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Evaluation of Exploitable Groundwater Reserves in Karst Terrain: A Case Study from Crete, Greece

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Abstract: Karst systems constitute valuable freshwater resources in Crete island, a region of Greece that is threatened by water scarcity. The present work refers to evaluation of the available groundwater potential in a karst terrain and contributes to providing adequate quantities of fresh water to the central southern Crete (Rethimno prefecture). The available groundwater potential was estimated by combining conventional hydrogeological approaches and an analysis of hydrographs of Kourtaliotis spring that drains the system. The research procedure contributed to the three-dimensional understanding of the karst system and provided reasonable estimates regarding the groundwater reserves in the area. The geological (permanent) storage in the karstified system was estimated to 415×10^6 m^3 while the dynamic reserves were calculated equal to 43×10^6 m^3. Based on the research results, it is considered possible to pump annually an amount of 21–29 $\times 10^6$ m^3 over the quantities of water which naturally outflow from Kourtaliotis spring, in order to satisfy the water demands in the region. The study provides a valuable guidance on predicting the groundwater reserves in aquifers with similar hydrogeological regime.

Keywords: groundwater; karstic aquifer; dynamic reserves; permanent storage; Maillet equation

1. Introduction

Carbonate rocks, permeable by fracturation and karstification compose the main aquifers in Crete island (Greece). A systematic study and a thorough understanding of the hydrological regime of such aquifers is essential for providing successful management practices of groundwater resources. However, the estimation of the groundwater balance in a karst terrain is a difficult task. The topographic and subsurface catchments coincide only in exceptional cases, and only in those places where the boundaries between catchments are located in impermeable rocks [1]. In dependence of the hydraulic conditions, the groundwater exchange with adjacent hydrogeological basins and the estimation of the reserves available for exploitation becomes complicated.

Taking into account that the internal structure of a karst aquifer may only be partially known, the main hydraulic aspects are usually deduced from spring and well hydrograph analyses [2]. Systematic records of spring discharges allow for a definition of the spring regime. Moreover, the shape of the hydrograph provides a useful tool to evaluate the aquifer karst condition [3,4].

The present work aims at evaluating the groundwater reserves in a karst aquifer in the central southern Crete (Greece), where the pressure on groundwater resources has increased significantly in recent decades due to irrigated agriculture, the increase in population and the tourism development.

The work concerns a research applied on the unexplored karst system which feeds the spring of Kourtaliotis. It combines conventional hydrogeological approaches and analysis of the spring hydrographs. Emphasis was placed on the identification of aquifer's hydrogeological boundaries and the analysis of spring hydrographs.

Typically, the investigation of a karst system requires a multidisciplinary approach including water-tracer tests which will give information concerning the conduit network. However, no such specific exploration technique has been conducted in the area. Besides, tracer studies can be costly, time-consuming, and sometimes confusing [5]. Therefore, the current research is limited to the evaluation and analysis of existing data.

In order to minimize the possible effects of uncertainties involved, a combined utilization of techniques was followed. More specifically, the available groundwater potential in the area was evaluated by combining conventional hydrogeological methods such as delineation of aquifer geometry, evaluation of water contributions from various sources, determination of piezometric head and an analysis of hydrographs of the spring that drains the system, using Maillet's formula [6]. The results are compared and the applicability of Maillet equation is discussed.

Despite the limitations that stem from the lack of sufficient information concerning the conduit network, the combination of conventional hydrogeological approaches with the analyses of the spring hydrographs resulted in reliable estimation of groundwater reserves.

The study provides a valuable guidance on predicting the groundwater reserves in aquifers with similar hydrogeological regime.

2. Geology

The exposed geology in the study area is displayed in Figure 1. The map was created using data derived from published geological maps of Institute for Geology and Subsurface Research [7,8] and the geological survey realized during the current research.

The oldest formation that outcrops in the region is represented by the Plattenkalk series (parautochthonous unit of Crete island). It outcrops in the west part of the region and consists of several thousand meters of crystalline limestone and dolomite, interbedded with chert. The Plattenkalk series is overlapped by the Trypali carbonate unit, that is in turn tectonically overlain in a structurally ascending order by the Phyllites-Quartzites series, the Tripolis and Pindos units, and the uppermost ophiolitic nappe.

The Phyllites–Quartzites series is Upper Palaeozoic–Triassic in age [9] and includes siliciclastics, carbonates and basic volcanics, which have undergone a polyphase deformation and low-grade regional metamorphism [10].

The carbonate rocks of the Tripolis unit crop out in approximately one third of the study area, and include shallow marine, pure limestones interlayered with dolomites, ranging in age from Upper Triassic to Upper Eocene [11,12]. The limestone formations are dominated by thick bedded to massive intervals. Rarely, thin-bedded limestone units and individual limestone beds are present. The intercalating dolomites appear to be of primary or secondary origin, and they often occur in an unregulated manner.

The overlying Pindos zone consists of a series of imbricate thrust slices that contain Mesozoic 'deep-water' sediments; these formations overthrust the carbonate formations of the Tripolis unit in the southern part of the area.

