Drought and water scarcity management plan for the Peloponnese river basin districts

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Abstract
The drought and water scarcity management plan was drafted for the Peloponnese River Basin Districts as outlined by the implementation of the Water Framework Directive 2000/60/EC [2] in Greece by the Special Secretariat of Water (Ministry of Environment Energy & Climate Change). The evaluation of meteorological droughts was mainly based on precipitation data, which was used to evaluate the SPI index at several time scales (from 3-month to 5-year). Moreover, the drought hazard was evaluated, taking into consideration the demands and the water resources availability, at various spatial scales. For this aim, we developed an innovative methodology, based on the estimation of a temporally varying water exploitation index, as generalization of the typical WEI. The possibilities of predicting drought events, by using simple statistical models and evaluating the probabilities of transition from the current carrying water condition to the next are also examined. Additionally, an operational plan for drought prediction is elaborated, on the basis of representative hydrologic data that is retrieved twice a year i.e. at the end of the first trimester and semester of the hydrological year. Finally, we provide guidance for the operational implementation of the above methodology by the competent authorities and its link to specific management measures depending on the classification of each drought event, at the alert scale.

Keywords: drought, scarcity, WEI, SPI, WFD 2000/60/EC, RBD, Peloponnese, Guidance Documents

1. INTRODUCTION

1.1 Study Area

The area under study in this project covers the 3 River Basin Districts (RBD) of Western (GR01), Northern (GR02) and Eastern Peloponnese (GR03) of ~23.100km^2 in total area. Each RBD is consisted of two or more River Basins (Table 1 & Figure 1). The main River Basins of the 3 River Basin Districts in Peloponnese are those of Alpheus (3.658 km^2), Eurotas (1.738 km^2) Pamisos (750 km2), Pinios (868 km^2), Peiros (600 km^2), Inahos (533 km^2), and also the inland basin of Tripoli's plateau (907 km^2) [2], [5].

1.2 Data used

1.2.1. Rainfall stations

As far as the rainfall data concerned, these were collected by 74 independent hydrological stations from different entities after the extension of their time series. The period during which these data were collected is from 1980-81 to 2001-2002 (22 hydrological years). The above time series were extended by newer data as they were available. The locations of all the rainfall stations that their data were used in the study area are shown in Figure 1.

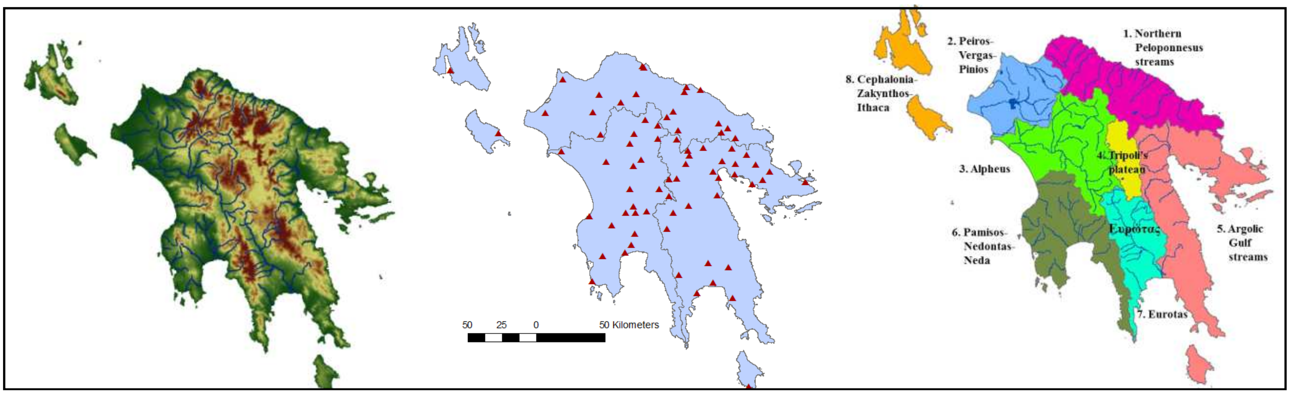

Figure 1. Study area, location of meteorological stations and operational units that are used

The analysis of the rainfall data was performed for 4 spatial scales: a. Point (74 stations), b. River Basins (8 RB), c. River Basin Districts (3 RBD) and d. For the total area of Peloponnese. eight overlapping time periods are utilized. Four of them are within hydrological year using a 3 month interval (October-December, October-March, October-June, October-September). The other four time periods are the 2, 3, 4 and 5 years (Figure 2).

