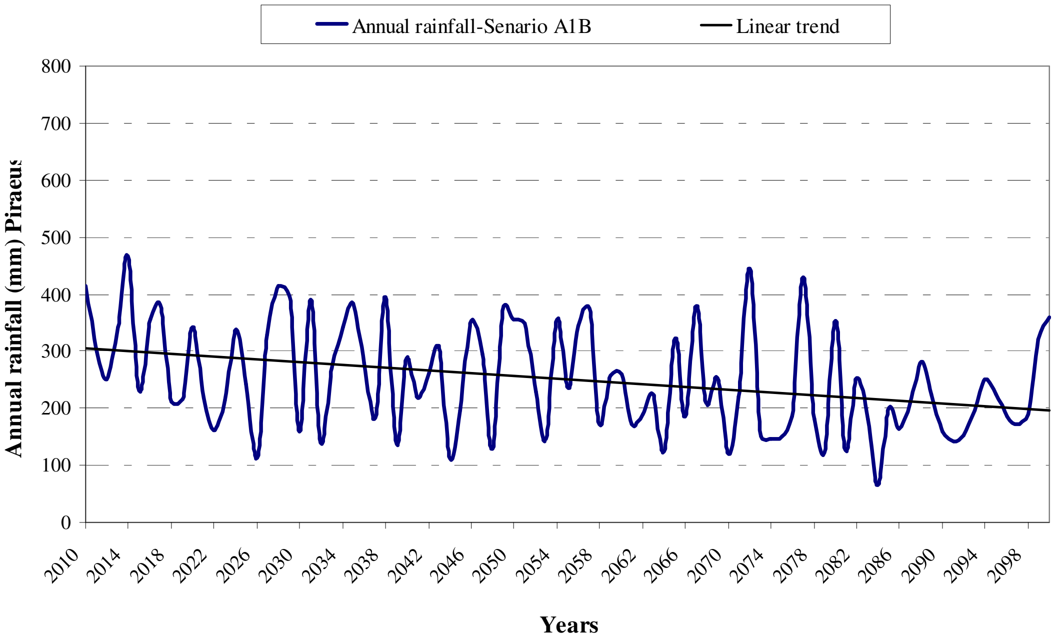


Figure 33. Annual rainfall and linear trend in the Piraeus station for the scenario A1B

The mean annual rainfall in the stations Vyronas, Elefsina, Elliniko, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Pyraeus is 298,5 mm, 293,8 mm, 289,0 mm, 349,9 mm, 345,1 mm, 280,1 mm, 351,9 mm, 332,4 mm, 362,8 mm, 250,9 mm, respectively, for the period January 2010 to December 2100 for the climate scenario A1B.

4.2. Climate scenario A2

Figures 34 to 43 show the variation and the linear trend of annual rainfall in the stations Vyronas, Elefsina, Elliniko, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Piraeus for the period 2010-2100.

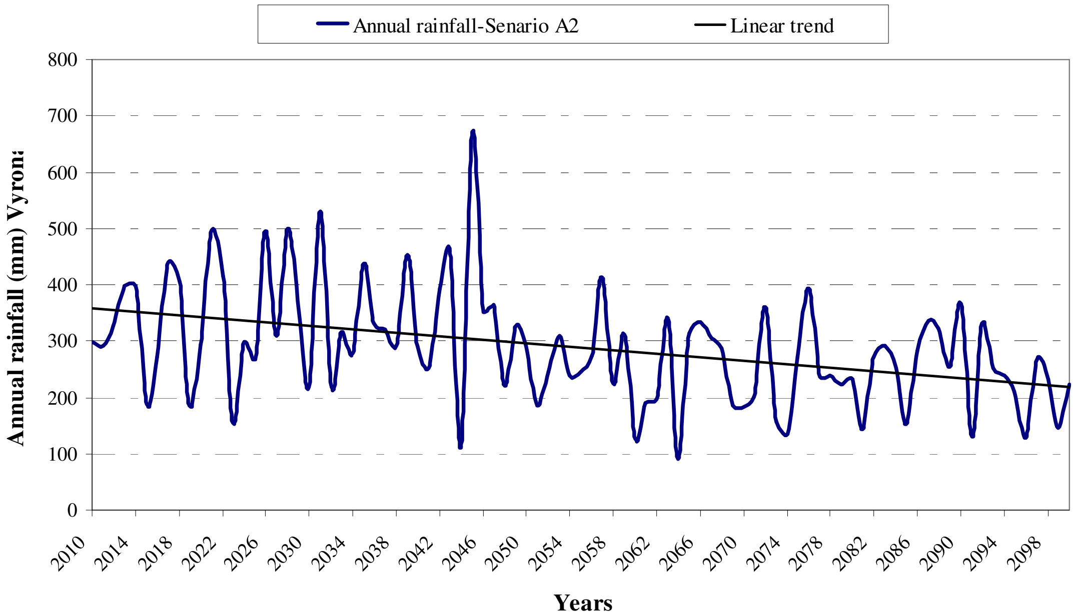


Figure 34. Annual rainfall and linear trend in the Vyronas station for the scenario A2

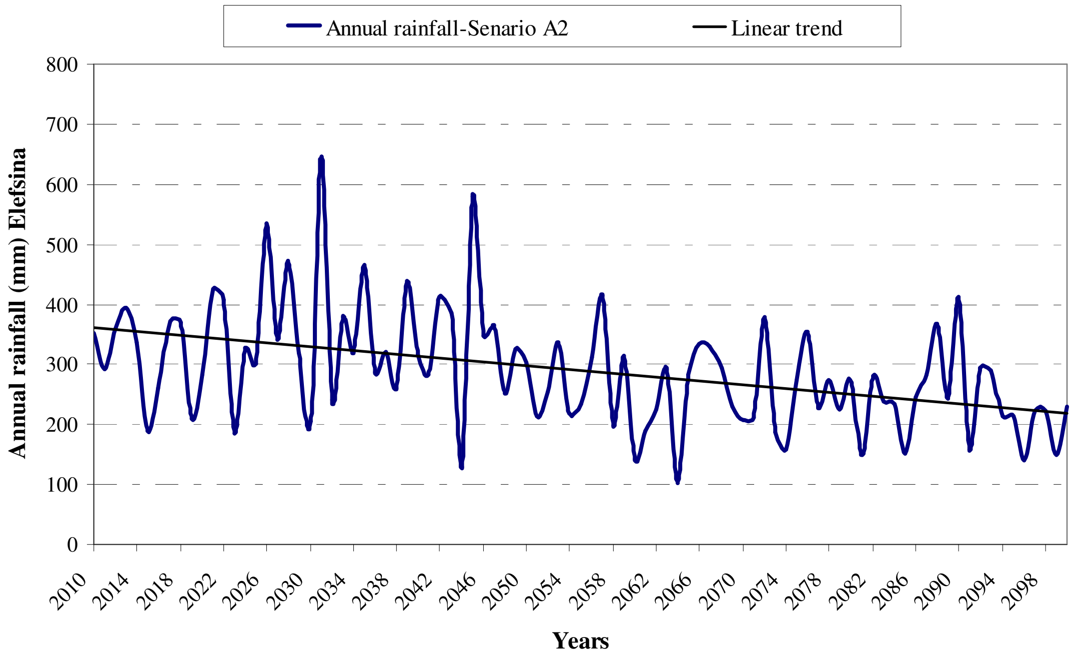


Figure 35. Annual rainfall and linear trend in the Elfesina station for the scenario A2

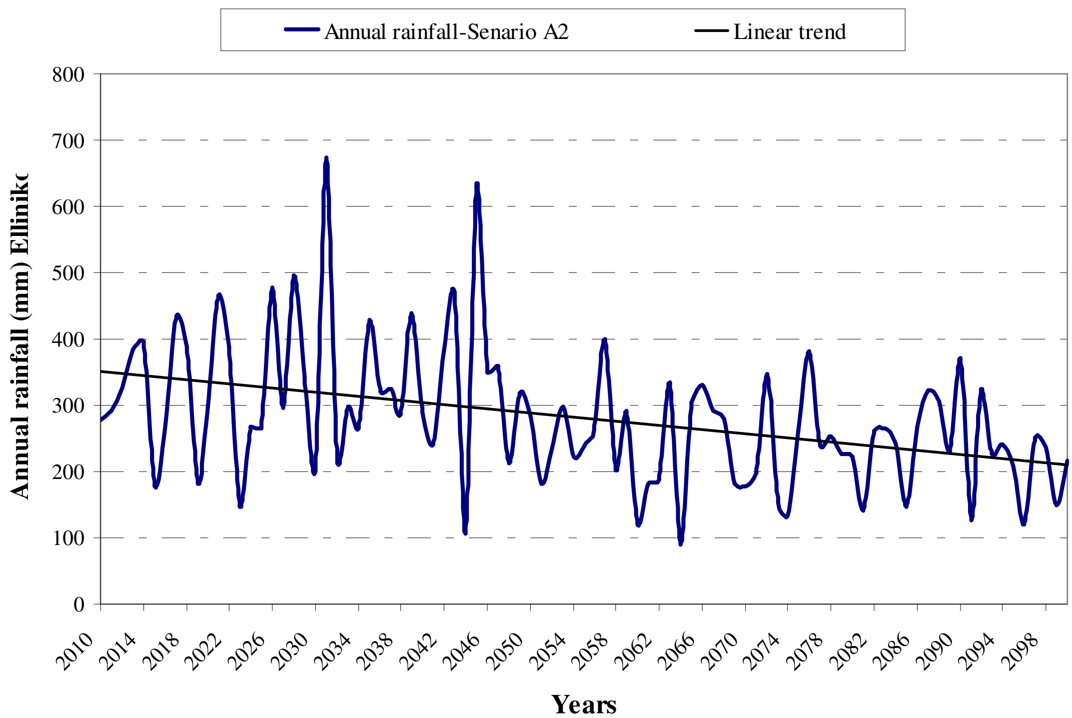


Figure 36. Annual rainfall and linear trend in the Elliniko station for the scenario A2

