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).
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 Km²), 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: Kerynitis 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 Corinthlakos 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 (Phillipson 1892, Doutsos et al. 1988), one middle with alluvial fans, proximal braided and alluvial fan delta deposits (Phillipson 1892, Psarianos 1943) and an upper one with marine terraces of Tyrrenian age (Negris 1910), moraines, pediments, talus cones (Phillipson 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.
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.

Figure 2 - Geological Map of the study area (Nikas 2004)
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 \times 10^6 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       |
| Standard 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 |

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5. Hydrogeological conditions

Medium to high productive carbonate aquifers are hosted in the Upper Cretaceous platy limestones ("Plattenkalk") of the Olonos –Pindos zone. Pumping tests 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 assess 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:

\[
P_a = kP_1 + \lambda P_{t-1} + \mu P_{t-2} + \ldots + \nu P_{t-v}
\]

Where \(P_i, P_{i-1} \ldots P_{i-v}\) = 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 \(i\)-th year or month, respectively. The weighting coefficients \(k, \lambda, \mu \ldots \nu\) 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

\[
D_R = \left[ \kappa \cdot i \right] + \left[ \lambda \cdot (i-1) \right] + \left[ \mu \cdot (i-2) \right] + \ldots + \left[ \nu \cdot (i-\nu) \right]
\]

Where \( \kappa, \lambda, \mu, \ldots, \nu \) = 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 \( \kappa, \lambda, \ldots, \nu \) 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 Basin | Nearest Raingauge Station | Antecedent Precipitation Index (Pa) equation | Relationship between Antecedent Precipitation Index (Pa) and runoff (R) | Pearson’s (r) correlation coefficient |
|------------------|---------------------------|---------------------------------------------|------------------------------------------------------------------------|-------------------------------------|
| Selinous         | Kouteli                   | \( \text{API} = 0.40 \cdot P_{i-1} + 0.60 \cdot P_{i-2} \) | \( \text{R} = 0.00558 \cdot \text{API} + 0.7231 \)                        | 0.79                                |
| Vouraikos        | Kalavrita                 | \( \text{API} = 0.60 \cdot P_{i-1} + 0.40 \cdot P_{i-2} \) | \( \text{R} = 0.0277 \cdot \text{API} + 1.0399 \)                        | 0.78                                |
| Kerinitis        | Kerpini                   | \( \text{API} = 0.50 \cdot P_{i-1} + 0.50 \cdot P_{i-2} \) | \( \text{R} = 0.0095 \cdot \text{API} + 0.3622 \)                        | 0.73                                |
| Krionis          | Perithorio                | \( \text{API} = 0.50 \cdot P_{i-1} + 0.50 \cdot P_{i-2} \) | \( \text{R} = 0.0075 \cdot \text{API} + 0.593 \)                        | 0.65                                |
| Krios            | Perithorio                | \( \text{API} = 0.40 \cdot P_{i-1} + 0.60 \cdot P_{i-2} \) | \( \text{R} = 0.011 \cdot \text{API} + 1.0436 \)                        | 0.69                                |
| Meganitis        | Leontio                   | \( \text{API} = 0.05 \cdot P_{i-1} + 0.95 \cdot P_{i-2} \) | \( \text{R} = 0.0051 \cdot \text{API} + 0.3564 \)                        | 0.79                                |
| Finikas          | Aigio                     | \( \text{API} = 0.70 \cdot P_{i-1} + 0.30 \cdot P_{i-2} \) | \( \text{R} = 0.0125 \cdot \text{API} + 0.5729 \)                        | 0.76                                |
| Ladopotamos      | Kalavrita                 | \( \text{API} = 0.45 \cdot P_{i-1} + 0.55 \cdot P_{i-2} \) | \( \text{R} = 0.0027 \cdot \text{API} + 0.0945 \)                        | 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 \( P_i \) is expressed mathematically by the equation:

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

\[
\text{API} = 0.40 \cdot P_{i-1} + 0.60 \cdot P_{i-2}
\]

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 (Km²) | River basin stream length (Km) | Mean altitude (m) | Peak altitude (m) | Mean gradient (%) | Bifurcation ratio | Drainage density | Bifurcation frequency | Aquifer 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
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 (Km²)                                      | -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.

9. References

Butler, S.S., 1957. Engineering Hydrology, Prent. Hall Inc. 227-229 pp.
Chow Ven Te: Runoff, pp.14.5-14.8. In Chow Ven Te (ed) 1964. Handbook of Applied Hydrology. Mc Graw Hill Book Comp.

