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THE USE OF "ANTECEDENT PRECIPITATION INDEX" AND "DELAY FACTOR" TO ESTIMATE RUNOFF FROM RAINFALL; A CASE STUDY FROM EIGHT DRAINAGE BASINS - ACHAIA, PELOPONESSOS, GREECE

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Abstract

The present paper deals with the relationship between precipitation and runoff. The results from application of the "Antecedent Precipitation Index" (API) technique after introduction of the "delay factor" in eight river basins from NE Achaia-Peloponessos are presented. Measurements of runoff in the exits of the basins were carried out during the period 1996-1999. Precipitation measurements were used from precipitation gauge stations lying in the river basins. Runoff seems to follow the course of rainfall with a time-lag varying from 30 to 60 days.After trial and error technique the best fittings of runoff and precipitation graphs were defined. Based on the best fitting equations to calculate the "Antecedent Precipitation Index" the "delay factor" was compiled. High correlation degree between rainfall and runoff was therefore achieved. The technique may be used to assess the expected runoff, based either on real rainfall dataset or on hypothetical scenarios. The "delay factor" of the runoff response to the precipitation is highly correlated with geomorphological and hydrogeological characteristics of the river basins.

Key words: *NE Achaia, precipitation, runoff, Antecedent Precipitation Index (API).*

Περίληψη

Αντικείμενο της παρούσας εργασίας αποτελεί η διερεύνηση της σχέσης «βροχόπτωση – απορροή» σε οκτώ υδρολογικές λεκάνες της ΒΑ Αχαΐας μετά από την εισαγωγή του δείκτη ***"Antecedent Precipitation Index" (API)*** *και του παράγοντα* ***"delay factor"*** *στη πιο πάνω η σχέση. Οι μετρήσεις βροχόπτωσης και απορροής έγιναν την περίοδο 1996-1999. Η μετρημένη απορροή, στην έξοδο των λεκανών αυτών, φαίνεται από τα σχετικά διαγράμματα να ακολουθεί την πορεία της βροχόπτωσης, όπως αυτή καταγράφηκε στον πλησιέστερα για κάθε λεκάνη βροχομετρικό σταθμό, με μια υστέρηση, που κυμαίνεται, από 30 έως 60 μέρες. Για να ληφθεί υπόψη η υστέρηση αυτή, εισάγεται η έννοια του δείκτη API Μετά από διαδικασίες βέλτιστης ταύτισης, μεταξύ των διαγραμμάτων βροχόπτωσης και απορροής ο δείκτης API προσδιορίζεται για κάθε λεκάνη, από μία μαθηματική σχέση. Με την εισαγωγή του δείκτη API*

επιτυγχάνεται υψηλός συντελεστής συσχέτισης μεταξύ των παραμέτρων της βροχόπτωσης και της απορροής και από την σχέση που εξάγεται είναι δυνατό να γίνουν προβλέψεις για την αναμενόμενη απορροή, στηριζόμενες σε πραγματικά ή υποθετικά (σενάρια) δεδομένα βροχόπτωσης. Ο παράγοντας "delay factor" δηλαδή η χρονική υστέρηση της απορροής ως προς την βροχόπτωση, όπως προκύπτει από τις εξισώσεις υπολογισμού του API παρουσιάζει υψηλή συσχέτιση με γεωμορφολογικά και υδρογεωλογικά χαρακτηριστικά της λεκάνης.
Λέξεις κλειδιά: *ΒΑ Αχαΐα, ατμοσφαιρικά κατακρημνίσματα, επιφανειακή απορροή, Andecedent Precipatation Index(API).*

1. Introduction

Runoff estimation through rainfall records is an essential issue for every hydrological basin, and has a major practical merit, since the optimal utilization of the expected runoff, especially in semi arid environments, like the one met in some parts of the Greek territory, can be a very crucial factor for the development of the area. The present paper deals with a simple statistical technique of processing precipitation measurements in order to determine the relationship between precipitation and runoff. The results obtained after application of that technique are presented.

The study area covers almost the 1/3 of Achaia region (1.230 Km^2), occupies its NE part and includes eight major drainage basins, namely (from W to E): Finikas, Meganitis, Selinous, Kerynitis, Vouraikos, Ladopotamos, Krathis and Krios (Fig. 1).

Figure1 - River basin boundaries and sites of precipitation and runoff gauge stations, in the study area. 1: Finikas R.B., 2: Meganitis R.B., 3: Selinous R.B., 4: Kerinitis R.B., 5: Bouraikos R.B., 6: Ladopotamos R.B., 7: Krathis R.B., 8: Krios R.B.