The Late Jurassic to Early Cretaceous ophiolitic nappe occupies the uppermost structural position. It is composed of mafic and ultramafic rocks like diorites, gabbros, pyroxenites and peridotites which are often serpentinized [13]. Neogene and alluvial formations are exposed in an area of limited extent.

All the aforementioned units are affected by folds and overthrusting structures. The large scale structures were checked in the field and nine geological cross sections were constructed. Four of them are presented in Figure 1, providing a detailed perspective of the geological structure in the area.

Field survey has shown that surface geomorphologic features have been carved into the rock surfaces through flowing water. They include moderately developed karren dissolution grooves and channels; major karst features are poorly developed at the surface. The widespread joint systems and the localized fissures induced by tectonics of the area, have a pronounced effect on the solution patterns and the movement of water in the carbonate formations exposed in the area.

Orogenic movements and eustatic effects related to the alpine orogenesis (Miocene to Oligocene age) combined with climate variations in the region, have developed an intensive karstification of the carbonate formations at great depth. The development of karst was controlled by drainage and base level in different stages of neotectonic evolution of the region, as indicated by the occurrence of spring outlets at different elevations.

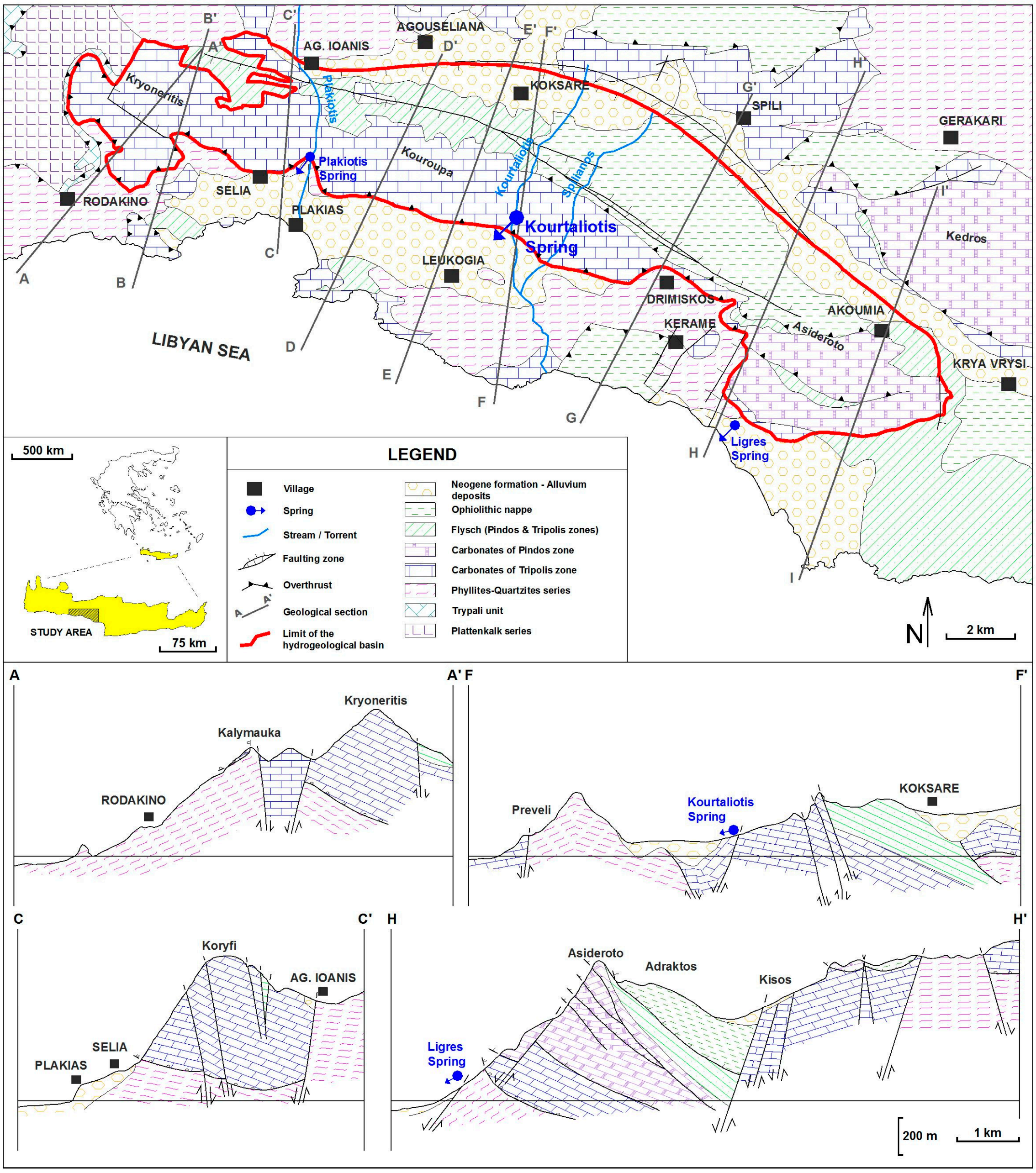


Figure 1. Geological map and structural cross-sections of the region. The black square on the inset map indicates the study area. The Kourtaliotis spring catchment is delineated in the figure by the red line.