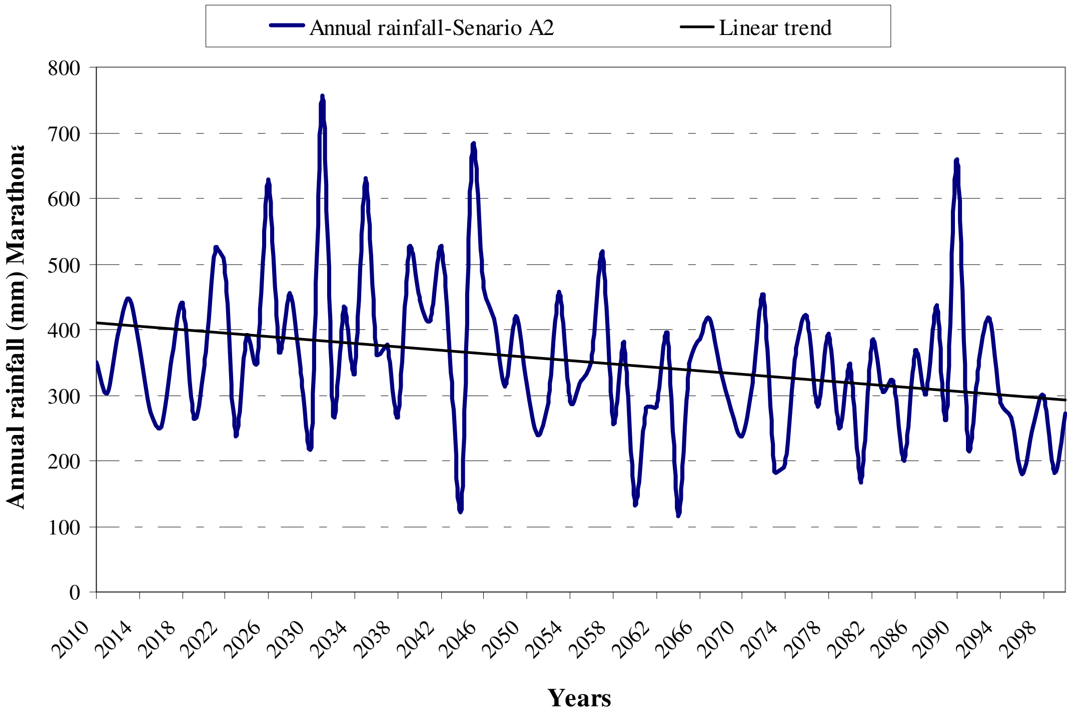


Figure 37. Annual rainfall and linear trend in the Marathonas station for the scenario A2

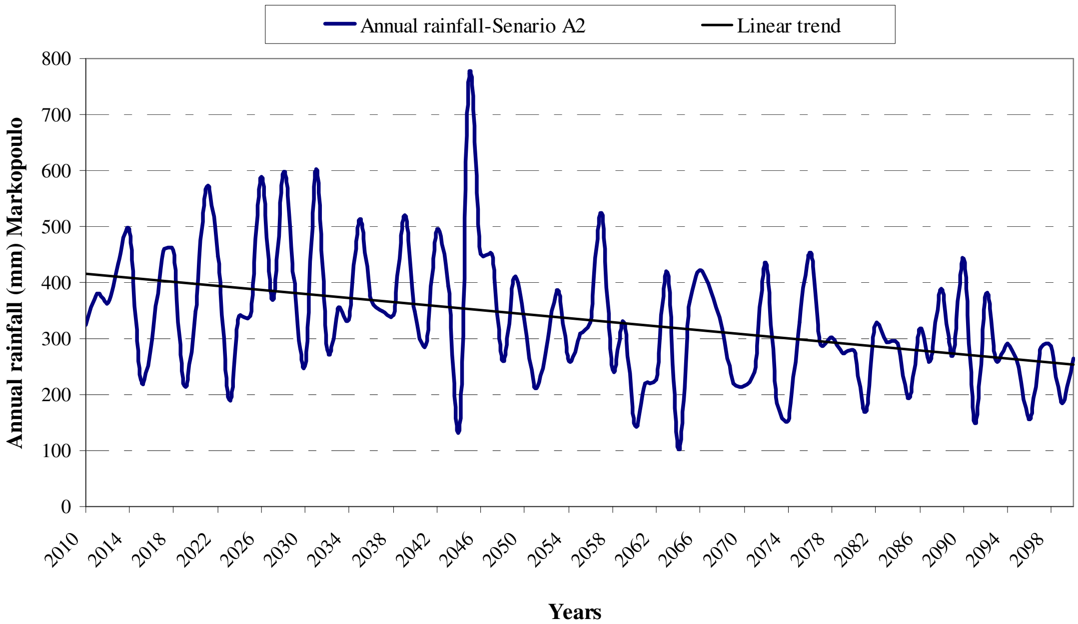


Figure 38. Annual rainfall and linear trend in the Markopoulo station for the scenario A2

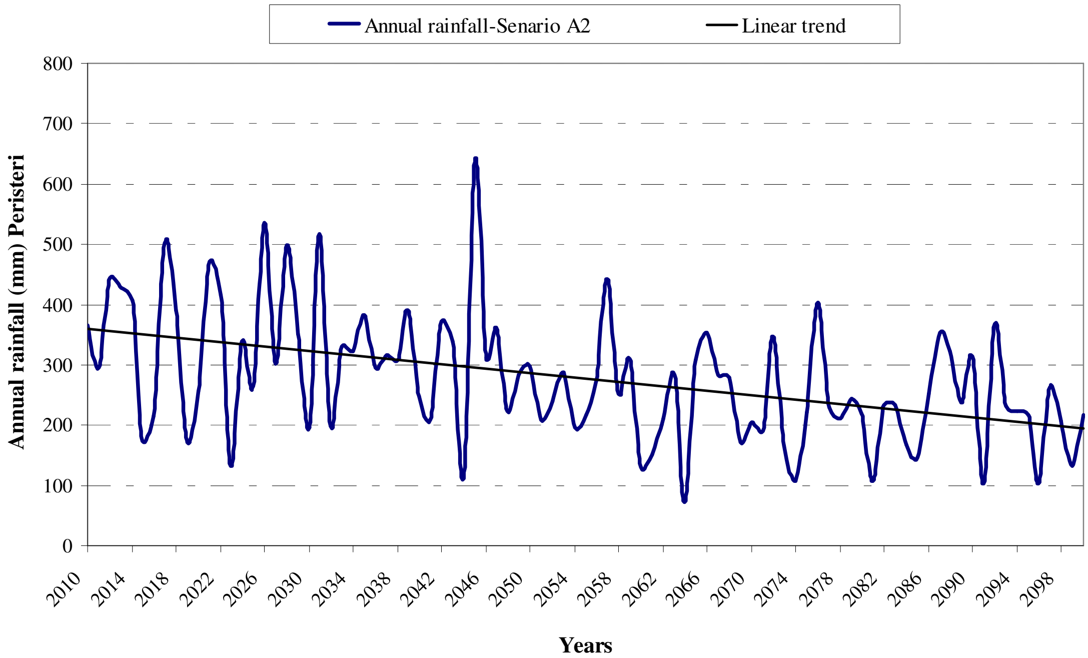


Figure 39. Annual rainfall and linear trend in the Peristeri station for the scenario A2