From the geomorphological point of view the basins are characterized by high gradient values which may be attributed to the combining effect of active tectonics (faulting- uplift) of the area and the extensive presence of rigid indurated rocks (limestones, radiolarites and Pleistocene conglomerates) forming steep slopes (Stournaras *et al.* 1998).

2. Geological setting in the area

The geological setting in the study area comprises two distinctive geological units consisting the alpidic bedrock of the study area; one autochthonous unit, namely the formations of the Gavrovo-Tripoli isopic zone and the Phyllites – Quartzites series, and one heterochthonous unit, namely the formations of the Olonos-Pindos zone (Fig. 2). The latter are overthrusted onto the Gavrovo-Tripoli zone. The overthrusted sheet has internal structure of scales. The formations of Gavrovo - Tripoli zone and the Phyllites – Quartzites series crop out as a tectonic window in a relatively small area, in the SE edge, consisting the Chelmos Mountain. The Olonos –Pindos zone occupies the major part of the study area.

The Gavrovo-Tripoli zone comprises a thick sequence of neritic limestones of Triassic to Eocene age. The alpidic sedimentation was completed by the deposition of the Eocene flysch.

The Olonos-Pindos zone consists of deep-sea limestones, of middle Triassic to upper Cretaceous age, with intercalations of radiolarites.

The stratigraphic sequence of the Olonos-Pindos zone comprises six geologic formations, aged from upper Triassic to Eocene, namely, from the more recent to the older ones, the Eocene flysch, the transition strata from older formations to the flysch (Upper Maestrichtian-Paleocene), the "Plattenkalk" limestones (Koniacian–lower Maestrichtian), the radiolarites-Mudstones (Dogger-Touronean) the Drymos Limestones (Upper Carnean-Lias) and the Triassic clastic sediments.

Each geologic formation is further divided into facies with similar petrologic features, reflecting the evolution of sedimentation during that geological era.

The postalpidic sedimentation in the area is in close relation with the active tension tectonism of Corinthiakos tectonic trough. During the whole Pleistocene clastic sediments are deposited under high tensional energy.

Poulimenos *et. al.* (1989) and Poulimenos (1991), recognized in the several sedimentation basins 14 different sedimentary facies. Zelelidis *et. al.* (1996) grouped and classified the above facies to five, in accordance with the five different sedimentary environments installed in the area, namely lacustrine-lagoonal, fluviolacustine, braided river, alluvial fans and fan-deltas.

During the Upper Pliocene to Quaternary a sequence of sedimentary rocks is deposited. The majority of researchers recognize three sedimentary cycles: one lower with fine mostly lacustrine and braided river deposits (Phillippson 1892, Doutsos *et al.* 1988), one middle with alluvial fans, proximal braided and alluvial fan delta deposits (Phillippson 1892, Psarianos 1943) and an upper one with marine terraces of Tyrrhenian age (Negris 1910), moraines, pediments, talus cones (Phillippson 1892, Mistardis 1937, Dufaure *et al.* 1979). Graben-filling sediments, form a northward-eastward thickening wedge, with a maximum thickness of almost 1000 m near the coast. The distribution of the Graben-filling sediments is strongly influenced by the WNW extensional faults and NNE transfer faults. The faults of the study area are mostly active, reveal listric geometry and are associated with a large curved ramp (Poulimenos 1991, 1993, Flotte and Sorel 2001).

3. Geomorphology - hydrography of the study area

The geomorphologic landscape of the study area is the result of the combined action of tectonics, erosion and weathering upon its lithologic structure.

