First outcomes from groundwater recharge estimation in evaporate aquifer in Greece with the use of APLIS method

E. Zagana, P. Tserolas, G. Floros, K. Katsanou, B. Andreo[1]

Laboratory of Hydrogeology, Department of Geology, University of Patras, 26500 Rion Patras, Greece
[1]Department of Geology and Centre of Hydrogeology, Faculty of Sciences, University of Malaga, 29071 Malaga, Spain

Abstract Groundwater recharge in karstic aquifers has to be determined taking into consideration the hydrogeological particularities of these aquifers. The APLIS method has been used to estimate the mean annual recharge in carbonate aquifers in southern Spain, expressed as a percentage of precipitation based on the variables altitude, slope, lithology, infiltration landform and soil type. The method developed for Mediterranean conditions, has been applied to a karstified evaporate aquifer in West Greece. In this paper, maps of the above variables have been drawn for the study area using a geographic information system. The autogenic groundwater recharge and the spatial distribution of the mean annual values by means of the APLIS method have been obtained. Because of the absence of previous studies about groundwater recharge estimations in the study area and detailed discharge values, it was impossible to corroborate the validity of the method in this phase of the research. In the frame of a research project taken place in the study area, discharge values are measured at the springs draining the system; thus the validation of the method will be done in the next step of this study.

1 Introduction

Knowledge of groundwater recharge is very important because it permits us to identify the water inputs entering the aquifer, which is very essential for appropriate water resources management and hydrologic planning. Different methods for groundwater recharge estimation have been developed in the last 20 years. These methods (direct measurement, water balance methods, Darcian approaches, tracer techniques, hydrochemical or isotopic models) and many of the problems encountered with each have been described by Gee and Hillel (1988), Sharma (1989), Lerner et al. (1990), Allison et al. (1994), Simmers (1997), Scanlon et al. (2002) among others. Recent advances on distributed methods of groundwater recharge calculations have been done by Udluft and Kuells (2000), Udluft et al. (2003),

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Heathcote et al. (2004), Hughes et al. (2006), Brito et al. (2006) and Zagana et al (2007). Most of the above mentioned methods have been developed in porous aquifers and are then used in carbonate aquifers. However, in karst aquifers, recharge computing is more complex, due to the specific characteristics of these aquifers and the duality of the recharge. In this sense the concentrate and the diffuse type of recharge are defined; these types have been also as allogenic and autogenic differentiated.

In Europe, carbonate terrains cover 35% of the land-surface and karst groundwater makes an important contribution to the total drinking water supply (European Commision, 1995). In Greece carbonate rocks cover more than 35% of the surface (European Commision, 1995). However, studies about groundwater recharge estimations in carbonate aquifers are not known. Generally studies about groundwater recharge estimations in any type of aquifer and/or in catchment area scale are very limited in Greece (Lambrakis and Kallergis 2001, Zagana et al. 2007).

In this paper the mean rate of the annual autogenic groundwater recharge as a percentage of precipitation has been estimated in the study area with the use of the APLIS method (Andreo et al. 2008), which has been developed from the studies carried out in carbonate aquifers in Andalusia (S Spain). Recently the APLIS method has been modified in order to improve the results (Marin 2009) and has been used for recharge estimations in tropical climatic conditions (Farfan et al. 2010). However, it is necessary to note that in the frame of this paper the recharge rate values obtained by this method have not been compared with recharge calculations by other methods or their corresponding discharge rates. The validation of the method is the next step and will be done in the immediate future.

2 Characteristics of the study area

The study area is located in the West Greece (Aitoloakarnania Province) with a surface of 146.3 km^2. It is a karstified system, which presents general lack of permanent streams, existent of shallow holes, small caves and occurrence of large springs at the southern part of the area. This front of springs (Lambra -Agios Dimitrios) drains the karstic system and presents discharge rates approximately $8m^3/s$ (Nikolaou 1993). The springs cover the drinking water needs of many villages in the broad area. The relief of the area is gentle, with the maximum altitude 520 m and the lowest altitude around 10 m above sea level (Fig. 1a). In the eastern part the karstic system comes in contact with Acheloos River and Ozeros Lake (Fig. 1a). According to previous studies (Marinos and Fragopoulos 1972, Marinos 1993) river water seeps through the karstified rocks and feeds the springs.