Similar viewpoint to karst processes with depth in the Mediterranean region have been stated by a number of researchers. As reported by Bakalowicz et al. (2008) [14], since the Miocene age all carbonate formations along the Mediterranean coast were subject to a remarkable instability of their base levels, driven by sea level and the related main river valleys. The Mediterranean sea lowered down to 1500 m at the end of Miocene, 5.5 million years ago [15,16], but locally the karstic process depends on the geological structure and tectonic activity of the area. As reported by Mijatović (2007) [17], the general erosion base of groundwater discharge in the wider Mediterranean region was estimated between 100 and 150 m below actual sea level. Also, systematic hydrogeological studies in Greece, undertaken by Papakis (1966) [18], Monopolis and Mastoris (1969) [19], Mastoris et al. (1971) [20] have also verified the existence of "open" karst voids to a depth of 70 to 100 m below sea level, due to karstification processes originated since Plio-Quaternary age.

The effects of the Messinian sea level lowering in study area have not fully assessed. However, it is estimated that the deepening of karst at that time had much more important consequences on karst development than the later uplift of the area, started as early as Middle Pliocene [21–23]. In any case, the impermeable layer of Phyllites-Quartzites formation is considered a barrier to vertical movement of groundwater and karstification process.

Based on the aforementioned references and taking into account the paleogeography and geological evolution of Crete island [23], the author considers that the base level of karstification in the region was more than 100 m b.s.l.

As a sequence of the tectonic activity and karstification process throughout the entire region, a karst fracture type of aquifer has been created in the carbonate formations of the area. Previous studies [24] provided the required data for the delimitation of the aquifer's catchment, that is well developed in limestone and dolomites with well-defined permeability boundaries (Figure 1).

More specifically, on its south-southwest the aquifer is delimited by a tectonic contact between the calcareous units and the Phyllites–Quartzites series which acts as a barrier to the coastal area (Figure 1). Moreover, in the north the permeability boundary is marked by a syncline structure, filled with flysch, flyschoide and other formations of similar composition.

This carbonate rock unit which outcrops in a direction WNW–ESE, along the mountains range of Kryoneritis, Kouroupa and Asideroto, comprises a hydrogeological basin that feeds Kourtaliotis and other minor springs (Plakiotis, Ligres; Figure 1). The extent of the spring catchment area was estimated using 1:50,000 scale topographic maps and the result reveals that it covers approximately 105 km^2 with generally high relief topography. The relief ranges from 100 to 1400 m, with an average elevation of 600 m.

3. Hydrogeological Setting

The Kourtaliotis spring catchment area is situated in the central to southern part of Crete (Figure 1). The climate is of the Mediterranean type with mean annual precipitation of about 1310 mm.

Steiakakis et al. (2011) [25] studied monthly rainfall data collected from six rain gauges stations installed in the area, which are found under comparable climatic conditions. A 20-year time series (1967–1987) of precipitation data was initially checked for continuity and consistency by the double-mass curve technique. After the completion of missing values, the average annual precipitation at each station was calculated and plotted against the altitude of the corresponding station. A regression line fitted to the data indicates that the relationship between the rainfall and the altitude is given by the following equation:

$$P = 1.14 \cdot h + 582.6, \quad (1)$$

where P is the precipitation in mm and h the altitude in m.

Based on this equation, isohyets were drawn and the volume of annual precipitation in the area was calculated in 71.32×10^6 m^3/y. This precipitation falling and the infiltration of water from creeks and torrents that cross the carbonate outcrops recharge the karst system.

Due to the lack of meteorological data for estimation of evapotranspiration in the region, the coefficient of effective infiltration and consequently the amount of the annual recharge of the karst system was determined by hydrologic balance calculations [25].

The annual yield of the springs was estimated around 44.7×10^6 m^3, the secondary recharge was evaluated equal to 8.1×10^6 m^3/y, and the "estimated" direct infiltration (i.e. the difference between springs yield and secondary recharge) amounts in 36.6 × 10^6 m^3/y. Taking into account that the aquifer is constrained by well-defined permeability boundaries, the quantity of direct infiltration was compared to average annual rainfall in the hydrogeological basin (71.32 × 10^6 m^3/y), and the infiltration coefficient for the carbonate rocks of the basin was estimated equal to 51.3%.

Based on the estimated coefficient, the infiltration in the basin was calculated by multiplying the volume of annual precipitation and the coefficient of effective infiltration. The result gave an infiltration volume of 44.7 × 10^6 m^3/y.

Groundwater with a potentiometric gradient of about 23.5‰–3.5‰ (during summer and winter respectively) feeds the springs which drain at the southern edge of the carbonate outcrop (Figure 1), with a total flow rate of about 1.4 m^3/s. The measurements taken by Land Reclamation Service (YEB) and Institute for Geology and Subsurface Research (IGME), were available by Decentralized Administration of Crete (2013) [26].

A cluster of four springs, namely Kourtaliotis spring comprise the main discharge outlet of the aquifer. It is situated at an altitude of 100 m a.s.l.; it has an average yield of about 38.8x10^6 m^3/y, corresponding to about 1.2 m^3/s.

Based on the hydrogeological regional mapping and considering the hydrological control function of Kourtaliotis spring, it may be classified as dammed spring [6]. It results from the location of a major fault barrier in the path of underground drainage (Figure 1); overflow takes place among the fault line, in response to high water table.