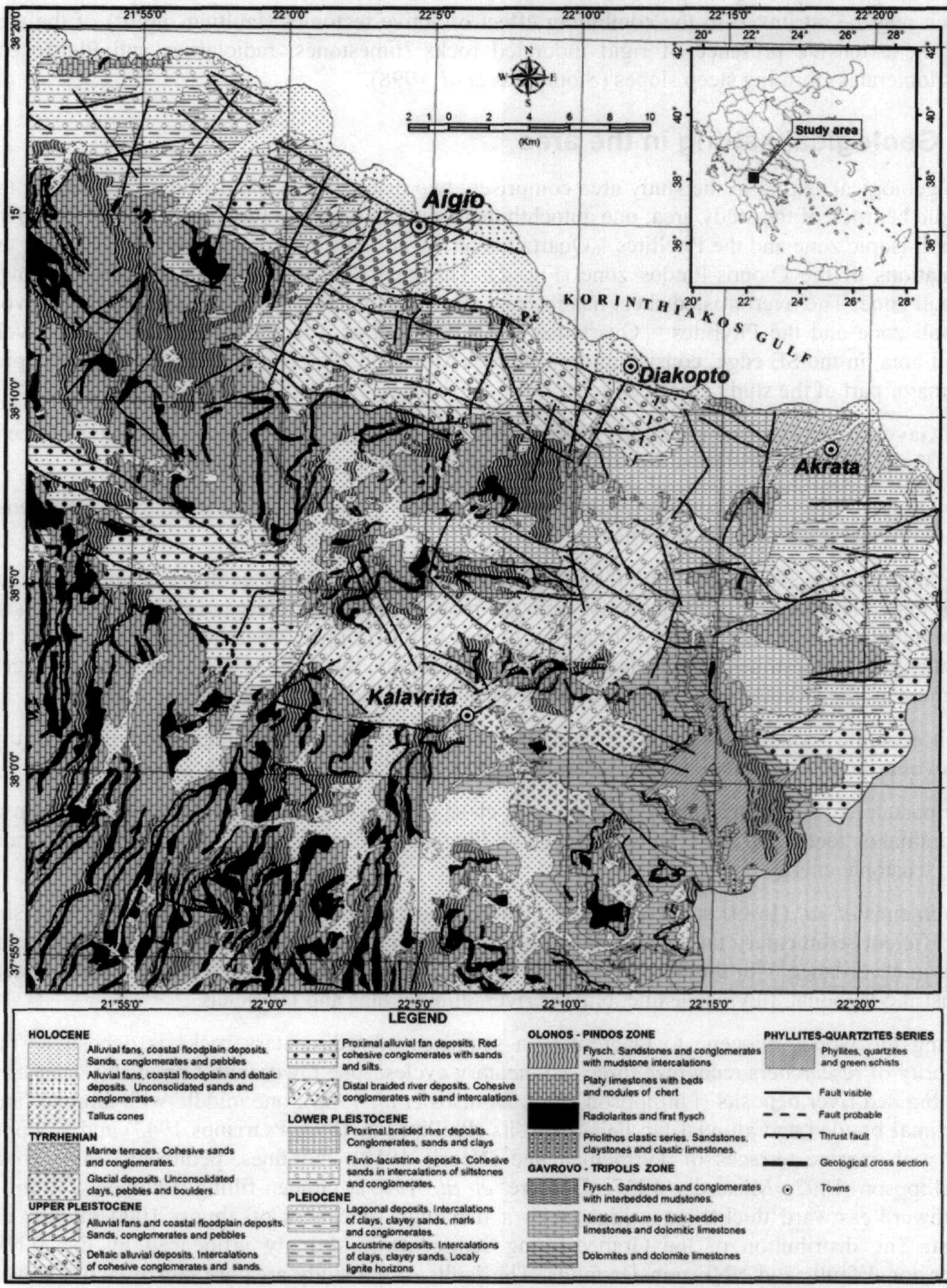

Figure 2 - Geological Map of the study area (Nikas 2004)

There is a steep relief preserved in the wider area. The preservation of the steep relief may be attributed to the active tectonics during the post-alpidic period as well as to resistance of the rocks in the area, mainly consolidated, to erosion and weathering.

Therefore the geomorphology influences significantly the evolution of the hydrogeological conditions of the area.

The mean altitude of the study area is 862 m and the mean slope 33, 5 %. These high values may be attributed to the persistent steep relief. The persistence of this steep relief may be attributed to the active tectonics in the area, during the Plio-Quaternary period. Part of the active tectonics, is the uplift of the southern part of the study area. The increase of the uplift rate, during the Quaternary, resulted in the development of the channel network, which in turn, is related with the fluvial sedimentation. The latter is characterised by abrupt changes in grain size distribution and, at the same time, the considerable increase of the volume of material produced.

The study area consists from the following eight main river basins (Fig. 1): Finikas, Meganitis, Selinous, Kerinitis, Vouraikos, Ladopotamos, Krathis, and Krios. All the rivers form alluvial deltas.

The mean slope of the river basins ranges between 15 % and 37 %. Table III shows the morphometric indexes of the river basins.

The development of the drainage network is weaved together with the development of the NNE transfer faults. This faulting followed in a second stage the WNW extensional faulting. Therefore the creation of the drainage network is placed also in a second stage of evolution.

4. Hydrological Balance

In the study area eighteen rain gauges recording precipitation from 1975 to 1999 were used for the estimation of the hydrological balance.