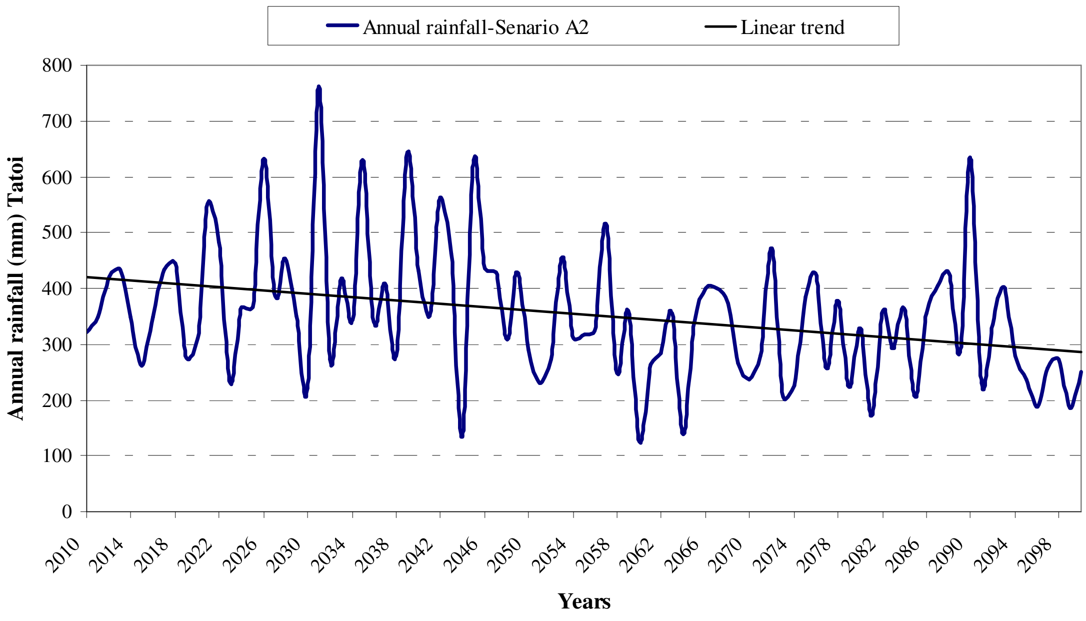


Figure 40. Annual rainfall and linear trend in the Tatoi station for the scenario A2

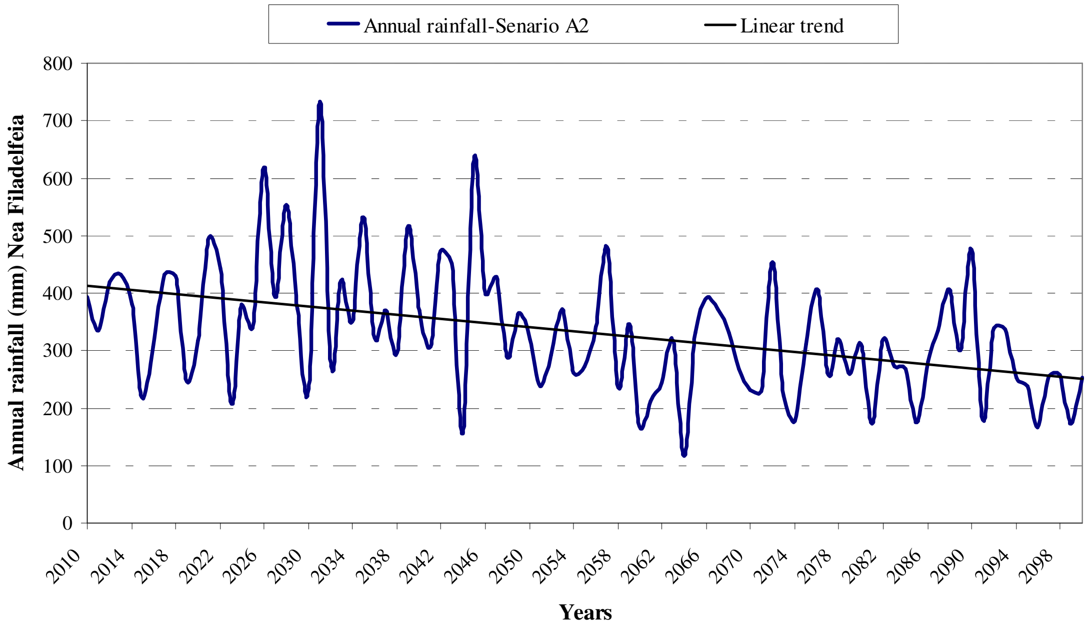


Figure 41. Annual rainfall and linear trend in the Nea Filadelfeia station for the scenario A2

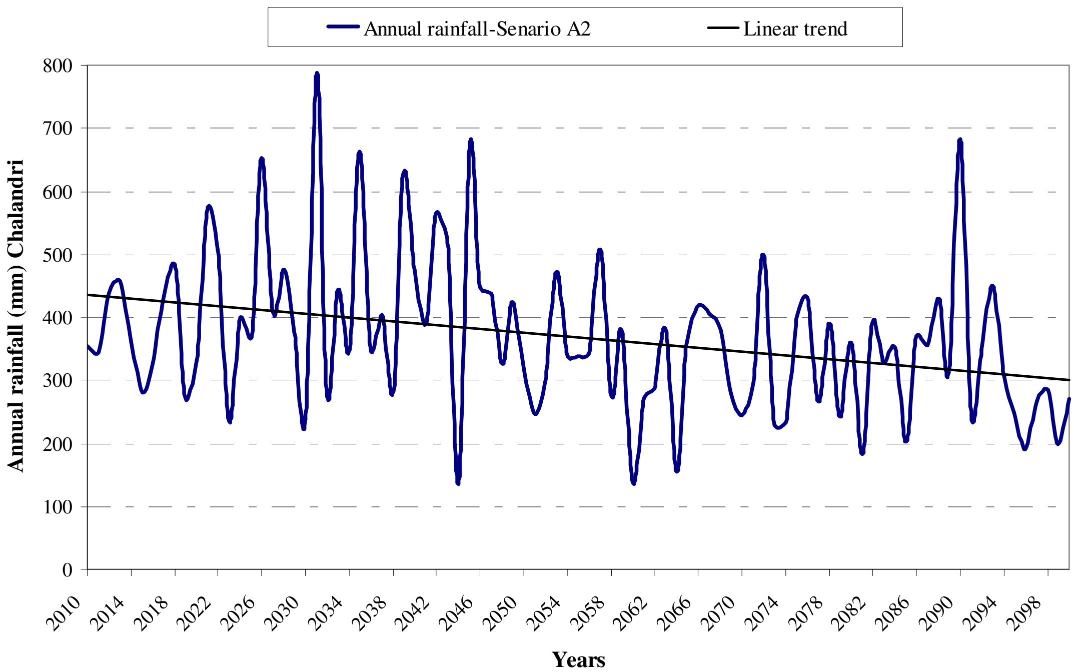


Figure 42. Annual rainfall and linear trend in the Chalandri station for the scenario A2

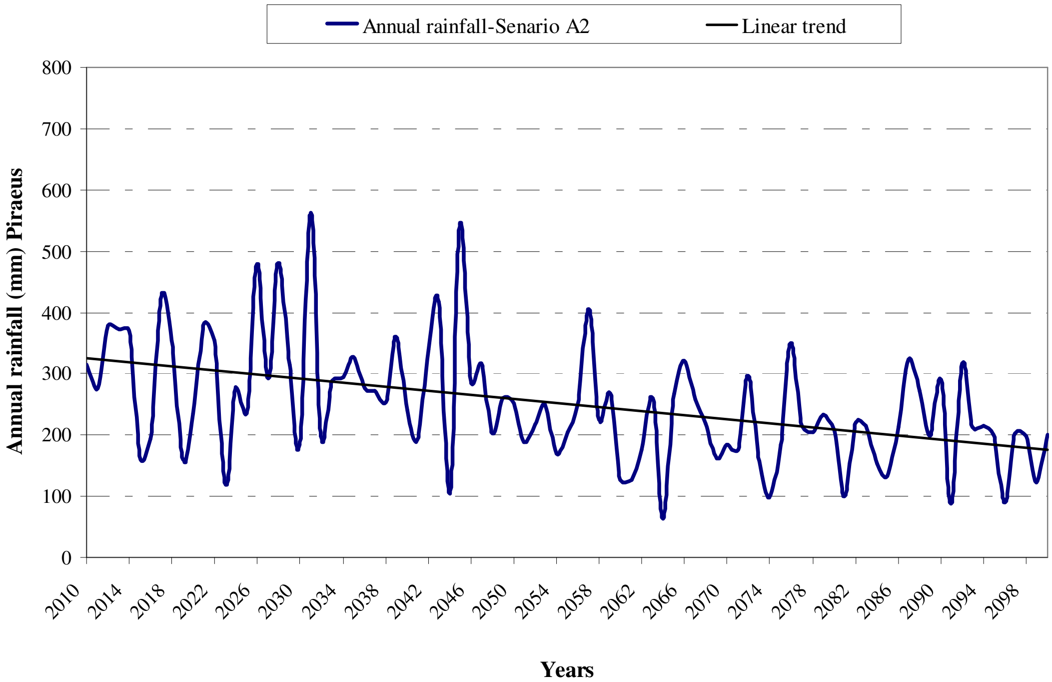


Figure 43. Annual rainfall and linear trend in the Piraeus station for the scenario A2

The mean annual rainfall in the stations Vyronas, Elefsina, Elliniko, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Pyraeus is 288,0 mm, 290,4 mm, 280,9 mm, 350,6 mm, 334,3 mm, 277,7 mm, 352,5 mm, 331,8 mm, 368,2 mm, 250,3 mm, respectively, for the period January 2010 to December 2100 for the climate scenario A2.