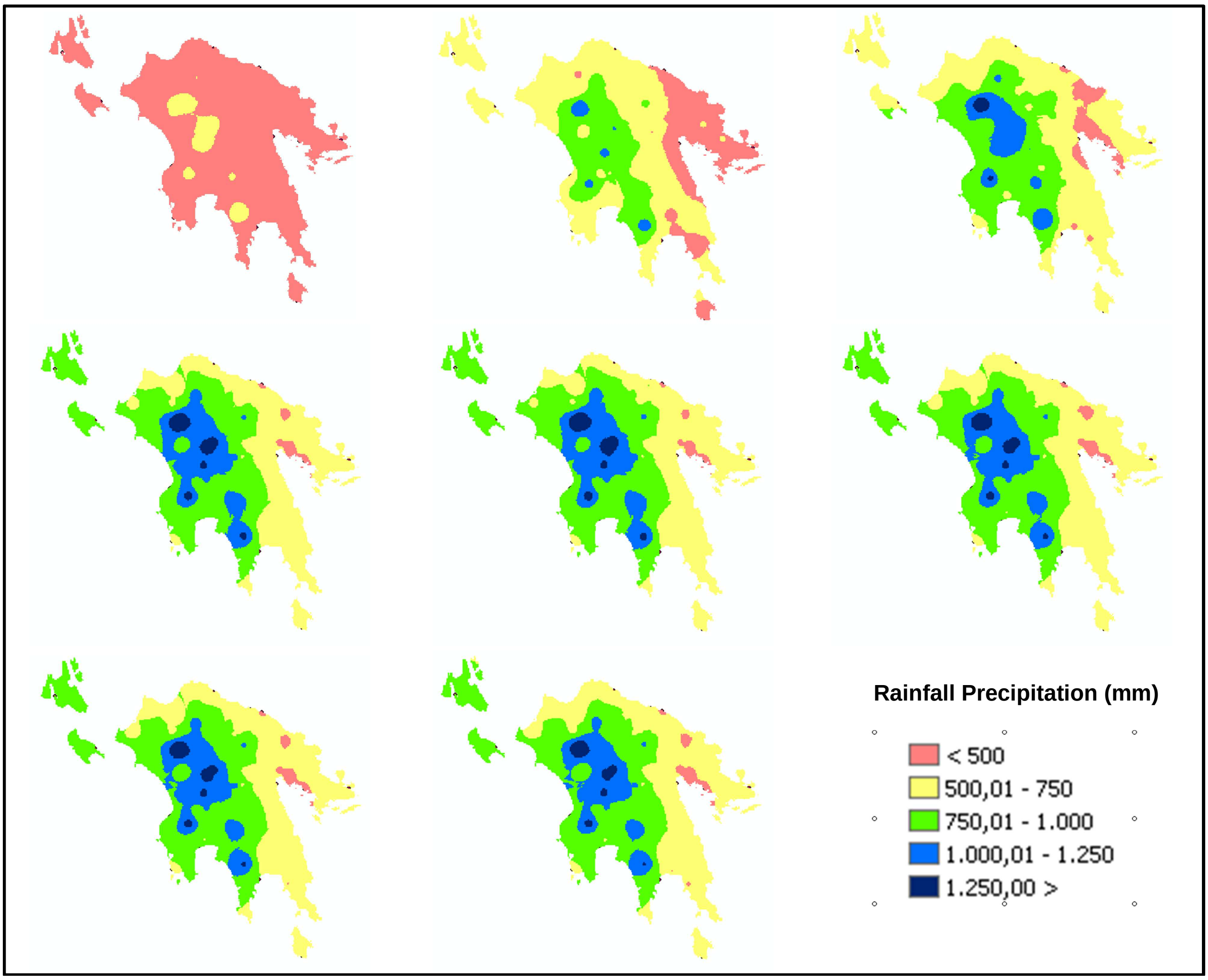

Figure 2. Geographical distribution of mean rainfall for various timescales. From upper left to down right: 3, 6, 9 months, 1, 2, 3, 4 and 5 years