The precipitation gradient in the area amounts to 63 mm for every 100 m in the west part of the study area and to 46 mm in the east part, respectively, the east watershed boundary of the Selinous river basin considered as borderline between the west and the east parts. (Nikas 2004).

The mean annual volume of precipitation falling over the study area amounts to 1.227 * 106 m^3 equivalent to a mean annual precipitation of 1.080 mm.

The evapotranspiration losses amount to 45 % of precipitation. Another 21 % of the precipitation infiltrates recharging the aquifers. From this infiltrating quantity of water 9 % reappears on the surface further downstream as interflow or base flow. The runoff amounts to 34 % of the precipitation flowing along the drainage network towards the sea. To this amount of runoff the interflow/base flow must also be added. Therefore the total runoff amounts to 43 % as measured in the exit of the river basins (Nikas 2004).

The surface runoff (overland flow) was estimated indirectly after elaboration of the approximate water balance for every river basin. The runoff was directly measured in the river's basin exit (Table I).

Table 1 - Statistic analysis of the measured runoff

	Vouraikos	Kerinitis	Krathis	Krios	Ladopotamos	Meganitis	Selinous	Finikas
Mean	3,074	1,075	1,765	1,222	0,260	0,900	5,540	1,350
Median	2,087	0,884	1,478	0,901	0,176	0,652	3,764	0,971
Standart Deviation	2,790	0,714	1,060	1,180	0,222	0,758	5,295	0,952
Variance	7,782	0,509	1,123	1,393	0,049	0,575	28,033	0,906
Range	13,987	2,749	4,946	6,865	0,911	3,329	22,356	3,186
Minimum	0,418	0,114	0,568	0,199	0,006	0,099	0,690	0,117
Maximum	14,405	2,863	5,514	7,064	0,917	3,428	23,046	3,303
Number of measurements	38	41	38	39	39	41	41	37

5. Hydrogeological conditions

Medium to high productive carbonate aquifers are hosted in the Upper Cretaceous platy limestones ("Plattenkalk") of the Olonos –Pindos zone. Pumping test in these formations (Voudouris 1995, Nikas 2001a, 2004) confirmed their high productivity. The radiolarites made of cherty and silty alternations constitute impermeable barriers, within the Olonos –Pindos carbonate aquifer system and define autonomous or semiautonomous hydrogeological units. These impermeable barriers contribute to the formation of numerous springs, usually of medium to low discharge. Rarely are encountered also springs (contact–overflow) with high discharges in the above formations (Skagias 1978, Voudouris 1995, Yannatos 1999, Nikas *et al.* 2001).

Generally speaking the "Plattenkalk" aquifer is the most promising in the study area. The aquifers in Quaternary alluvial fans constitute also considerable sources of ground water. The upper Pleistocene alluvial fans and the alluvia in the Logos- Aighion – Diacopto coastal plain, form a unified unconfined aquifer with significant productivity. This aquifer has relatively high values of effective porosity, hydraulic properties and recharge rates from riverbeds. The lower Pleistocene aquifer has reduced productivity in relation with the upper Pleistocene/ Holocene and is of local interest only (Nikas 2004).

Highly productive aquifers are developed within the recent clastic deposits given also that the hydro-meteorological conditions in the area are very suitable. Pumping tests analysis in those aquifers in the study area confirms this ascertainment.

Active tectonics has also played decisive role in the evolution of the hydrogeological units in the area. Active normal faults, act as hydraulic barriers, defining thus hydrogeological units with explicit hydraulic and in some cases hydrochemical differentiations (Nikas 2001b, Nikas and Antonakos 2005).

6. Relationship between precipitation and runoff in the study area

The relationship between precipitation and runoff is affected by many different independent factors. Therefore several techniques have been developed to asses it. The simplest way to deal with the estimation of runoff from precipitation measurements is to use the statistical correlation between precipitation and runoff.