Hydrogeological investigations in the area recognized two more water outlets with lesser discharge rate, namely Plakiotis and Ligres springs (Figure 1). The estimated average annual discharge is 3.5 × 10^6 m^3 for the Plakiotis spring and 2.4 × 10^6 m^3 for the Ligres spring [26]. The latter spring is a permanent spring, and it is located 9 km south east of Kourtaliotis outflow, at elevation 50 m a.s.l.

Combined interpretation of geological structure, spring outflow rate and intensive onsite research indicate that Ligres and Plakiotis springs are in hydraulic communication with Kourtaliotis spring, draining the same karstic system. However, dye tracing tests are the best way for knowing about the hydraulic connection between springs. Such specific exploration method should be applied in future research program. Meanwhile, it should be noted that Ligres and Plakiotis outlets are disregarded in the following discussion due to their low discharges comparing to the Kourtaliotis spring.

The mean annual discharge of Kourtaliotis spring is 38.8 × 10^6 m^3/y, representing 85 percent of total outflow volume from all the springs which drain the groundwater basin. The flow rate of the spring is substantial and steady over time but it still remains largely untapped, due to the sparse population of the surrounding area.

Records of Kourtaliotis spring discharge are referred to the period 1981–2000, with a small gap from July 1995 to August 1996 (Figure 2). It is shown that the outflow varies from 725 to 1809 L/s; the minimum rate is measured in September or October, and the maximum in April or May.

The spring discharge variability, given by the ratio of the maximum and minimum discharges [27,28] is estimated equal to 2.5. This value indicates a poorly variable discharge of the spring.

Kourtaliotis spring was sampled and chemical analyses of water were conducted by different government agencies and institutes (Land Reclamation Service (YEB); Institute for Geology and Subsurface Research (IGME) and Technical University Crete (TUC)), between 1975 and 1999. The results, available by Decentralized Administration of Crete (2013) [26], indicate that the water is cold (~18 °C), fresh (average value of total dissolved solids equal to 257 mg/L), moderately alkaline with pH approximately 7.9, and slightly hard (220 mg/L hardness as $CaCO_3$). Ca^{2+} is the predominant ion in all samples with a concentration of 59 mg/L. Moreover, the water contains 76 mg/L SO_4^{2-} and 174 mg/L HCO_3^-. Small concentrations of Cl^- (approximately 32 mg/L) and Na^+ (approximately 13 mg/L) are also present.

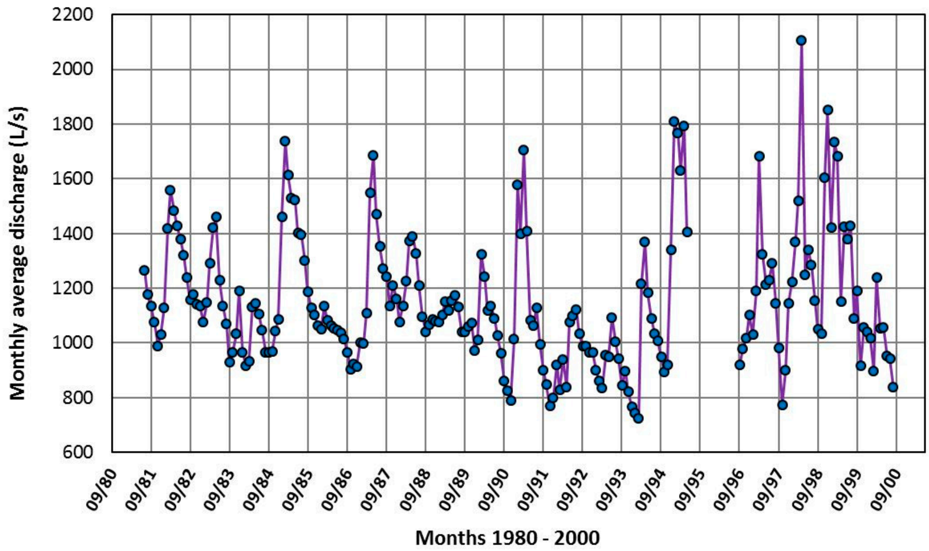


Figure 2. Records of spring discharge between 1981 and 2000.

The classification of groundwater samples is illustrated in Figure 3 by a trilinear plot (Piper diagram). It indicates that the groundwater is of the calcium bicarbonate (Ca^{2+}–HCO_3^-) type, and meets drinking-water standards [29]. The increased concentration of Na^+ is attributed to water circulation through flysch and flyschoides formations exposed in the study area.