Figures 44 to 53 show the mean monthly rainfall in the stations Vyronas, Elefsina, Elliniko, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Pyraeus for the scenarios A1B and A2.

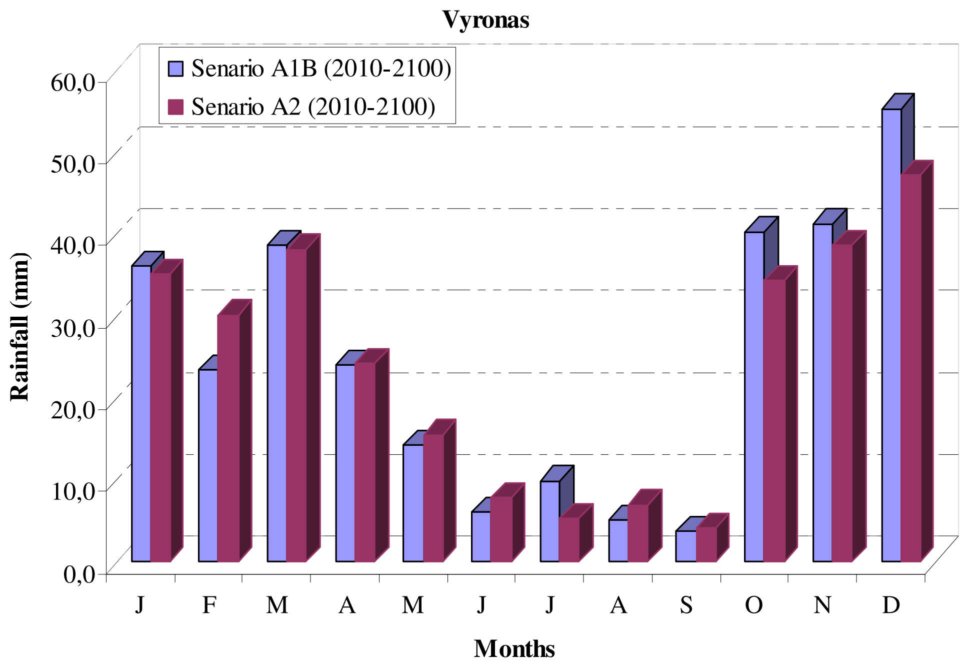


Figure 44. Average monthly rainfall in Vyronas station for the climate scenarios A1B & A2

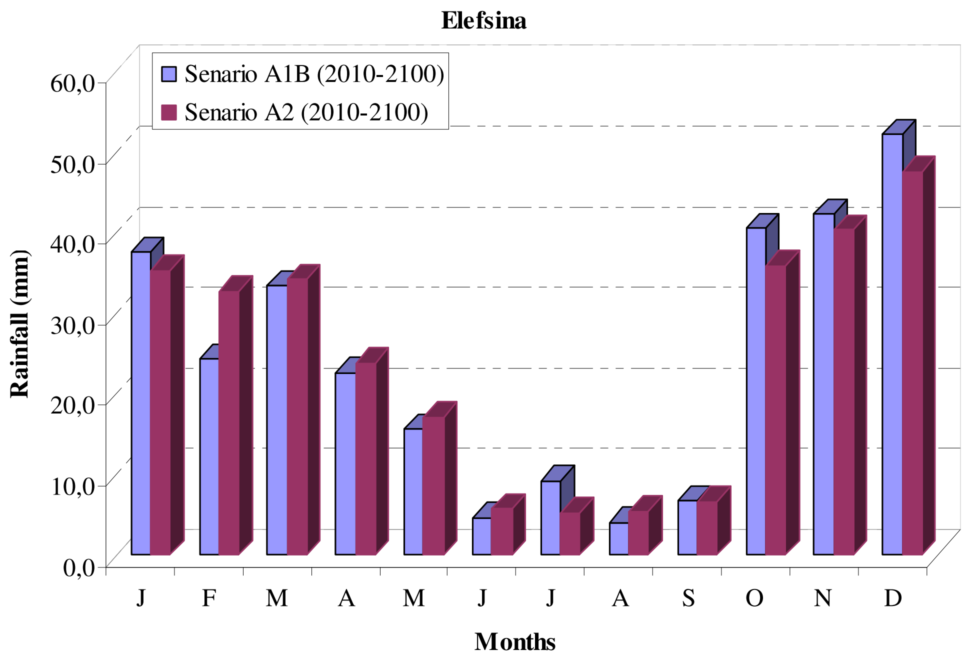


Figure 45. Average monthly rainfall in Elefsina station for the climate scenarios A1B & A2

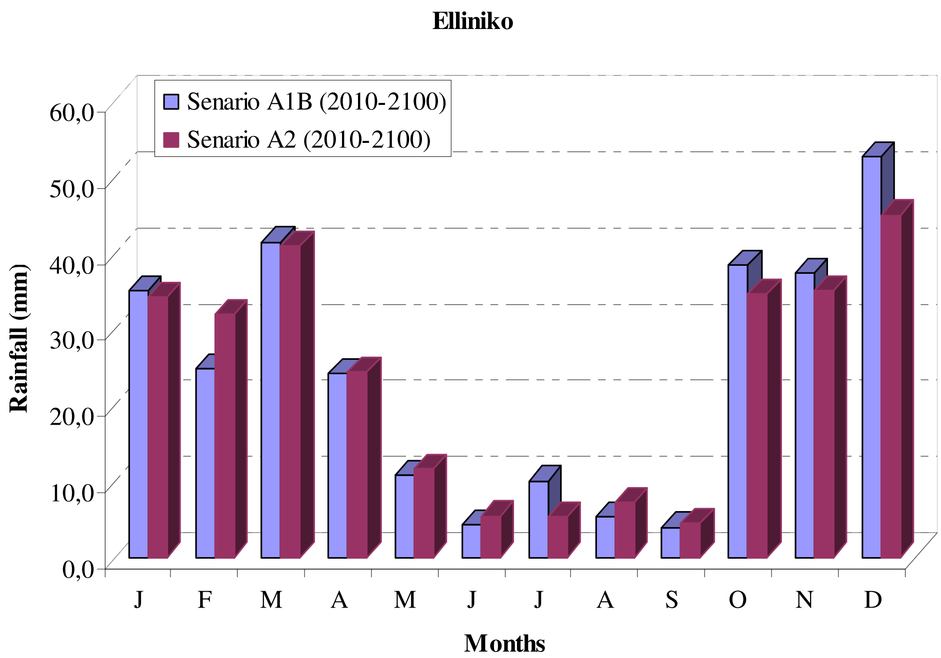


Figure 46. Average monthly rainfall in Elliniko station for the climate scenarios A1B & A2

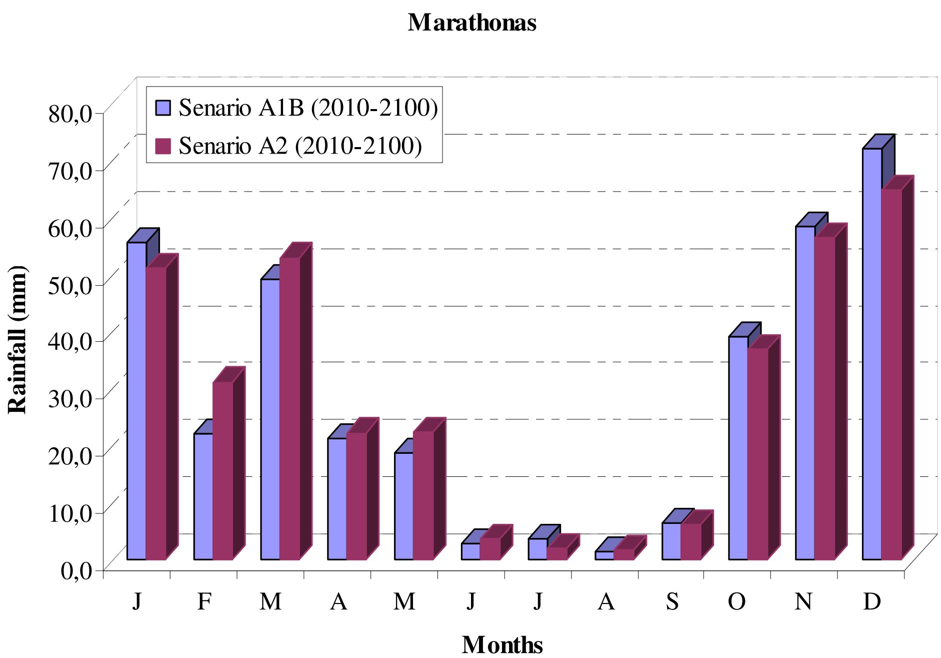


Figure 47. Average monthly rainfall in Marathonas station for the climate scenarios A1B & A2