Mean monthly values of runoff in most cases exhibit a time-lag to the corresponding mean monthly values of rainfall. Figures 3 and 7 show that this time-lag ranges, in the study area, from 30 to 60 days, in annual basis examination. Apparently these two parameters of the hydrological balance are not directly correlated and if so they produce small and insignificant correlation coefficients (Figs 4, 8). In order to achieve a reliable correlation of the two parameters there - to the initial rainfall values contributing to runoff - the quantity of precipitation stored as ground water in shallow aquifers and superficial strata influencing therefore, to some extent, the runoff of the next hydrological year, must be added. This amount of rainfall that contributes to runoff during this time-lag namely "Antecedent Precipitation Index" (API) (Butler 1957, Ven Te Chow 1964, Kohler and Linsley 1951) can be expressed essentially as:

Equation 1 - Antecedent Precipitation Index definition

$$P_a = \kappa P_i + \lambda P_{i-1} + \mu P_{i-2} + \ldots + \nu P_{i-v}$$

Where Pi, Pi-1… Pi-v= the annual or the monthly rainfall of the current year or month, the antecedent year or month, the second antecedent year or month and the i-vth year or month, respectively. The weighting coefficients κ, λ, μ…ν with their sum equal to unity, are determined by trial and error in order to obtain a best correlation between the runoff and the weighted API.

In order to quantify the runoff time-lag a new variable called "delay factor" is introduced, determined by the following equation:

Equation 2 - Delay factor definition

$$D_R = [\kappa \cdot i] + [\lambda \cdot (i-1)] + [\mu \cdot (i-2)] + ... + [\nu \cdot (i-\nu)]$$

Where κ, λ, μ…,ν = the coefficients of equation (1) and i = -1.

With the help of these equations and applying simple regression analysis, the relationship between mean monthly rainfall values and mean monthly runoff values was examined for the eight river basins of the study area based on measurements made in the period 1996-1999.

In every case after the construction of the graph showing the temporal distribution of the two parameters (rainfall /runoff) resulted the approximate time-lag, the approximate contribution of the rainfall to runoff of the previous months and, in a first approximation, the coefficients of the equation (1). These values of the coefficients κ, λ, …ν were finalized after optimization of the Pearson's correlation coefficient r between effective API and runoff.

After trial and error the best fit between rainfall/runoff graphs was obtained (optimal correlation). Finally the mathematical equations of "Antecedent Precipitation Index" were compiled for the eight river basins and the corresponding rain gauges of the study area (Table 2). The simple linear equation that produces the optimum correlation coefficient was used for the estimation of runoff as shown in table II.

Table 2 - Equations for the determination of the mean monthly "Antecedent Precipitation Index" (API)

Hydrologic Bassin	Nearest Raingauge Station	Antecedent Precipitation Index (Pa) equation	Relationship between Antecedent Precipitation Index (Pa) and runoff (R)	Pearson's (r) correlation coefficient
Selinous	Kouteli	API = 0,40*P_{i-1} + 0,60*P_{i-2}	R = 0.0558 * API + 0.7231	0,79
Vouraikos	Kalavrita	API = 0,60*P_{i-1} + 0,40*P_{i-2}	R = 0.0277 * API + 1.0399	0,78
Kerinitis	Kerpini	API = 0,50*P_{i-1} + 0,50*P_{i-2}	R = 0.0095 * API + 0.3622	0,73
Krios	Perithorio	API = 0,50*P_{i-1} + 0,50*P_{i-2}	R = 0.0075 * API + 0.593	0,65
Krathis	Kakavrita	API = 0,40*P_{i} + 0,60*P_{i-1}	R = 0.011 * API + 1.0436	0,69
Meganitis	Leontio	API = 0,05*P_{i-1} + 0,95*P_{i-2}	R = 0.0051 * API + 0.3564	0,79
Finikas	Aigio	API = 0,70*P_{i-1} + 0,30*P_{i-2}	R = 0.0125 * API + 0.5729	0,76
Ladopotamos	Kalavrita	API = 0,45*P_{i-1} + 0,55*P_{i-2}	R = 0.0027 * API + 0.0945	0,73

Figure 3 shows the temporal distribution of the mean monthly values of rainfall - measured in the Kouteli rainfall gauge station- and runoff of the Selinous river – measured in the exit of the river basin. The correlation coefficient between these two parameters shown in the scatter diagram of figure 4 is too low (r = 0, 47). After introduction of the "Antecedent Precipitation Index" API, (Fig. 5), the correlation coefficient between "Antecedent Precipitation Index" (API), and runoff increases to 0, 79 (Fig. 6).

The relationship between API and Pi is expressed mathematically by the equation:

Equation 3 - Antecedent Precipitation Index for Kouteli gauge station and Selinous river

$$API = 0{,}40 * P_{i-1} + 0{,}60 * P_{i-2}$$

where P_{i-1} = the rainfall of the antecedent month and P_{i-2} = the rainfall of the second antecedent month.