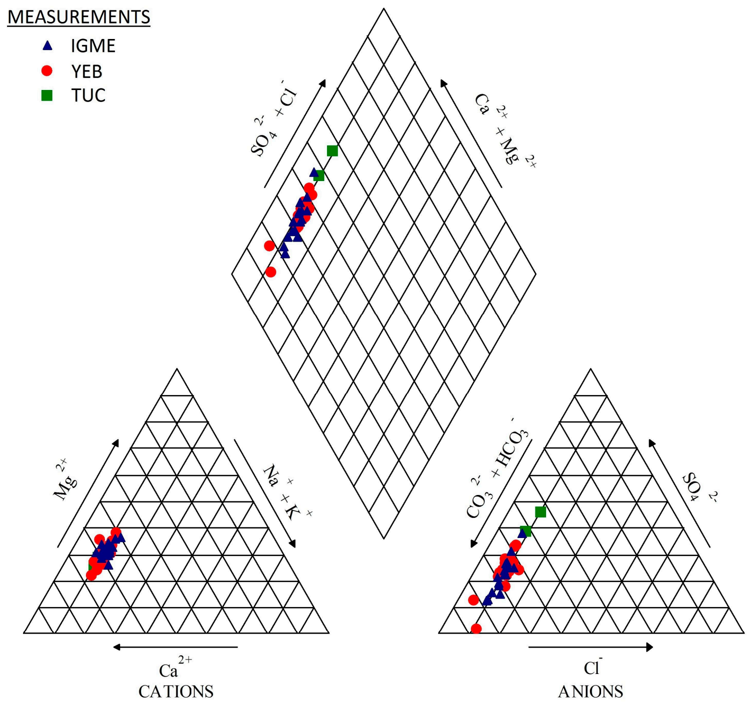


Figure 3. Trilinear diagram for representing analyses of groundwater quality.

4. Groundwater Reserves

The volume of groundwater reserves in the study area was estimated based on the geological structure of the karst hydrogeological system and an assumption on the porosity value. In order to verify these estimations, the results were compared with the corresponding values derived by analyzing the hydrographs of Kourtaliotis spring.

4.1. Assessment of Permanent and Dynamic Reserves Based on the Hydrogeological Framework of the Groundwater System

Initially, the aquifer's geometry was defined by geologic data collected from outcrops, borehole logs and cross sections drawn transversely to the longitudinal axis of the catchment area (Figure 1). A surface which graphically represents the base of aquifer was drawn, with base the tectonic boundary between the carbonate formations and the underlying Phyllites–Quartzites series (Figure 4).

More specifically, after evaluating the geological information using a semi-variogram analysis, the elevation estimates of the aquifer's base were developed. Taking into account that the objective of the analysis is to provide the best linear unbiased estimate of a regionalized variable at unsampled locations with constant but unknown mean, and that variograms analysis indicates data free of nonrandom trends, the ordinary kriging was used as the appropriate estimation method [30].

Elevation contours were developed using a 100 by 100 m grid, and the contouring subroutine of Surfer v.8.04 [31]. Given the accuracy of the elevation data, a 100 m contour interval was selected for the aquifer's base definition.

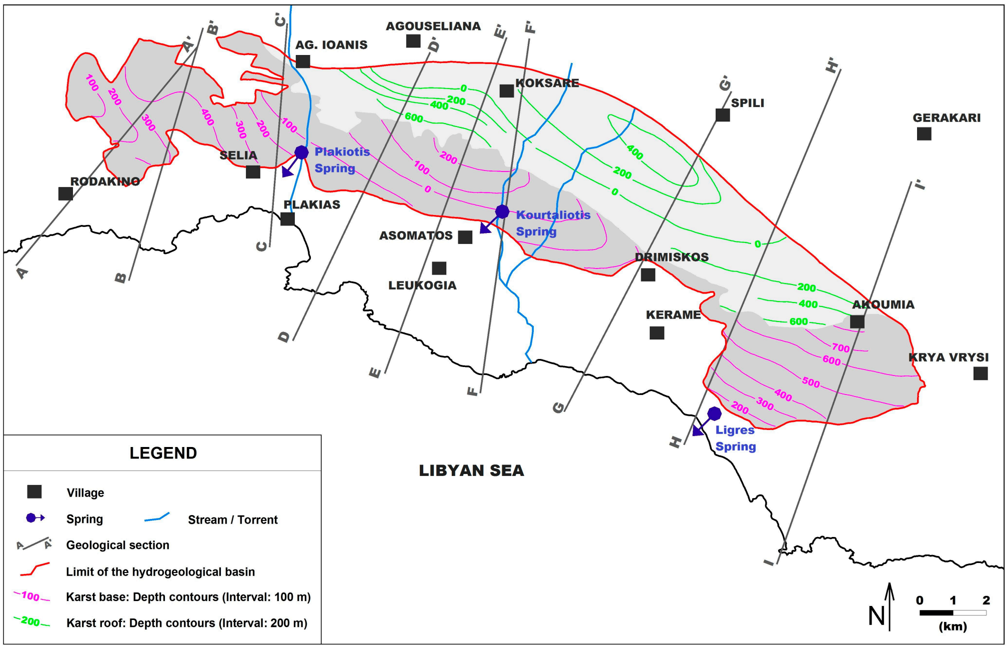


Figure 4. Structure contours drawn to represent the base and the top of the hydrogeological unit.

Data reflecting the top of the hydrogeological unit was also analyzed. The uppermost surface of the carbonate rocks was defined by surface morphology of the groundwater basin. Only in the northeastern part of the study area, the top of the hydrogeological unit is delimited by its borders with the adjacent impermeable formations of flysch and flyschoides.