The area is characterized by mean annual precipitation of 914 mm, estimating using the data of four rain stations located in the broad area for a time period of twenty years (1981-2001). From the geological standpoint the study area belongs to the Ionian geotectonic Zone of the External Hellenides. It is part of the karstified mountainous chain system of Akarnanika Mountains which is developed at the Western part of Greece. Triassic breccias dominate in the study area (Fig. 1b).

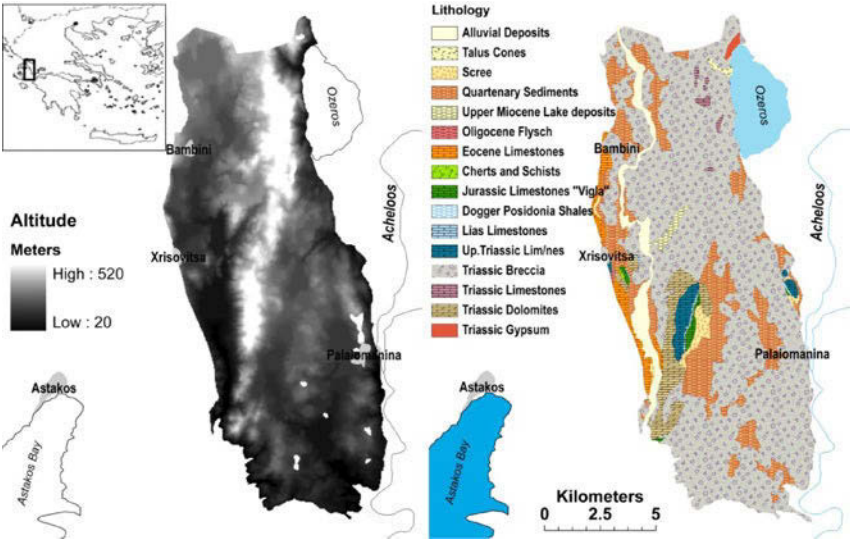

Fig. 1. a: Location and topographic map of the study area, **b:** Geological map of the study area.

They are typically un-bedded rocks including masses of dark-grey, brown or black fragments of limestones and dolomites, as well as gypsum. Similar dark colored Triassic limestones occur as individual masses in the northeastern part of the area, west of Ozeros Lake, while the Triassic dolomites outcrop in the southwestern part of the area, with a thickness approx. 200m. Several bodies of gypsum occur also west of Ozeros Lake. Bornovas (1960) mentioned that gypsum is relatively old and had been brought to the surface by diapisism phenomena, assisted by faulting. The Triassic breccias were derived from the fragmentation of the Triassic limestones and dolomites through the diapirism of the evaporate series. These structures play a significant role in the karstification of the breccias presented in the study area. Jurassic - Eocene limestones and Quaternary deposits, which consist of red clays and sandy material, with dispersed carbonate and siliceous pebbles occur also in the study area. In the western margins of the area Oligocene flysch appears in small parts. Fault tectonics has also contributed in the formation of the karstic structure of the area. A big thrust known as Makhalas thrust combined with strong normal faulting extend along the belt of the Triassic breccias. The intensively karstified breccias host significant aquifers, which are delimited by evaporite masses functioning as hydrogeological barriers. The soils above the Triassic breccias outcrops in the area are poorly developed and belong to leptosol type. The soils above carbonate rocks (Triassic - Eocene limestones) are less permeable and belong to calcareous lithosols, while above alluvial deposits the soils are fluvisols. The soil map of the area is presented in Figure 2a.