Using this expression it is possible to estimate the runoff in the exit of a river, if a set of rainfall data is available

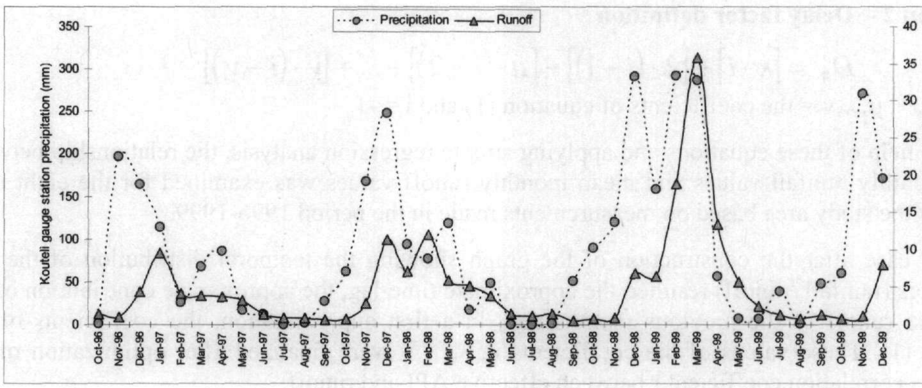

Figure 3 - Temporal distribution of mean monthly rainfall and runoff for the Kouteli gauge station and Selinous River

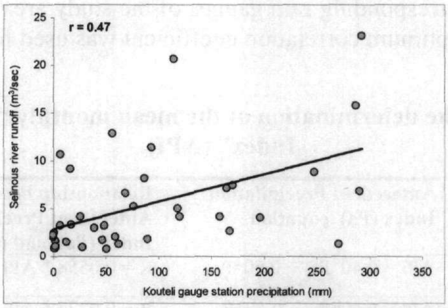

Figure 4 - Scatter diagram between mean monthly rainfall for the Kouteli gauge station and runoff of the Selinous river

The same procedure was applied in the case of Kerinitis river using the rainfall data from Kerpini's raingauge station (Figs 7-10) as well as for the rest six river basins. Runoff measurements were carried out monthly in the exit of the rivers. The relations between API and Pi itself are shown in Table 2. Correlation coefficients are statistically significant for all eight river basins but their values are not as high as expected. This result can be attributed to the fact that mean monthly values of runoff were estimated from weekly discrete measurements and not from continuous or daily ones. As a result, many flood events that last less than a week were no recorded.

The API method to predict or estimate runoff is not sufficiently accurate in order to be used for operational purposes. However it very useful for general planning and for design of long-term water resources management.

7. Relationship between runoff time-lag and morphometric parameters

The runoff time-lag may be attributed partly to the temporary storage of the rainfall water in the soil layer and the shallow aquifers and partly to the time needed for lateral, interflow and/or base flow, runoff to reach the outlet of a river basin. The time-lag may range from some days to some months depending mostly on the hydrogeological and geomorphological characteristics of the river basin itself.

The correlation between runoff and time-lag, expressed by the "delay factor" and some hydrogeological and geomorphological indices of the river basins was studied.

Table 3 - Morphometric and hydrographic characteristics of the river basins

	Runoff delay factor	River basin area (Km^2)	River basin stream length (Km)	Mean altitude (m)	Peak altitude (m)	Mean gradient (%)	Bifurca-- tion ratio	Drainage density	Bifurca-tion frequency	Aquicludes percentage (%)	Aquifers percentage (%)
Selinous	2,6	363	668	859	2.169	17,4	3,83	1,84	0,30	27	60
Vouraikos	2,4	237	513	970	2.325	18,1	5,53	2,16	0,40	31	41
Krathis	1,6	145	351	1.091	2.325	20,2	4,95	2,42	0,49	40	36
Krios	2,9	99	318	973	1.836	17,1	3,64	3,22	0,67	36	18
Finikas	2,6	92	185	779	1.924	15,4	3,95	2,00	0,33	43	56
Kerinitis	2,5	87	177	847	1.573	18,5	4,01	2,04	0,37	50	44
Meganitis	3,0	62	95	698	1.618	13,7	4,06	1,53	0,14	23	51
Ladopotamos	3,1	48	109	877	1.921	17,1	3,42	2,26	0,34	39	50