1.2.2. Hydrometric, Springs and Walls level data

The study area is poor in hydrometric data due to infrequent surface measurements. Ladonas is the exception with a great number of runoff data from 1956-57 to 2010-11. Due to the lack of surface hydrological measurements, the use of time series of monthly drainage is adopted for the period from 1980 to 2002. The drainage data were re-evaluated after the extension of the rainfall time series. Runoff was calculated again until 2011, maintaining the model's parameters for the river basins of the study [5], [7].
Data of monthly flow rates were recovered especially for the decades of 1960 and 1970 by 24 important sources. These data are based on measurements of various public departments (PPC, IGME, Ministry of Rural Development and Food, Ministry of Infrastructure, Transport and Networks). New measurements for the years 2004-2008 were taken by IGME which supplement the past time series. From the hydrological data of the rainfall stations, it is attempted to represent the size of the over-yearly variation of the underground runoff and its correlation with the rainfall.
The well's data are based on evidence provided by measurements of the underground level that were collected during older studies and also provided by measurements taken by the IGME during the period from the years 2000 to 2008.
The correlation between water supply and groundwater runoff cannot be evaluated from the existing few data of level measurements and the groundwater level cannot be evaluated especially during dry periods.

1.2.3. Data of water management

The annual average water balance is given by the next equation.

$$P = ET + R - AEI \qquad \text{(Equation 1)}$$

Where P is the surface precipitation, ET are the losses due to the evaporation, R is the total surface and groundwater runoff and AEI are the inflows from the neighboring river basins. The groundwater runoff includes the amount of infiltrating water, which either reappears within the same river basin as surface spring discharge, or it is directed underground to the sea or to the neighboring basins. The groundwater runoff is practically identical with the buffer stocks and the renewable groundwater. The external inflows are finally referred to the groundwater supply of the aquifer by neighboring basins infiltration, in which there is hydraulic communication. Based on the data that have been obtained within the study, the values of the average annual water balance and the average annual water requirements for the River Basin Districts of Peloponnese are the following (Table 1 & Table 2):

Table 1. Average annual water balance for each River basin of Peloponnese

River Basin District	River Basin	Name	Area (km^2)	Rainfall (m^3)	Evaporation (m^3)	External inputs (m^3)	Runoff (m^3)
GR01	29	Alpheus	3.810	4.037.000	1.891.000	185.000	2.331.000
GR01	32	Pamisos-Nedondas-Neda	3.425	3.971.000	2.155.000	24.000	1.839.000
GR02	27	North Peloponnese streams	3.685	3.273.000	1.635.000	2.800	1.641.000
GR02	28	Piros-Vergas-Pinios	2.423	2.169.000	1.249.000	10.000	930.000
GR02	45	Kefalonia-Ithaca-Zakynthos	1.289	946.000	490.000	0.000	456.000
GR03	30	Tripoli’s plateau	907	771.000	359.000	0.000	412.000
GR03	31	Argolikos bay streams	5.296	4.123.000	2.346.000	0.000	1.777.000
GR03	33	Eurotas	2.239	2.021.000	1.113.000	10.000	918.000
		Total	**23.074**	**21.311.000**	**11.238.000**	**231.800**	**10.304.000**

Table 2. Average annual demand for various water uses for each River Basin of Peloponnese

River Basin District	River Basin	Name	Area (km^2)	Water Supply (m^3)	Irrigation (m^3)	Industry (m^3)	Livestock (m^3)
GR01	29	Alpheus	3.810	14.414.000	89.332.000	15.035.000	1.680.200
GR01	32	Pamisos-Nedondas-Neda	3.425	20.639.000	90.905.000	1.399.000	1.069.400
GR02	27	North Peloponnese streams	3.685	40.315.000	157.419.000	1.962.000	2.032.100
GR02	28	Piros-Vergas-Pinios	2.423	18.774.000	253.533.000	5.884.000	3347.900
GR02	45	Kefalonia-Ithaca-Zakynthos	1.289	10.699.000	5.177.000	391.000	1.168.900
GR03	30	Tripoli's plateau	907	4.660.000	13.656.000	113.000	628.800
GR03	31	Argolikos bay streams	5.296	20.117.000	233.246.000	6.311.000	2.810.700
GR03	33	Eurotas	2.239	6.626.000	82.856.000	1.270.000	1.120.600
		Total	**23.074**	**136.244.000**	**926.124.000**	**32.365.000**	**13.859.000**