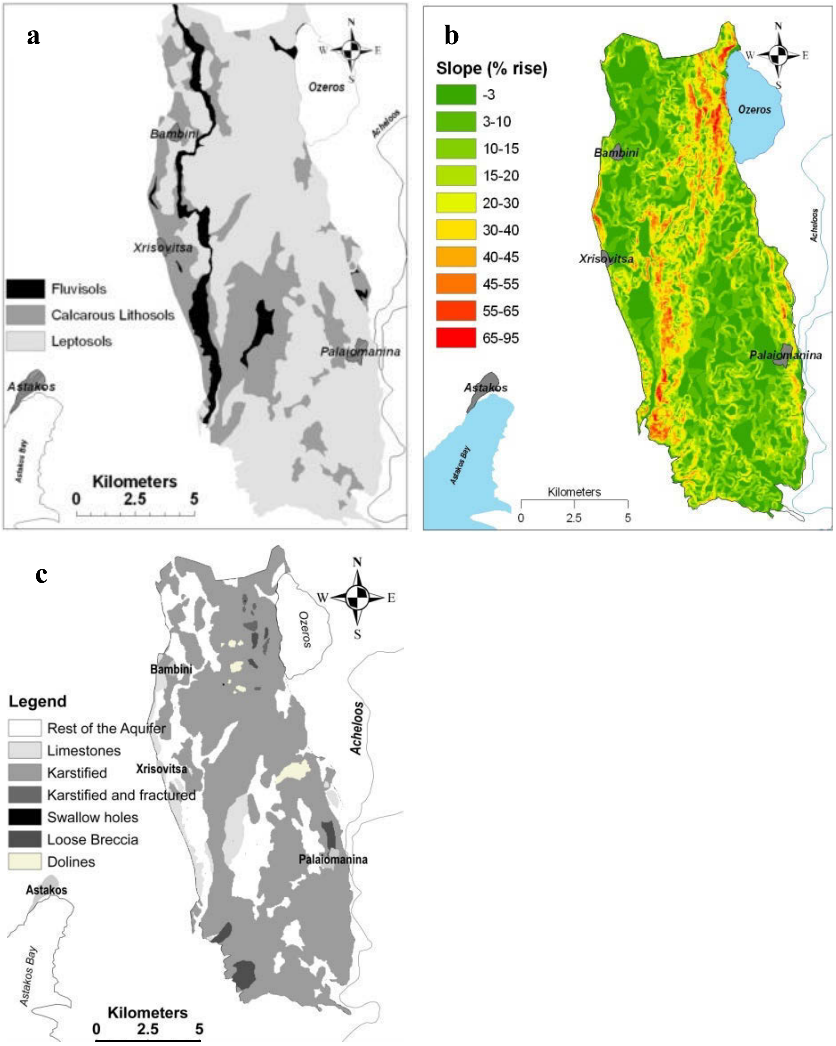

Fig. 2. a: Soil map of the study area**, b:** The map of slopes of the study area, **c:** Areas of preferential infiltration.

3 Methodology

APLIS is a parametric methodology, which enables us to estimate the mean rate of annual autogenic recharge in carbonate aquifers, expressed as a percentage of precipitation and based on the variables that influenced the recharge (Andreo et al. 2008). The method uses 5 variables, the initials of which (in Spanish) comprise its acronym and a correction factor. These variables are: Altitude (A), Slope (P), Lithology (L), Preferential Infiltration layers (I), Soils (S) and a correction factor (F_h), the last one depends on the hydrogeologic characteristics of the material outcropping on the surface. Maps for the above mentioned variables have been drawn for the study area using ArcGIS 9.3. The altitude map (Fig. 1a) and the map of slopes (Fig. 2b) have been derived from the digital elevation model (DEM) produced by digitizing the 1:50.000 contour lines map of the area. Soil maps are available only for some areas in Greece. The soil map of the study area was derived from field word (soil mapping) using also as basis a land resource map 1:50.000 of the Ministry of Agriculture. Finally the areas of preferential infiltration (Fig. 2c) were mapped over aerial photographs. For each variable, categories or intervals were established, and for each of these a rating value between 1 and 10 were assigned. A value of 1 indicates a minimal incidence of the values of this variable on aquifer recharge, while a value of 10 means maximum influence on recharge (Andreo et al. 2008). As the method has been developed for karstified limestones and dolostones, a slight modification related to the lithology has been necessary. For the karstified Triassic breccias has given the score 9 considering them as karstified limestones. In the Table 1 the values of all variables are presented.

Table 1. Rating values in APLIS for altitude, slope soil, lithology and preferential infiltration areas.