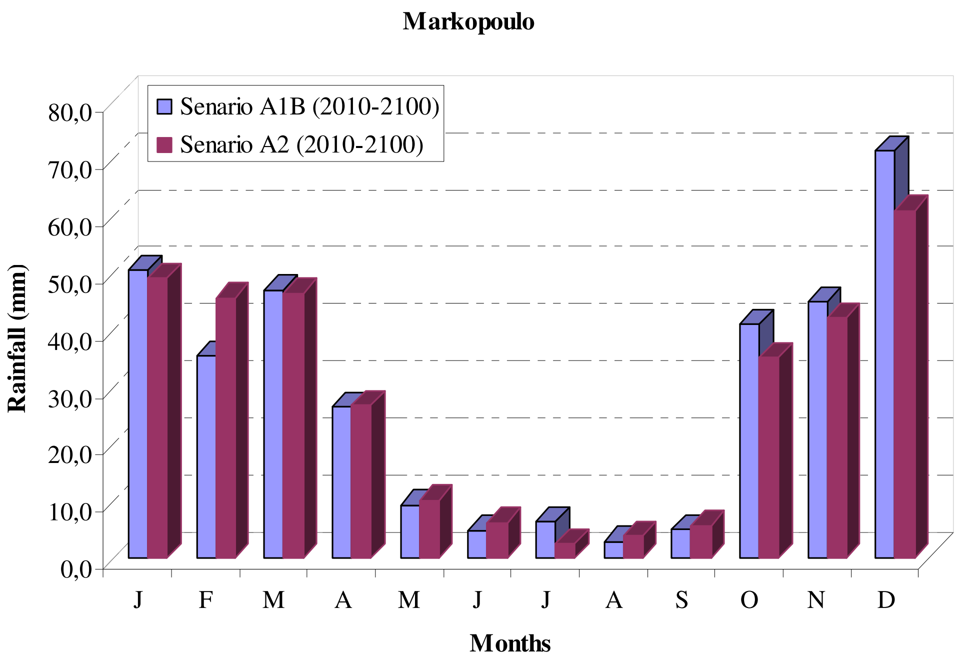


Figure 48. Average monthly rainfall in Markopoulo station for the climate scenarios A1B & A2

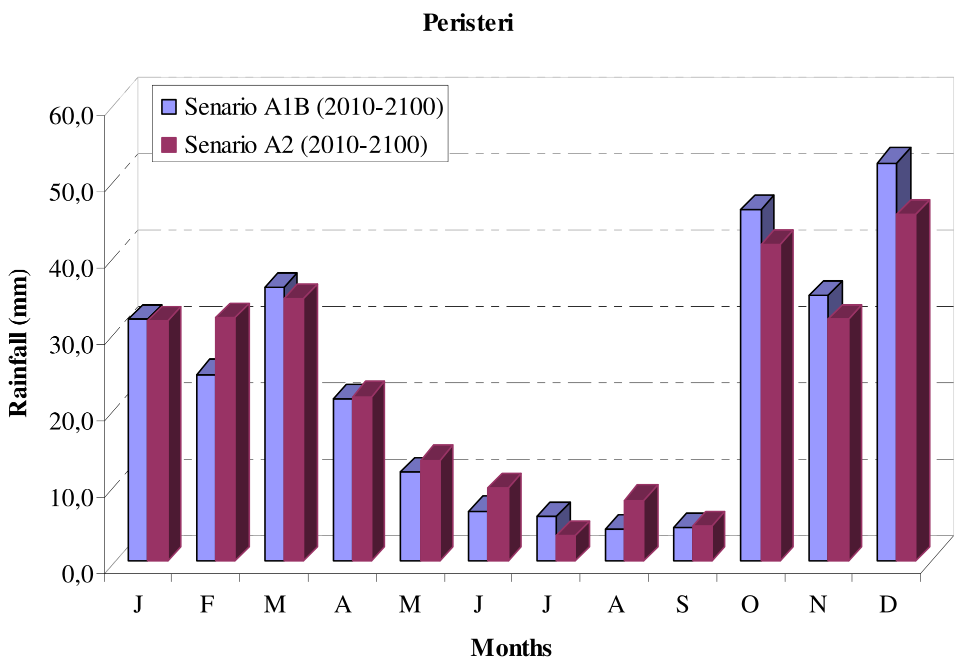


Figure 49. Average monthly rainfall in Peristeri station for the climate scenarios A1B & A2

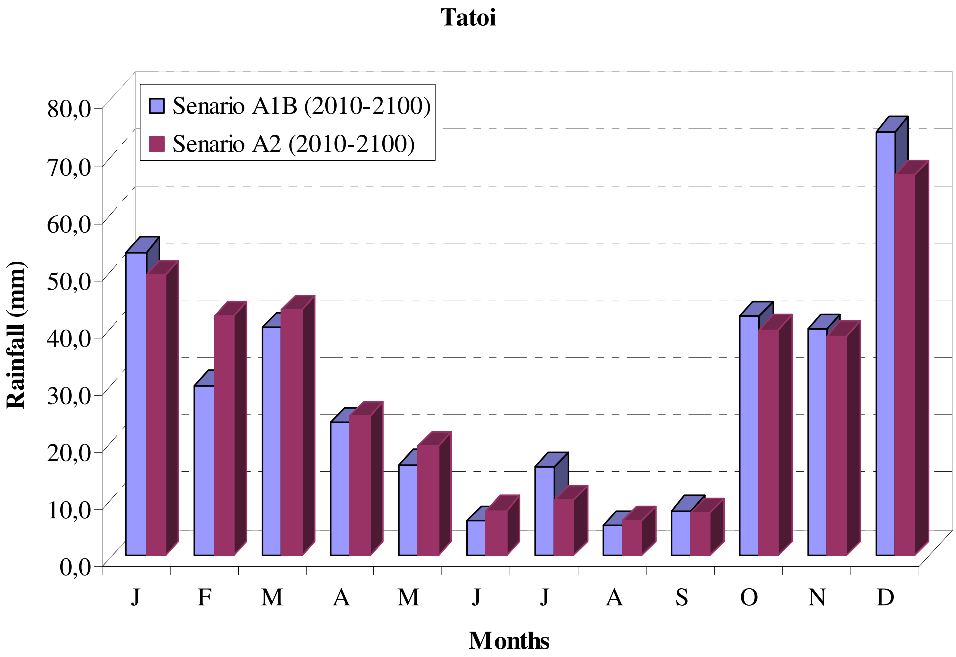


Figure 50. Average monthly rainfall in Tatoi station for the climate scenarios A1B & A2

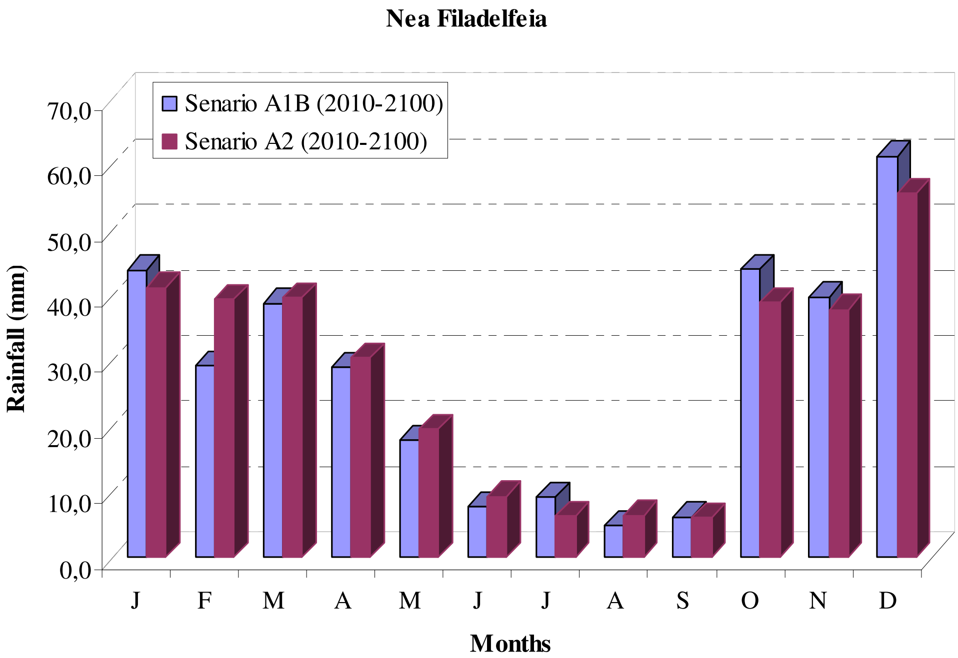


Figure 51. Average monthly rainfall in Nea Filadelfeia station for the climate scenarios A1B & A2