2. EVALUATION OF METEOROLOGICAL DROUGHTS

The Standardized Precipitation Index (SPI) is widely used for tracing meteorological drought [1], [11]. The SPI introduced by McKee et. al., 1993 [8] and it has extensively used in several places of the world (Nalbandis and Tsakiris 2009, Angellidis et. al, 2013). The researchers categorized the intensity of meteorological drought in four states, depending on the value of the calculated SPI. These states are: mild (-1<= SPI <0), moderate (-1.5<= SPI <-1), severe (-2<= SPI <-1.5) and extreme (SPI <-2) [6]. In the current analysis the four drought states were adopted and symbolized as A-, B-, Γ- and Δ-, respectively. Additionally four more "wet" stages were considered and symbolized as A+, B+, Γ+ and Δ+ from the mild wet conditions to the extreme [10]. The limits of SPI that separate the four new wet stages are symmetrical (1, 1.5, 2) with those of the drought stages. The SPI was calculated for the following seasonal times scales: 3 months (Oct-Dec), 6 months (Oct-Mar), 9 months (Oct-Jun) and hydrological year (Oct-Sep). This methodology is common in the literature because the drought quantification at the end of each season can be connected to the measures that will be established for the remaining time period. Also the SPI was calculated for 2, 3, 4, 5 successive years in order to identify the droughts in long time periods. This methodology is also common in the literature because the droughts during long time periods are stress test for hydrosystems and permanent measures or hydraulic works can be scheduled. Finally the SPI was calculated for severalspatial scales (point, operational unit, water district, total area). In Figure 3 the evolution of the annual and 5-year SPI for total area of Peloponnese, is presented. It is worth mentioning that the four most dry hydrological years (1988, 1989, 1991, 1992) are almost consecutive as the interrupted by a wet one (1990). That leads to an almost severe 5-year drought period (1988-1992). Using the point SPI values (74 stations) for each hydrological year the spatial distribution of SPI was calculated and is presented in Figure 4 for 6 hydrological years. For the spatial interpolation of point values the Inverse Distance Weighted method, was used.

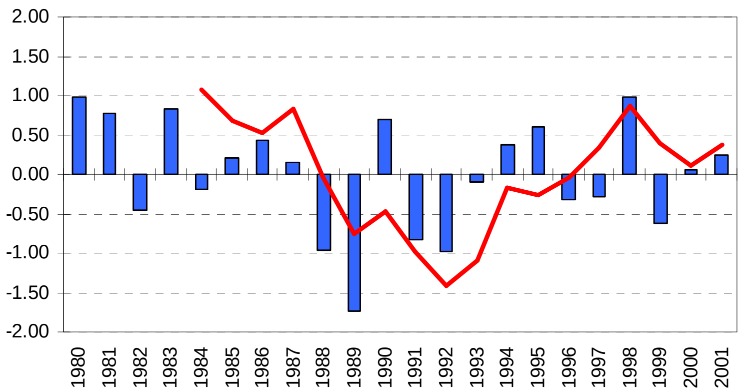

Figure 3. Temporal evolution of the annual SPI (bars) and 5-year SPI (line) for total area