Contours were generated by inputting the coordinates and the elevation of each of the data points into Surfer software. Ordinary kriging on the data followed by contouring was carried out using a 200 m contour interval (Figure 5). Different contour interval for the base and the top of the hydrogeological unit was used, so that the figure to be legible.

Following, the water table was defined in summer and winter periods, based on spring outflow (altitude 100 m a.s.l.) and hydraulic gradients of 2 (summer) and 3.5‰ (winter period), respectively. These inclinations were deduced by interpolating data from well drillings (in Koxare, Myxorouma and Akoumia locations) and groundwater outlets (Figure 4). It should be noted that the scarcity of boreholes in the region constrains the construction of a detailed water table map.

All the aforementioned surfaces are laterally bounded by the catchment boundaries, as they are specified by lithology and tectonics of the area. It is clear that in the western part of the basin (Figure 1, geological section AA′), the impervious base of the aquifer remains above the ground water table, preventing lateral extension of the saturated zone. In this zone, the hydrogeological basin seems to drain towards east.

The total thickness of the karst carbonate formations was determined by subtracting the grid node values of the impermeable base from the values of the grid referring to the top of the hydrogeologic unit. An isopach map was drawn to show the distribution and the thickness of the carbonate formations in the catchment area (Figure 5). Results show that the average thickness of the karst formations in the most part of the region, ranges between 150 and 250 m. It increases in the central and in the southeast part of the basin (Asiderotos mountain range) approaching locally a thickness of 350 m.

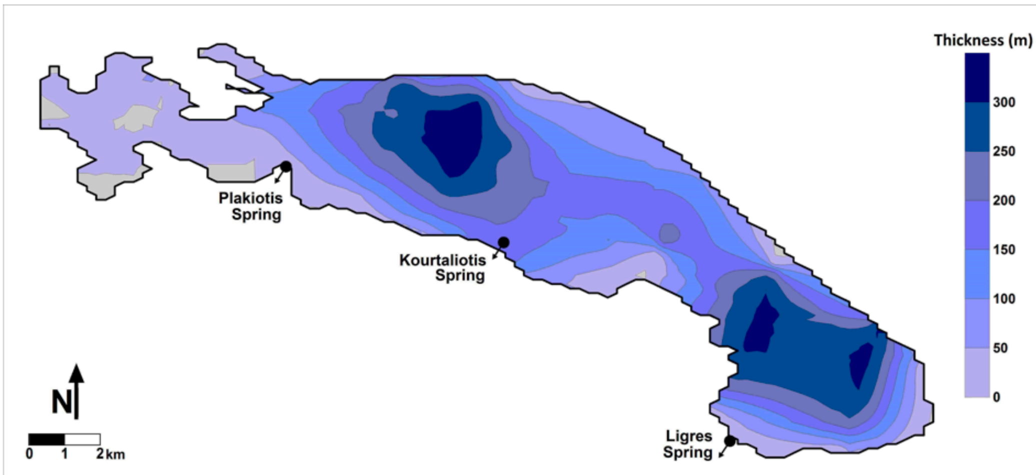


Figure 5. Thickness of the carbonate formations in the hydrogeological basin. The contours represent the combined thicknesses of Tripolis and Pindos carbonate formations.

After gridding, calculation of aquifer's volume was carried out employing the trapezoidal, Simpson's and Simpson's 3/8 rules, based on numerical approximation of the parallel sections method [32].

The geological (permanent) groundwater reserves were calculated by multiplying the volume of the saturated aquifer up to the lower water table (summer period) and the average effective porosity. Based on the literature [33–36], carbonate formations such as those exposed in the study area, display effective porosity values ranging from 0.5% to 7%, depending on the degree of karstification and local tectonic conditions. Considering that the effective porosity of the carbonate formations is equal to 3% (viz the mean value of the aforementioned range), the permanent groundwater reserves are approximately 415×10^6 m^3. Furthermore, the volume of water in the saturated zone above the elevation of the spring's outflow (dynamic reserves) was estimated at 43.4×10^6 m^3.

The buffering capacity of the aquifer, calculated as the ratio between the dynamic reserves and the permanent groundwater storage [37] amounts to 0.1. In addition, the groundwater renewal rate, defined as the ratio between the permanent groundwater reserves and recharge volume, is estimated equal to 9.56. Hence, the average hydrological replenishment time will be on the order of 10 years, which means that the water reserve is completely renewed roughly every ten years.

4.2. Evaluation of Aquifer Dynamic Reserves by Analyzing Recession Hydrographs

Quantitative analysis of the hydrograph recession curves of Kourtaliotis spring was conducted through Maillet's equation [6].

According to Maillet formula, the recession of a spring (hydrograph of base flow) as a function of time may be approximated by Equation (2):

$$Q_t = Q_0 \cdot e^{-\alpha t} \quad (2)$$

where Q_t in m^3/s is the discharge at time t; Q_0 in m^3/s, the discharge from storage at the beginning of the recession; t is the time elapsed between Q_0 and Q_t; and α is termed the recession (discharge) coefficient; this value is a function of aquifer transmissivity, storage coefficient and catchment geometry.