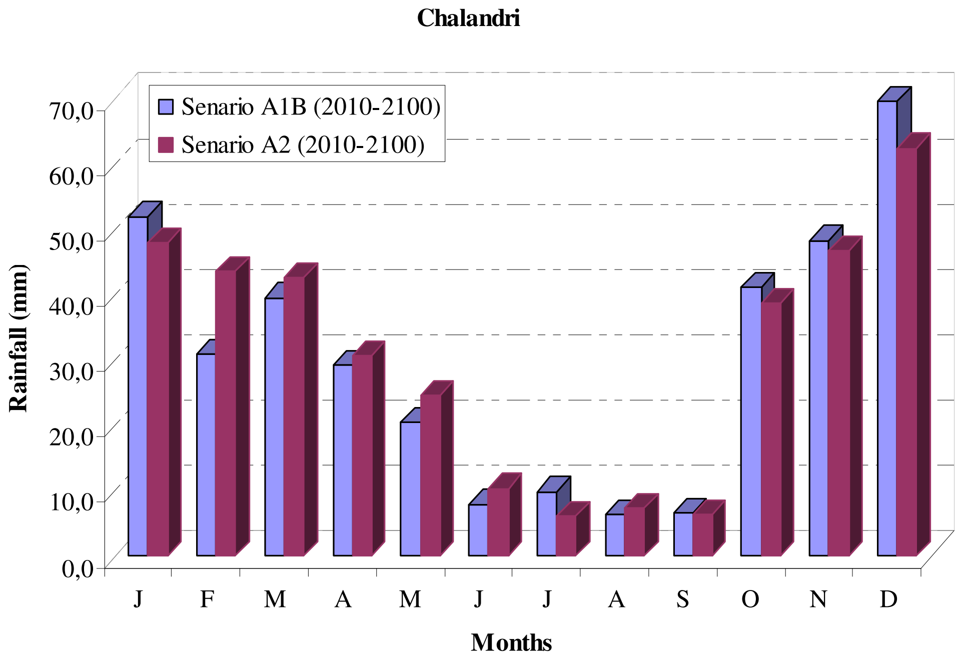


Figure 52. Average monthly rainfall in Chalandri station for the climate scenarios A1B & A2

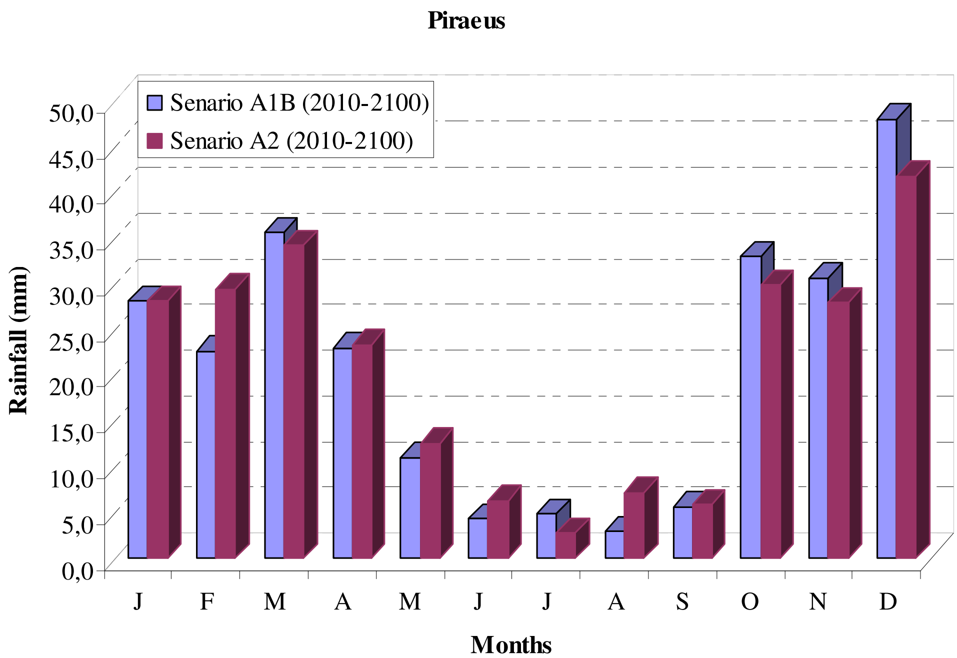


Figure 53. Average monthly rainfall in Piraeus station for the climate scenarios A1B & A2

Based on Figures 44-53, the maximum rainfall appears in December in all meteorological stations for both climate scenarios. The minimum rainfall appears for the scenario A1B in August in stations Elefsina, Marathonas, Markopoulo, Peristeri, Tatoi, Nea Filadelfeia, Chalandri, Piraeus and in September in stations Vyronas, Elliniko, and for the scenario A2 in August in stations Marathonas, Tatoi, in September in stations Vyronas, Elliniko, Nea Filadelfeia and in July in stations Elefsina, Markopoulo, Peristeri, Chalandri, Piraeus.

Figure 54 shows the average annual rainfall in all stations during the historical period 1970-2010 and the period 2010-2100 (based on climate scenarios A1B and A2); in all stations, the annual rainfall is decreased in scenarios A1B and A2 compared to the historical period.

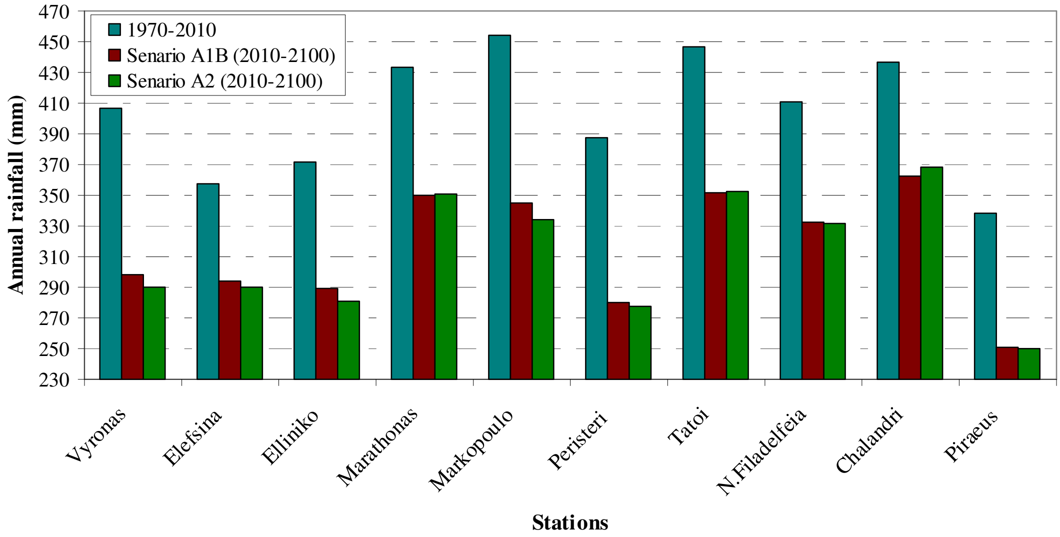


Figure 54. Annual rainfall for the historical period (1970-2010) and for the climate scenarios A1B & A2 (2010-2100)

5. CALCULATION OF SPI INDEX

The SPI-12 index in the period 2010-2100 was calculated based on the methodology presented in Chapter 2.

In Annex I is shown graphically the SPI-12 index in the period 2010-2100 for the climate scenarios A1B and A2.

In Annex II is given in tabular form the duration and the intensity of drought events in each station in the period 2010-2100 for the climate scenarios A1B and A2.

Figures 55 and 56 show the drought events, their intensity and duration in the period 2010-2100 for the climate scenarios A1B and A2, respectively.

Based on Figure 55, in which the drought events for the climate scenario A1B are shown, it can be concluded:

- Up to 2031 are expected three to four drought events of low intensity and short duration; the last event would be more intensive in the stations of Nea Filadelfeia, Elefsina and Elliniko.
- From 2033 to 2064, the frequency of drought events is expected to increase. However, the intensity of drought events would not be high, except for two events in 2040 and 2054. The regions in the vicinity of stations Elefsina, Peristeri, Tatoi, Chalandri is expected to appear the higher intensity.
- From 2064 to 2092, the frequency and the intensity of drought events are considerably increased in all stations.

Based on Figure 56, in which the drought events for the climate scenario A2 are shown, it can be concluded:

- Up to 2031 are expected a few drought events of low intensity and short duration; the last event would be more intensive in the stations of Nea Filadelfeia, Elefsina and Elliniko.
- From 2041 to 2060, the frequency of drought events is expected to increase; their intensity, however, would be low.
- From 2073 to 2099, the frequency and the intensity of drought events are considerably increased in all stations.