Altitude (m)	Rating (A)	Soil	Rating (S)	Infiltration areas	Rating (I)
		Fluvisols	6	Rest of the aquifer	1
0-300	1	Calcareous Lithosols	6	Non karstified limestones	1
300-600	2	Leptosols	10		
Slope (%)	**Rating (S)**	**Lithology**	**Rating (L)**	Karstified limestones, breccias	5
<3	10	Alluvial	4	Swallow holes	10
3-5	9	Quaternary	1	Dolines	10
5-10	8	Scree	3		
10-15	7	Flysch	1		
15-20	6	Non karstified Limestones	2		
20-30	5	Triassic Dolomites	7		
30-45	4	Triassic Limestones	9		
45-65	3	Triassic Breccia	9		
65-100	2	Triassic Evaporates	2		

Then the layers of information corresponding to the variables that influence recharge have been introduced into a GIS. The rate of the recharge and its spatial distribution was finally estimated. The final recharge map is computed be the expression (Andreo et al. 2008):

$$R = ((A + P + 3 * L + 2 * I + S) / 0.9) / Fh$$

where R means Recharge (expressed in percentage of precipitation); A: Altitude; P: Slope; L: Lithology; I: Infiltration areas; S: Soil and Fh factor derived from the lithology map.

4 Results

With the APLIS method the recharge rate has been calculated and the map of recharge spatial distribution has been obtained in a GIS (Fig. 3a).

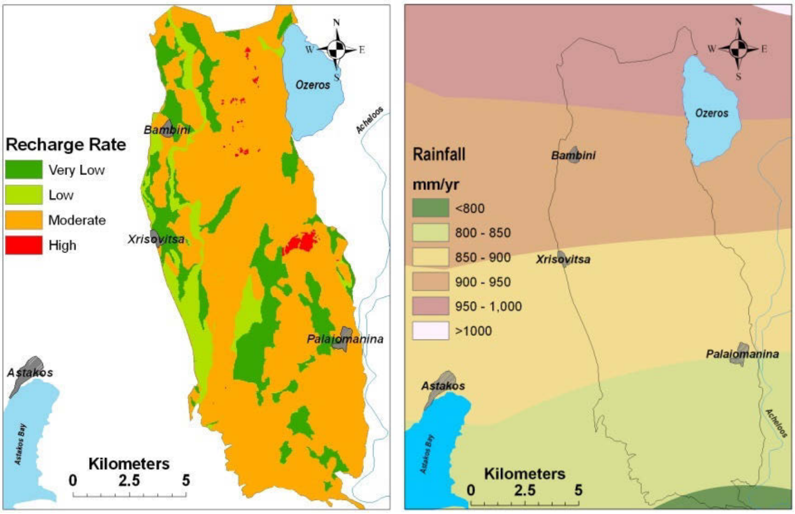

Fig. 3. a: Recharge map in the study area, **b:** Precipitation map of study area.

In the study area moderate recharges (40-60% of precipitation) are the most represented. They are associated with karstified breccias and limestones. These results are acceptable, taking into account the study of Marinos and Fragopoulos (1972) presenting that the infiltration rate in the karstified formations is 50% of precipitation. The areas with non karstified rocks and quaternary deposits present very low recharge rates, 20% of the mean annual precipitation as is shown in Table 2, while the alluvial deposits show low recharge rates. High recharge areas are associated with the presence of shallow holes and dolines. In these areas the recharge raters represent 60 - 80% of mean annual precipitation (Table 2). The average value of the autogenic recharge rate for the study area deduced from APLIS method is 53% of precipitation, while the average value of the infiltration coefficient according to Marinos and Fragopoulos (1972) is 52.5% of the precipitation. Using the recharge map by means of the APLIS method (Fig. 3a) and the distribution map of precipitation (Fig. 3b) the recharge rates as mm/y of precipitation were derived (Table 2). As it is shown in table 2 in the areas with moderate recharge rates, the recharge rate varies from 170mm/y to 550 mm/y dependent of the spatial distribution of the precipitation.

Table 2. Recharge rate as (%) and mm/y of mean annual precipitation.

Recharge rate	(%) of Mean annual precipitation	mm/y of precipitation
Very Low	20	13-60
Low	20-40	60-170
Moderate	40-60	170-550
High	60-80	550-600

5 Conclusions

In this study, the APLIS method is applied to estimate the mean annual autogenic recharge expressed as a percentage of precipitation in a study area in Greece, which consists mainly of karstified evaporite and carbonate breccias. The application shows that autogenic recharges remain prevalent in the area; the major part of the area presents moderate recharges. Thus, in the major part of the study area the recharge rate is 40-60% of the mean annual precipitation. The average value of the autogenic recharge rate deduced from APLIS method is 53% of precipitation. These results are acceptable, taking into account that the average value of the infiltration coefficient according to an older study is 52.5% of precipitation.

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