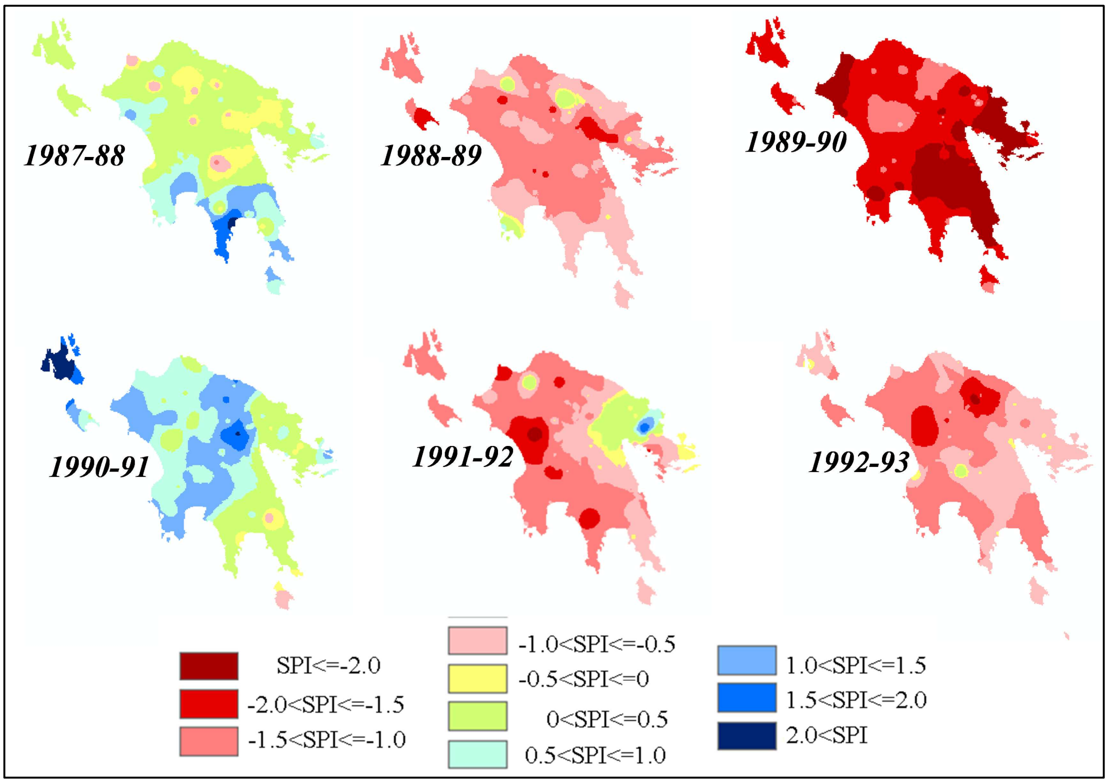

Figure 4. Geographical distribution of the annual SPI for six hydrological years

3. ESTIMATION OF WATER EXPLOITATION INDEX PLUS (WEI+)

The Water Exploitation Index Plus (WEI+) is applied to a particular hydrological district and time period [3], [4] and it is calculated as the ratio of the volume of water available for uses (Total Water Abstraction, TWA) divided by the available amount of renewable water resources (Renewable Water Availability, RWA):

$$WEI+ = TWA / RWA \qquad \text{(Equation 2)}$$

The total average annual abstraction, TWA, is calculated based on the average annual demand data, referred on 4 basic consumptive uses of water (Table 2). This term does not include the non-consumptive uses (eg. hydropower production), since the non consumptive uses return to the environment. The average annual availability of renewable water resources, RWA, is estimated as follows:

$$RWA = P - ET + AEI - WR + RW \qquad \text{(Equation 3)}$$

Where P is the surface precipitation, ET are the losses due to the evaporation, AEI are the inflows from the neighboring river basins, WR are the water demands for the environment use and RW is the amount of the water that returns to the system from several consumptive uses on an average annual scale. For each management unit, the mean values of annual precipitation and the mean values of annual real evaporation are given by the Table 1. In the present study, the water requirements for environmental use, WR are estimated as a percentage of 50% of the total runoff:

$$WR = 0.50\,(P - ET + AEI) \qquad \text{(Equation 4)}$$

Consequently, it is considered that only half of the natural water supplies are available to satisfy different consumptive uses. Finally, the amount of water that is returned to the system, RW, estimated as a percentage of 30% of the total demand. So, it is considered that a percentage of 70% from the water that is being consumed for various uses is converted into losses due to the evaporation and transpiration effects or it discharges into the sea, through the sewer systems. The remaining amount of water is returned to the natural system, mainly through irrigation drainage works, so it is accumulated in renewable reserves, although in these cases, water quality is degraded.