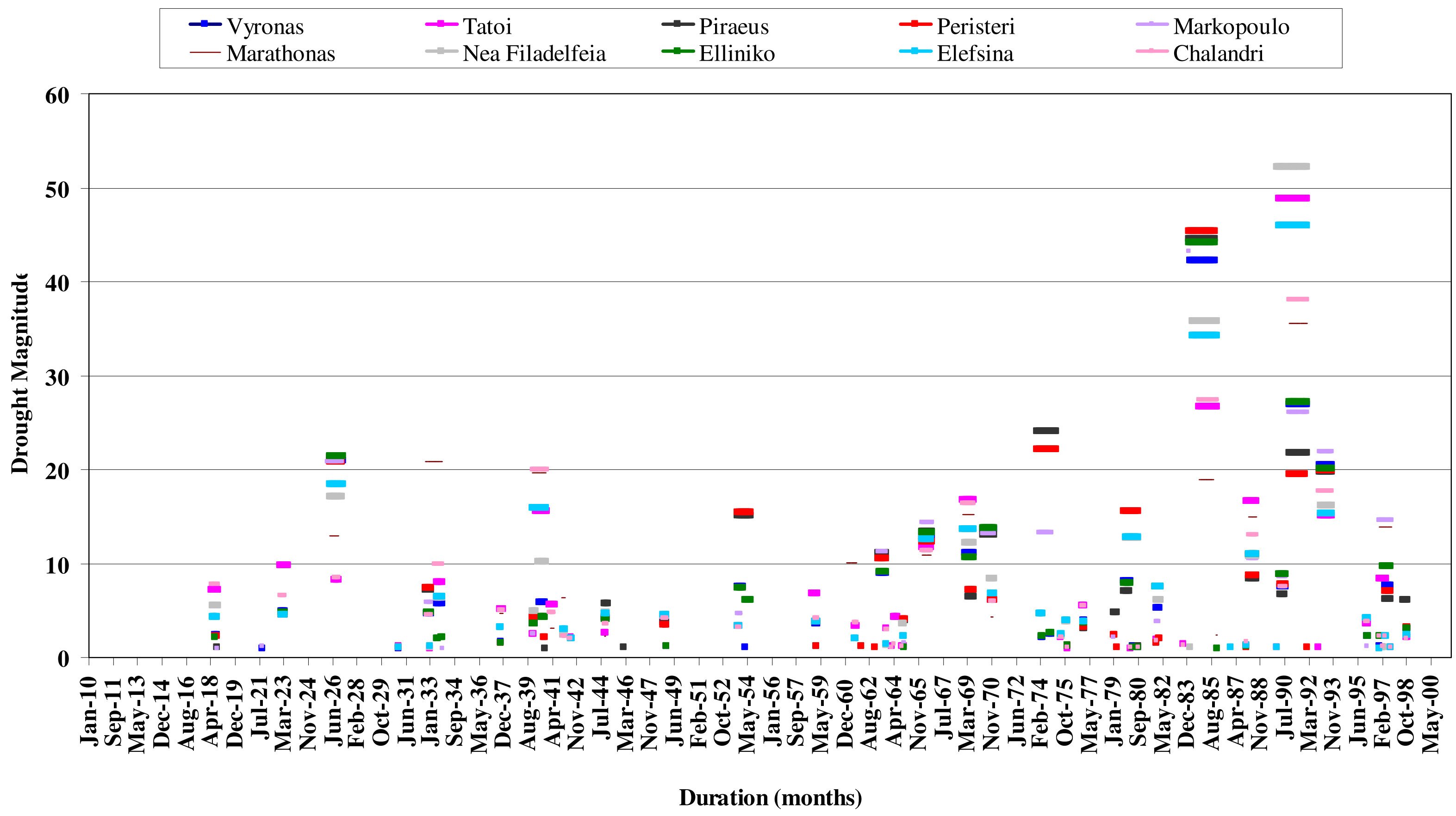


Figure 55. Drought events, intensity and duration in the meteorological stations of Attica for the climate scenario A1B (2010 – 2100)

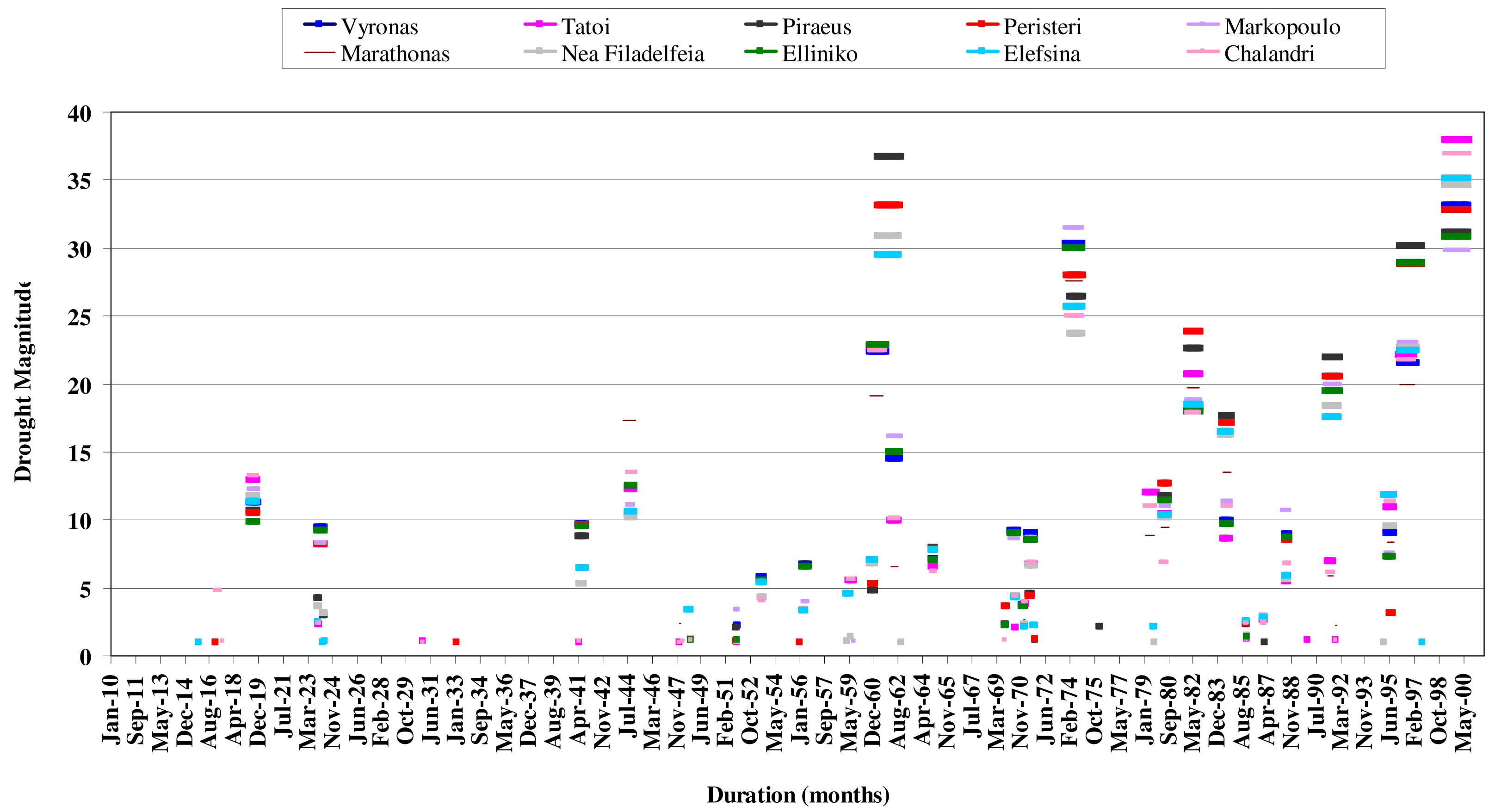


Figure 56. Drought events, intensity and duration in the meteorological stations of Attica for the climate scenario A2 (2010 – 2100)

6. CALCULATION OF DROUGHT VULNERABILITY INDEX (DVI)

The DVI index is calculated in each meteorological station for the two climate change scenarios A1B and A2 (Figure 57). The DVI value is greater in scenario A1B than A2 in all stations except for Marathonas and Chalandri. In Maps 2 and 3 is shown the spatial display of DVI index for the scenarios A1B and A2, respectively.