The formula implies that the discharge of a spring is a function of the volume of water held in storage [38]. If the spring discharge is plotted as a function of time, the dynamic reserves (V_S) at any time t is equal to the area under the curve bounded between the time t and the time when discharge reaches zero [39]. By integrating Equation (2) and allowing for units, the dynamic reserves may be estimated by Equation (3) [40]:

$$V_S = Q_0 \cdot c/\alpha \quad (3)$$

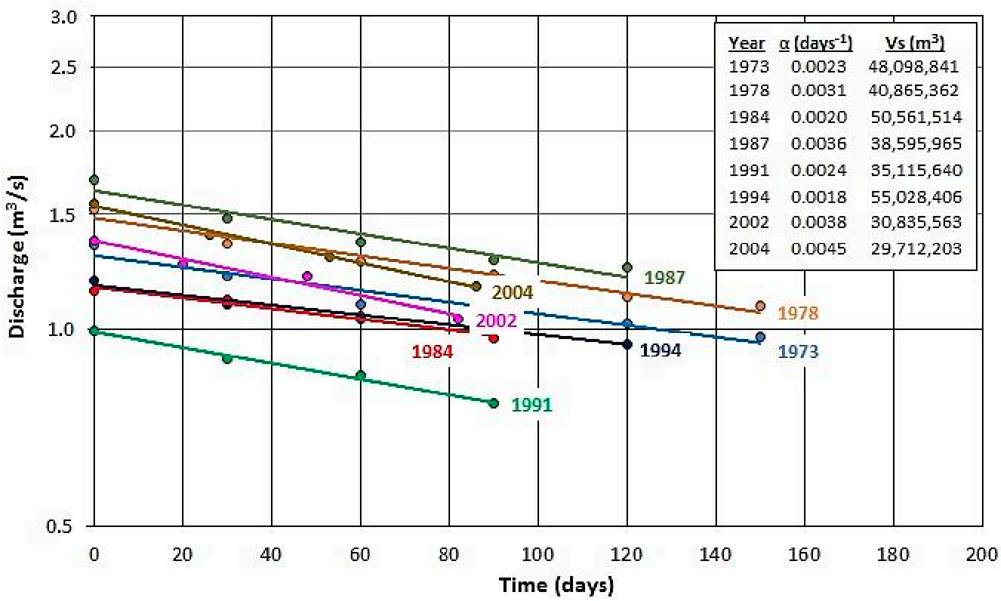
where c is the unit conversion factor (days to seconds), equal to 86,400 when Q_0 is the flow rate at the beginning of recession in m^3/s and α in $days^{-1}$.

The recession coefficient (α) can be estimated by the end part of the spring hydrograph (recession curve). This part of the curve it becomes a straight line on semi-logarithmic paper with slope log (α) [41]. More specifically, the recession coefficient can be defined as:

$$\alpha = (\log Q_0 - \log Q_t)/0.4343 \cdot t \quad (4)$$

As reported by Dewandel et al. (2003) [42], Maillet's exponential formula provides satisfying results only when the depth of the substratum is equal to, or more than about 160 m under the spring outlet. Based on the tectonic activity and karstification process throughout the entire region, this requirement is met in the study area and the Maillet's equation was applied.

The hydrograph data of the Kourtaliotis spring was analyzed for the years between 1973 and 2006, by the best fit of the observed curves with the Maillet's equation. In detail, the hydrograph data of the spring were plotted on semi-logarithmic graphs and the recession coefficients (α) were estimated by Equation (4). Results referring to representative years are presented in Figure 6.



Year	α (days⁻¹)	Vs (m³)
1973	0.0023	48,098,841
1978	0.0031	40,865,362
1984	0.0020	50,561,514
1987	0.0036	38,595,965
1991	0.0024	35,115,640
1994	0.0018	55,028,406
2002	0.0038	30,835,563
2004	0.0045	29,712,203

Figure 6. Discharge hydrographs of Kourtaliotis spring; values of its discharge coefficients (α); and dynamic reserves (V_S).

According to the results and the analysis presented above, the mean value of recession coefficient derived from the different years studied, equals to 0.002 $days^{-1}$. The order of magnitude of the discharge coefficient is 10^{-3} $days^{-1}$, indicating that the flow of groundwater is primarily through joints and fissures [43].

Also, the recession curves show little change of drainage in relation to time, indicating that the aquifer has a large storage capacity. Any deviation from the straight line found, is getting greater with the increase of flow rate, as the linearity is not applied at the beginning of the depletion curve [27].

The value of dynamic reserves (V_S), as a function of Q_0 and α, varies from year to year as it is affected by groundwater renewal. The slightly higher discharge rate during specific hydrologic years, can be attributed to the lower rate of water table degradation, that depends on the hydrodynamic volume at the beginning of low stage recession.

The estimated mean annual dynamic reserves of the aquifer (Figure 7) is calculated at about 43×10^6 m^3, equivalent to the mean annual spring discharge.