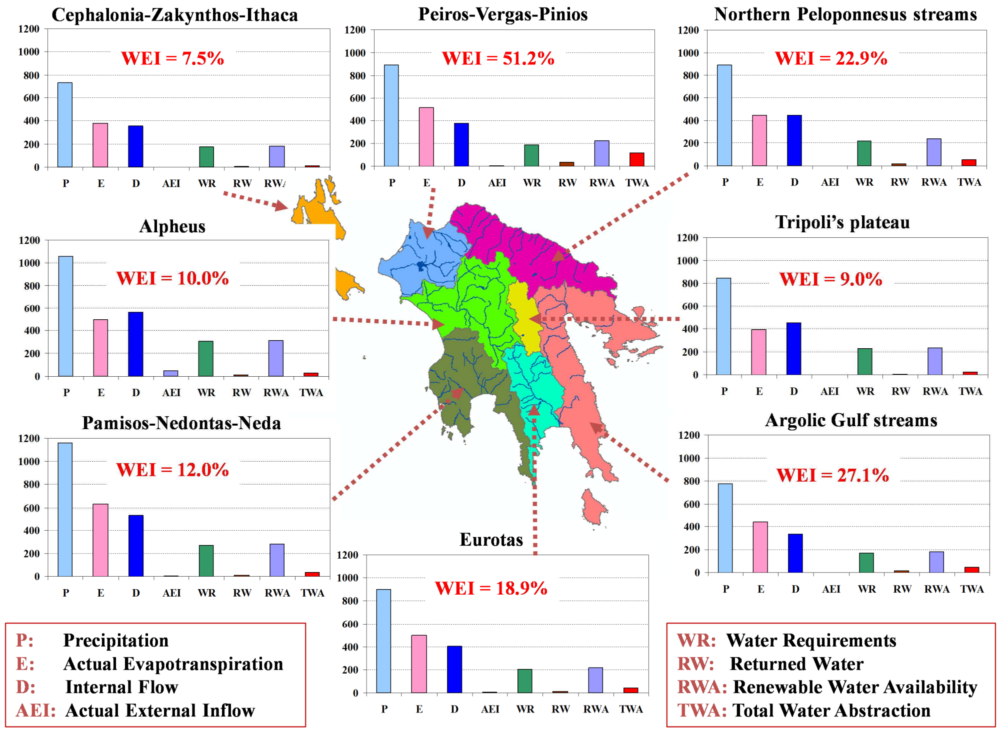

Figure 5. Water Exploitation Index Plus (WEI+) values (%) for each Operational Unit and mean annual values (mm) for the main components of the water budget.

Table 3. Average annual water balance for each River Basin of Peloponnese (mm)

River Basin District	River Basin	Name	Rainfall, P	Evaporation, E	External inputs, AEI	Enviromental Demand, WR	Returned Water, RW
GR01	29	Alpheus	1.059,6	496,3	48,7	306,0	9,5
GR01	32	Pamisos-Nedondas-Neda	1.159,4	629,3	7,0	268,5	10,0
GR02	27	North Peloponnese streams	888,4	443,7	0,8	222,7	16,4
GR02	28	Piros-Vergas-Pinios	895,2	515,5	4,2	191,9	34,8
GR02	45	Kefalonia - Ithaca - Zakynthos	734,0	380,0	0,0	177,0	4,1
GR03	30	Tripoli's plateau	850,0	396,0	0,0	227,0	6,3
GR03	31	Argolikos bay streams	778,5	443,0	0,0	167,7	14,9
GR03	33	Eurotas	902,7	497,1	4,5	205,0	12,3
		Total	**7.267,8**	**3.800,9**	**65,2**	**1.765,8**	**108,3**

Table 4. Calculation of WEI + for each River Basin of Peloponnese

River Basin District	River Basin	Name	Renewable Water Availability, RWA (hm^3)	Total Water Abstraction, TWA (hm^3)	WEI+ (%)	Vulnerability
GR01	29	Alpheus	1202.0	120.5	10.0	Low
GR01	32	Pamisos-Nedondas-Neda	953.9	114.0	12.0	Low
GR02	27	North Peloponnese streams	881.1	201.7	22.9	Moderate
GR02	28	Piros-Vergas-Pinios	549.5	281.5	51.2	High
GR02	45	Kefalonia - Ithaca - Zakynthos	233.3	17.4	7.5	Low
GR03	30	Tripoli's plateau	211.7	19.1	9.0	Low
GR03	31	Argolikos bay streams	967.1	262.5	27.1	Moderate
GR03	33	Eurotas	486.6	91.9	18.9	Low
		Total	**5.485,2**	**1.108,6**	**20.2**	**Moderate**

Based on the above assumptions, the average annual index WEI + is estimated for the entire study area and for every River Basin District of Peloponnese (Figure 5). The relative calculations about water supply and water demand are demonstrated in the Table 4. The correlations of index WEI + with several levels of vulnerability are defined as follows: for WEI + <20% no water stress, so low vulnerability, for values of 20% <= WEI + <40% low water stress, so moderate vulnerability and for WEI +> = 40%: significant water pressure so severe water stress and great vulnerability [4], [9].