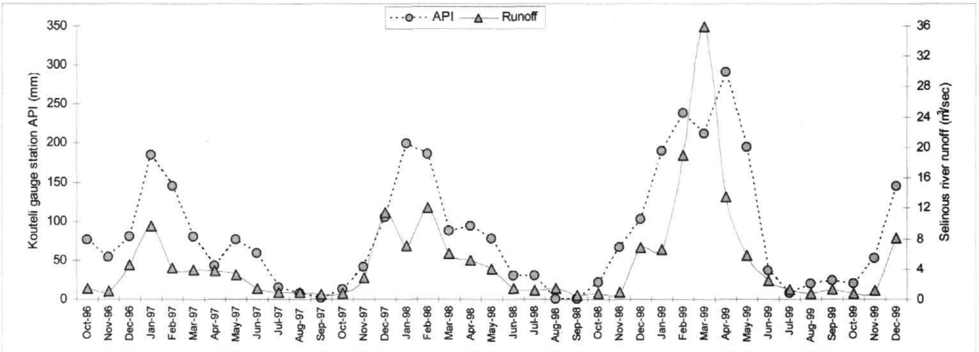

Figure 5 - Temporal distribution of mean monthly "Antecedent Precipitation Index" (API) and runoff for the Kouteli gauge station and the Selinous river

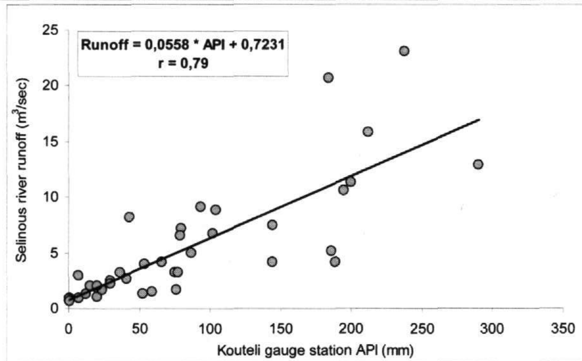

Figure 6 - Scatter diagram between mean monthly "Antecedent Precipitation Index" (API). and runoff for the Kouteli gauge station and Selinous river

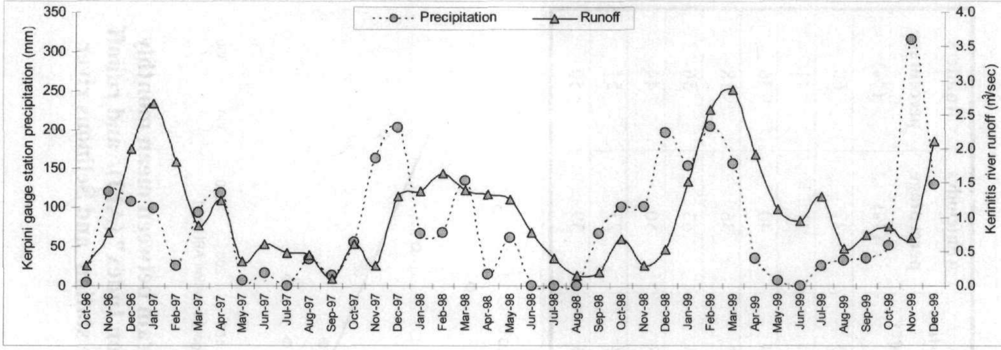

Figure 7 - Temporal distribution of mean monthly precipitation and runoff for the Kerpini gauge station and the Kerynitis river

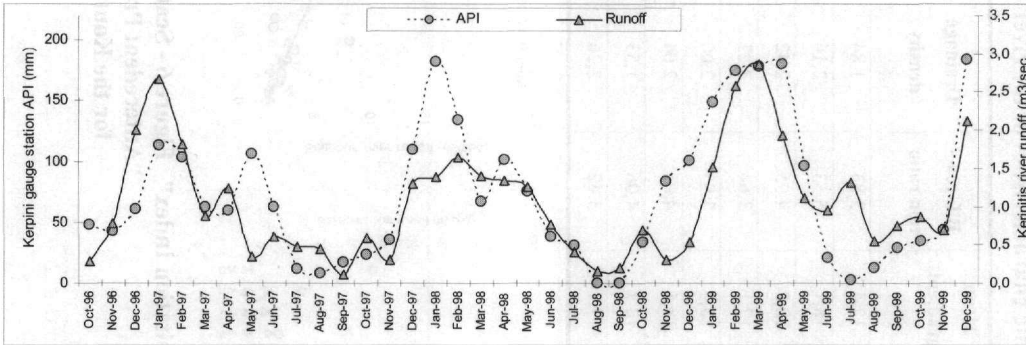

Figure 8 - Temporal distribution of mean "Antecedent Precipitation Index" (API), for the Kerpini gauge station and the Kerinitis river