Doutsos, T., Kontopoulos, N., and Poulimenos, G., 1988. The Corinth Patras rift as the initial stage of continental fragmentation behind an active island arc (Greece), Basin Research, 1, 177-190.

Dufaure, J. J., Bousquet, B., and Pechoux, P. Y., 1979. Contributions de la geomorphologie a la connaissance du Quaternaire continental grec, en relation avec les etudes de neotectonique, Rev. Geogr. Phys. Geol. Dyn., 7, 235-252.

Flotte, N., and Sorel, D., 2001. Structural cross sections through the Corinth – Patras detachment fault – system in Northern Peloponnesus (Aegean Arc, Greece), Bull. Geol. Soc. Greece, XXXIV/1, 235-241.

Kohler, M.A., and Linsley, R., 1951. Predicting the runoff from storm rainfall, U.S. Weather Bur. Res. Paper, 34.

Mistardis, G., 1937. Recherches géomorphologiques dans la partie supérieure des Monts Aroania (Chelmos), Proc. Athens Acad., 12, 94-103.

Negris, P., 1910. Les terrasses du Nord du Peloponnesse et la régression Quaternaire, P.D. Sakellarios, Athens.

Nikas, K., 2001a. Research – Making useful Achaia Prefecture water resources, Study in compliance to I.G.M.E -2nd E.E. Framework project. 199pp, 63 thematic maps in A3. I.G.M.E. Library. (in Greek –English abstract and summary)

Nikas, K., 2001b. Hydrogeology of the tectonically active zone of North Achaia. Corinth Rift Laboratory Workshop, Aighion (Greece), Abstracts, Institut Physique du Globe Paris.

Nikas, K., 2004. Hydrogeological conditions of the NE part of Achaia Prefecture, Doctorate thesis. Patras University, Geology department, 331pp. (in Greek –English abstract and summary)

Nikas, K., Aggelikakis, J., Vergou, A., and Vassiliadis E., 2001. Hydrogeological and Geochemical survey in Achaia Prefecture, Bull. Geol. Soc. Greece, XXXIV/5, 1875-1884. (in Greek –English abstract)

Nikas, K., and Andonakos, A., 2005. Influence of the active tectonics on the shaping of hydrogeological-hydraulic conditions and on the setting boundaries between the relevant units. The NE Achaia prefecture area example, In Proc. 7th Hydrog. Conf., Athens. 383–392pp. (in Greek –English abstract)

Philippson, A., 1892. La tectonique de I Egeide Ann de Geogr, 7,112-141, Paris.

Poulimenos, G., 1991. Tectonic analysis and sedimentation in the western Corinth graben, Doctorate thesis, Patras University. Geology Department. 296pp. (in Greek –English abstract and summary).

Poulimenos, G., 1993. Tectonics and sedimentation in the western Corinth graben, NJb.geol.Paleont.Mh., 10, 607-630.

Poulimenos, G., Albers, G., and Doutsos, T., 1989. Neotectonic evolution of the central section of the Corinth graben, Zeitschrift. dt. geol. Ges., 140: 173-182; Hannover.

Psarianos, P., 1943: The Pliocene sediments of Achaia Prefecture, Ann. Geol. des Pays Hell. Volume III, 193-214. (in Greek)
Skagias, S., 1978. Inventory of Karstic Springs of Greece (Peloponnesus), 1G.M.E. Publication Series "Hydrological and Hydrogeological investigation" Publ. N°28. (in Greek –English summary)

Stournaras, G., Tsimpidis, G., Tsoumanis, P., Yannatos, G., and Guillaume, R., 1998. Instability Phenomena in the Neogene Deposits of Northern Peloponnesus, Greece, Bull. Eng. Geol. Env., 57, 65-68.

Voudouris, K., 1995. Hydrogeological conditions of the NW part of Achaia Prefecture, Doctorate Thesis. Patras University, Geology department, 237pp. (in Greek –English summary)

Yannatos, G., 1999. Hydrodynamic analysis of Carbonate formation with prevailing discontinues interstices aquifers. The Upper Vouraikos river basin, Doctorate Thesis. Athens University. (in Greek)

Zelilidis, A., and Kontopoulos, N., 1996. Significance of fan deltas without toe-sets within rift and piggy-back basins: examples from the Corinth graben and the Mesohellenic trough, Central Greece, Sedimentology, 43, 253-262.