4. DROUGHT PREDICTION

The drought indicators that have been used in this study are the rainfall SPI and the hydrological SRI predictive models as a medium-term evolution of the drought phenomenon in the coming time periods. The correlation between the index that is observed in specific time with the index that is referred to the next time period is also examined. The treatment is based on the time series rainfall of 22 hydrological years (1980-81 to 2001-02). These data have been measured and collected by 74 rainfall stations in the study area. The linear correlation coefficient of three (October-December), six (October to March) and nine (October-June) months drought indices is also calculated and compared with the hydrological year’s index. Furthermore the correlation coefficient of annual drought index is compared with the two-three-four or five years index. The transition probabilities of the 6th and 9th month’s category to a yearly hydrological drought event are presented at the next figure (Figure 6). The confirmation of a drought event is finally occurred at a half of a year, when the forecast of annual hydrological sizes is much more reliable.

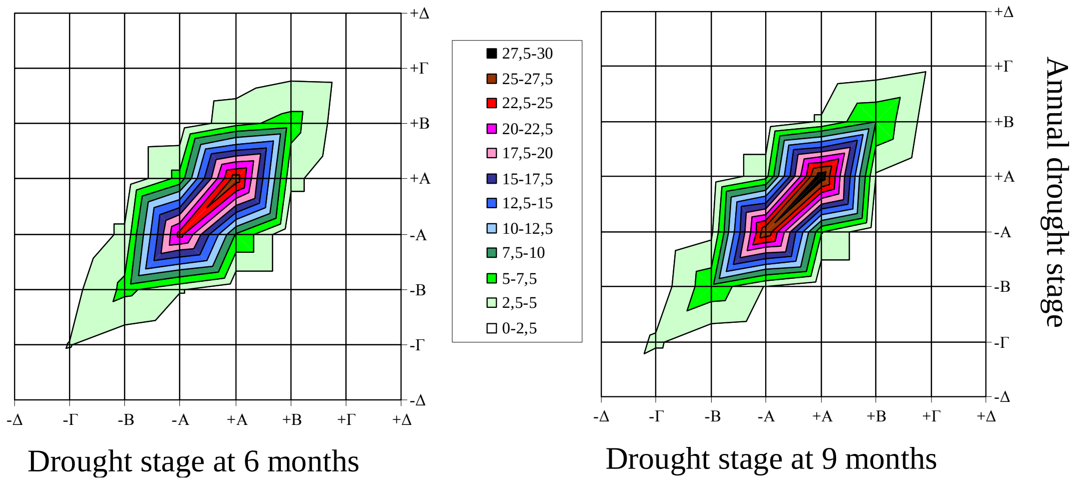

Figure 6. Transition probabilities between drought categories from 6 and 9 months to year

5. CONCLUSIONS

The conclusions arising from this study are the following:

- The vulnerability index (WEI+) in the River Basin Districts of Eastern and Northern Peloponnese is higher than the Western Peloponnese, showing greater vulnerability to these areas due to the increased water demand of irrigation and the reduced rainfall mainly in the Eastern Peloponnese.
- A drought event is confirmed in the half of the year, when the forecast of annual hydrological sizes are much more reliable, since they have been based on the semester’s measurements (cumulative rainfall and cumulative runoff October - March) compared with forecasts based on the relative sizes of the quarter.
- The 2-year period SPI indicator is suggested to calculate only for the Groundwater bodies.
- The main objective of the drought – scarcity management plan is the creation of a practical and reliable operational system of indicators which reflects the spatial and temporal aspects of drought and scarcity events. This system is delivered to the competent authorities who are the responsible of the usage, maintenance and the benefits exploitation of this tool. Based on this operational system,

competent authorities may assess and predict the severity of drought events and they can proactively respond by taking measures to mitigate the effects. The combination of measures that are selected every time depends on the analysis results and the expected intensity of the drought or scarcity events. Taking the above into consideration, such measures were prepared for Peloponnese and are included in the Water Framework Directive's 60/2000/EC RBMPs [2].

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