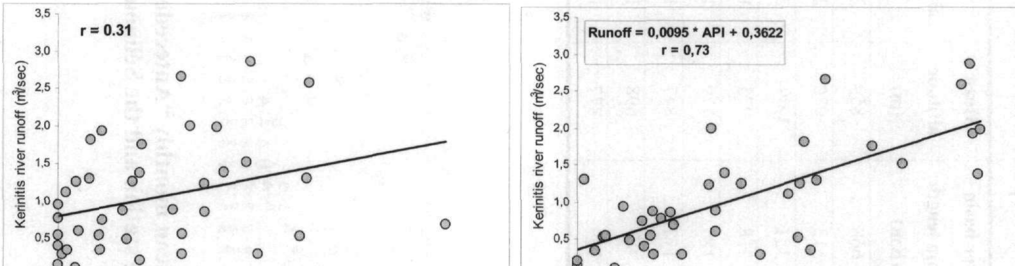

Figure 9 - Scatter diagrams between mean monthly precipitation and runoff and mean monthly "Antecedent Precipitation Index" (API) and runoff for the Kerpini gauge station and the Kerinitis river

Table 4 and figure 11 show that the "delay factor" presents high and statistically significant negative relationship with the mean altitude, the 50 % altitude and the mean slope of the river basin. On the other hand it is independent from the extent of the basin area and from the total stream length of the channel network while it presents weak positive correlation with the extent of the highly productive aquifers in the area and negative correlation with the extent of the aquicludes.

Table 4 - Pearson's (r) correlation coefficient between "Runoff delay factor" and morphometric, hydrographic and hydrogeological indexes

Morphometric, hydrographic or hydrogeological index	Runoff delay factor
Total basin area (Km^2)	-0,14
Total stream length (Km)	-0,27
Mean altitude (m)	**-0,89***
Altitude 50%	**-0,76***
Peak altitude	-0,68
Basin relief (m)	-0,65
Mean gradient (%)	**-0,87***
Bifurcation coefficient	-0,51
Drainage density	-0,43
Bifurcation ratio	-0,57
Aquicludes areal extent	-0,40
Highly productive aquifers areal extent	0,39

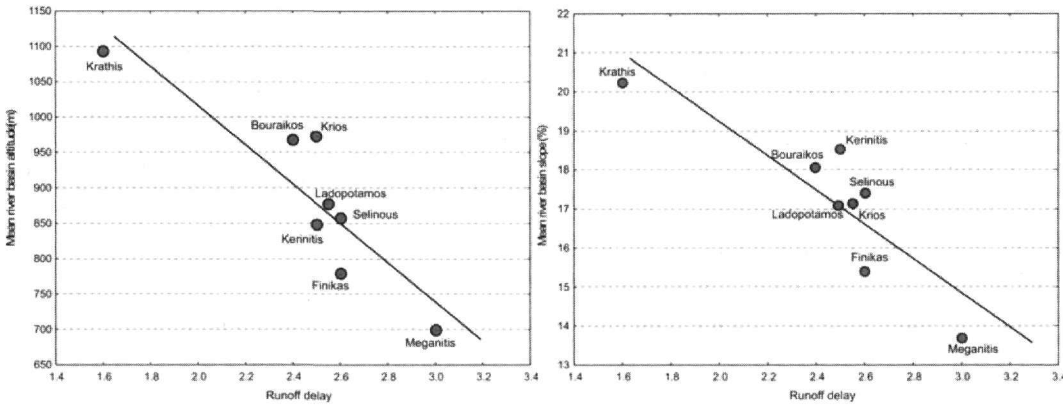

Figure 11 - Scatter diagram between mean river basin altitude, mean river basin slope and "runoff delay factor"

From the above statements results that high altitude gradients and high mean altitude as well of the river basins, favor generally the surface runoff at the expenses of lateral flow and infiltration and reduce therefore the time needed by a peak runoff episode (flood episode) to arrive to the exit of the river basin. Significant extent of aquicludes in the river basin produces the same effect. On the other hand significant extent of aquifers favors generally infiltration and lateral flow at the expenses of surface runoff.

8. Conclusions

By the use of the "Antecedent Precipitation Index" (API) and with the aid of some easy to follow procedures a high correlation degree between rainfall and runoff can easily be achieved. Therefore it is possible to estimate the expected runoff based either on real rainfall dataset or on hypothetical scenarios.

The time lag of the runoff response to the corresponding rainfall resulting from the "Antecedent Precipitation Index" (API) equation, presents a high correlation coefficient with some of the geomorphological and hydrogeological characteristics of the river basin.

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