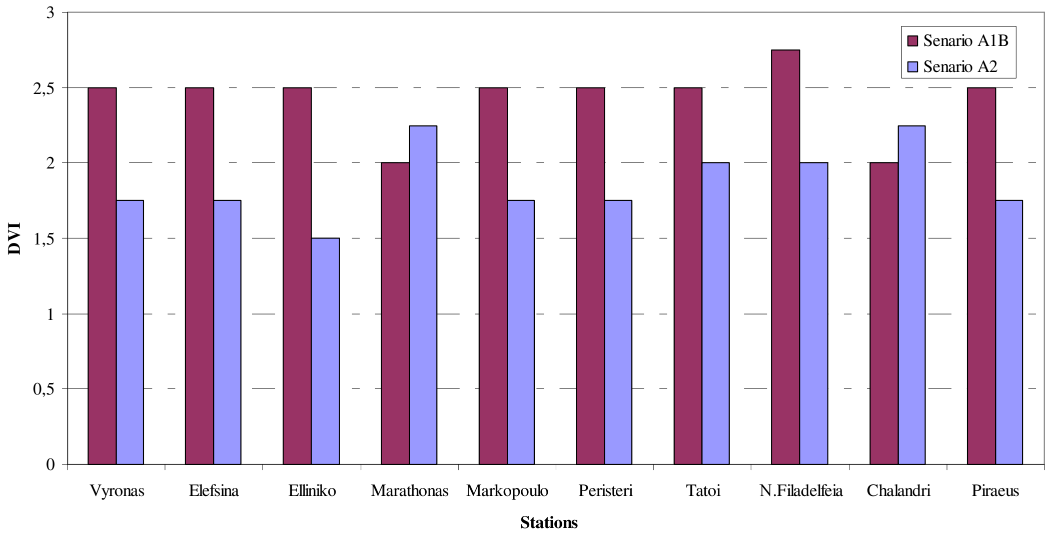
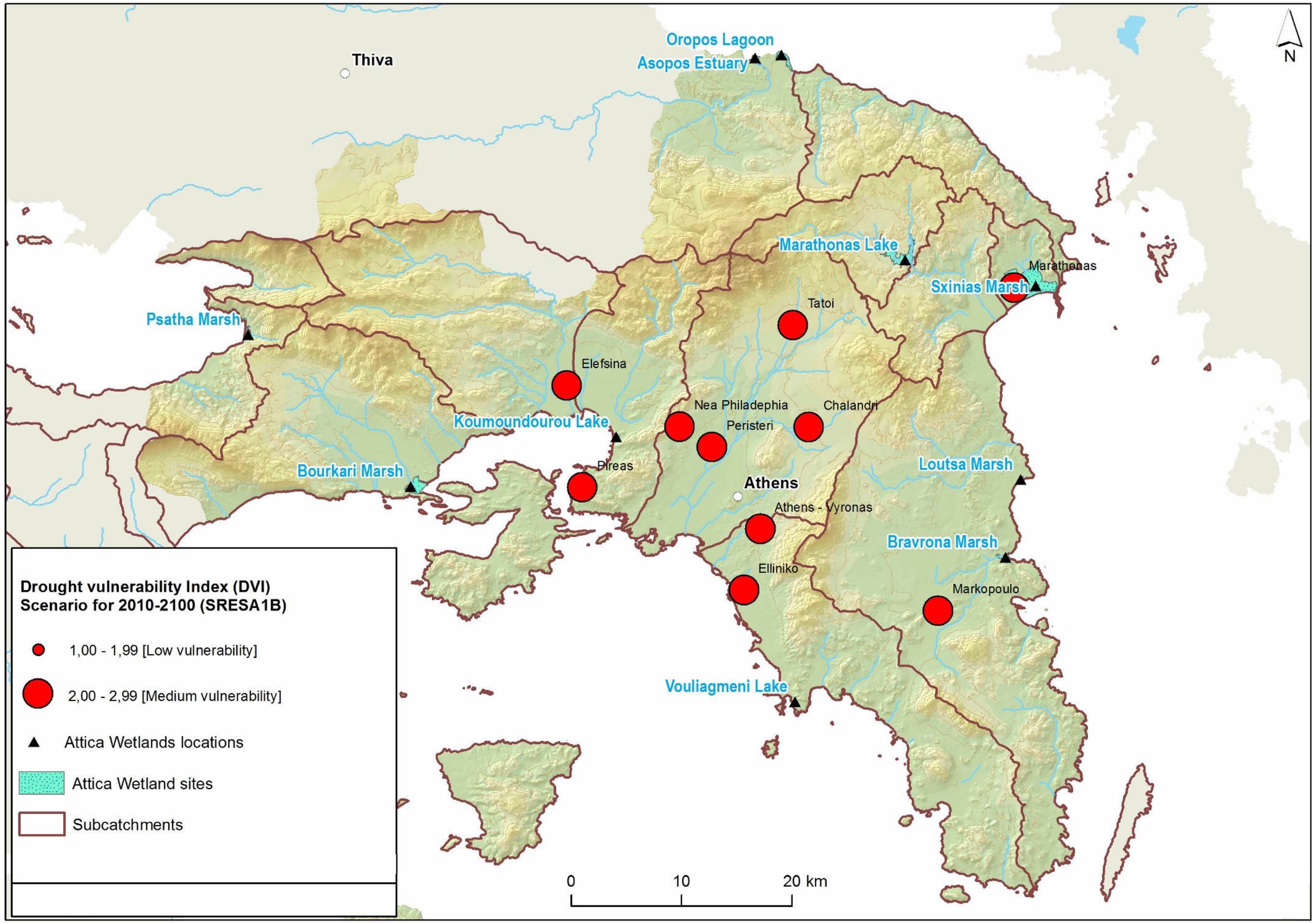
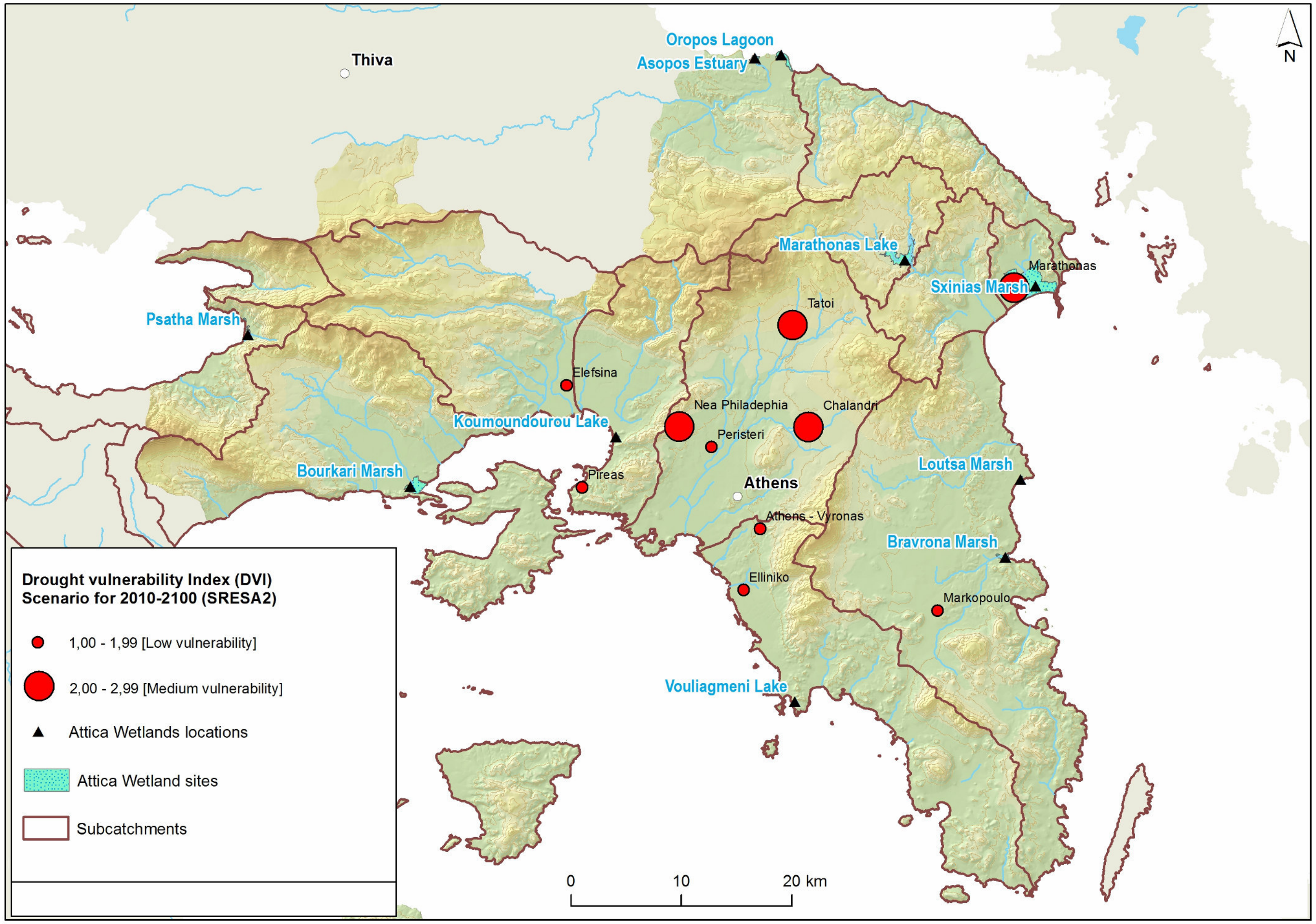


Figure 57. Drought Vulnerability Index (DVI) in the meteorological stations of Attica for the climate scenarios A1B & A2 (2010-2100)



Map 2. Drought Vulnerability Index (DVI) in the meteorological stations of Attica for the climate scenario A1B (2010-2100)



Map 3. Drought Vulnerability Index (DVI) in the meteorological stations of Attica for the climate scenario A2 (2010-2100)

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