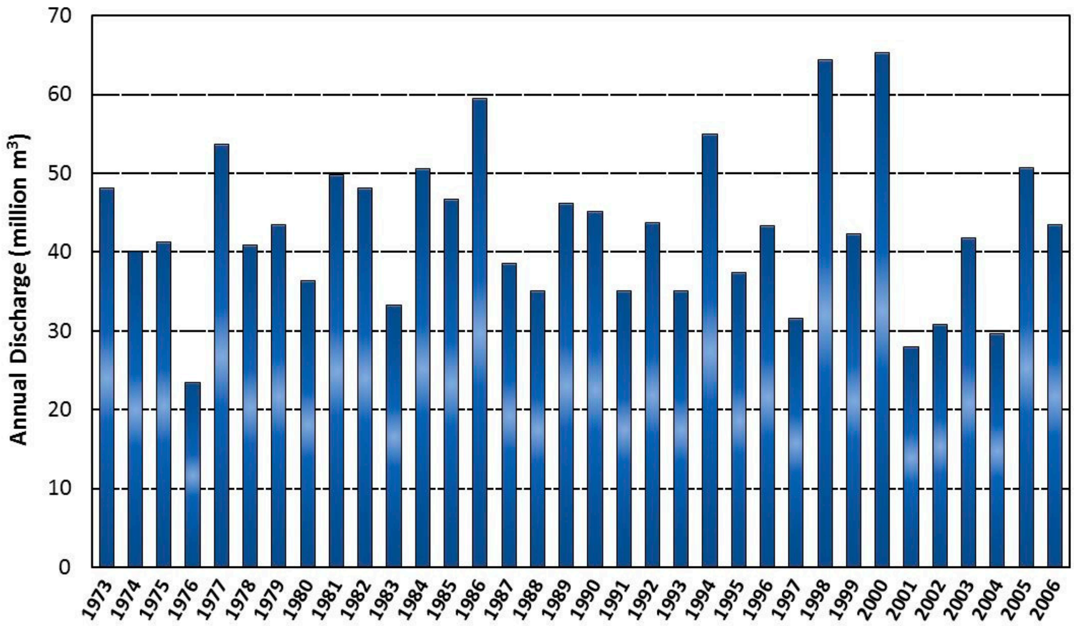


Figure 7. Annual dynamic reserves of Kourtaliotis spring.

This amount is generally in agreement with the value derived from the analysis of the hydrogeological framework of the groundwater system. The good match can be attributed to the reliable considerations regarding the geological structure of the catchment area and the reliability of active porosity value. The latter value is also confirmed by the analysis of the base flow recessions of the spring. As reported by Pérez and Sanz (2011) [37] the effective porosity of an aquifer may be estimated considering the value of the recession coefficient (α) and Equation (5).

$$\alpha = 2 \cdot T / S \cdot L^2 \quad (5)$$

where T is transmissivity; S is the coefficient of storage (=effective porosity for karst unconfined aquifers); L is the “average length” of the aquifer, from the center of gravity to the discharge point.

For the study aquifer, the transmissivity value (T) is equal to 5×10^{-3} m^2/s (=432 m^2/day) [44,45] and the “average length” (L) of the aquifer is evaluated to be about 3500 m (Figure 5). Hence, the effective porosity is estimated approximately equal to 0.035 (=3.5%) which is in satisfactory agreement with value of 3%, assumed for storage assessment in the first stage of analysis.

5. Discussion and Conclusions

The applied procedure provides a comprehensive knowledge of hydrogeological features of the aquifer and valuable information regarding its capacity to release groundwater (dynamic storage). The estimation of the dynamic reserves derived by analyzing the recession hydrographs of the spring is generally in agreement to the results obtained by considering the aquifer's hydrogeological framework. This certifies the claim of Dewandel et al. (2003) [42] that Maillet's formula can be used to define characteristics of karst aquifers when the depth of the substratum under the outlet is more than 160 m.

The permanent reserves of the aquifer were estimated to 415×10^6 m^3 while the recoverable quantity of the groundwater storage (dynamic reserves) was calculated to 43×10^6 m^3. Furthermore, the average hydrological replenishment time in the karst system will be on the order of 10 years.

It should be noted that more complete data concerning the elevation of groundwater table, the hydrographs of the spring and the knowledge of the functioning of the karst system are essential for more accurate estimations. The acquisition of these data typically requires more specialized investigation methods such as water-tracing tests, and discharge monitoring at higher temporal resolutions [4,6].

Also, geophysical methods may be used in locations of the karst system where boreholes are not available, or for interpolation between existing boreholes, in order to obtain indirect information concerning the internal geometry, the external boundaries of the aquifer and its hydraulic properties [46].

Despite the fact that the discharge rate of Kourtaliotis spring is not highly variable, (reflecting the large capacity of aquifer), the spring is capable of undertaking regulation. The aim of this control measure of the spring outflow, is to secure additional quantities of water during periods of increased demand, while counting on sufficient aquifer replenishment during wet seasons [41,47].

Based on the amount of dynamic and geological reserves in the study area, it is apparent that during the irrigation period (May–September) it is possible to draw from the aquifer an additional quantity of water around 1600 L/s, in a safe manner. This amount (two times higher than the extreme minimal natural spring flow), is equal to about 21×10^6 m^3 annually. Such a volume of water can be easily replenished during the subsequent hydrologic cycles.

The first example of such exploitation was done on the Lez spring in Montpellier (France) in 1981, after a detailed study of the spring regime and pumping tests [48]. Also, similar control measures have been applied for regulating karstic aquifers in Serbia with a significant improvement of water supply [49].

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