# Quality and potentiality of water resources in an area intensively cultivated of the Sicilian hinterland

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*A hydrogeochemical study, along with a geological and hydrogeological support, permitted the groundwater circulation in the Canicattì hydrogeological basin, which is located in the inner part of Sicily to be reconstructed. The territory is heavily cultivated with vineyards, which are the driving force of the local economy, and a geochemical-environmental evaluation on the status of the groundwater resources of the area was carried out to obtein some indications on their quality and utilization. The study evidenced that in the area there is a critical situation from a hydrogeological point of view because the climatic condition does not guarantee a sufficient supply to the aquifers. From a geochemical point of view, the waters resulted force chloride-sulphate earth alkaline types, related to water-rock interaction, where the rocks belong to the evaporite series. Considering their quality, some contamination from fertilizers and wastewaters are present, making them unsuitable for drinking purposes but still suitable for irrigation.*

**Qualità e potenzialità delle risorse idriche in un ambiente intensamente coltivato nell'entroterra Siciliano**

*Uno studio idrogeochimico, supportato da dati geologici e idrogeologici, ha permesso di ricostruire un modello idrogeologico di circolazione idrica sotterranea nel bacino di Canicattì, una cittadina nell'entroterra del territorio Siciliano intensamente coltivato a vigneti, ed una prima valutazione geochimico-ambientale sulla risorsa idrica sotterranea. Dall'interpretazione dei dati si evidenzia uno stato idrogeologico critico, dovuto soprattutto alle condizioni climatiche che non assicurano un'alimentazione adeguata delle falde sotterranee, caratterrizzate da un punto di vista geochimico da acque essenzialmente clorurato solfato alcalino terrose, a causa di processi di interazione con rocce prevalentemente di origine evaporitica. Da un punto di vista ambietale invece si notano contaminazioni da fertilizzanti e scarichi fognari tali da escludere un uso diretto umano ma ancora idoneo per un uso irriguo.*

**Qualité et potentialité des ressources hydriques dans terrains intensément cultivé dans l'arrière-pays sicilien**

*Les études hydro-geochimiques, supportés par les données géologiques et hydrogéologiques, ont permis de reconstruire un Model hydrogéologique de circulation hydrique souterraine dans le bassin de Canicattì, un petit village dans l'hinterland de la Sicile, fortement cultivé à vignobles et une première évaluation geochimique-ambiant sur les ressources hydriques souterraines. Des interprétations des données, on voit un état hydrogéologique critique, imputé surtout aux conditions du climat qui n'assurent pas une alimentation proportionnée aux nappes souterraines, geochimiquement caractérisées par des eaux essentiellement $Ca+Mg - Cl+SO_4$, à cause des processes d'interaction avec des roches surtout evaporitiques. Du point de vue ambiant on voit plutôt la contamination par des fertilisants et des égouts qui excluent une directe utilisation humaine mais encore approprié pour l'irrigation.*

## Introduction

The territory studied (Fig.1) is located within the Province of Agrigento. It can be considered, as a whole, a hilly area with an altitude between 400 and 500 m (a.s.l.). The hydrographic network is little developed, since only the top portion of rain-collecting basins are involved. The surface water flows, even if of minor consistency, constitute a modest feeding source for artificial collecting lakes, used from the farmers in order to balance the aquifer deficiency.

The Sicily has having in the last years a huge development in the agricultural field, especially in high quality products requesting high amounts of fertilizers.

The economy of the study area, mainly starting from seventies, is based on the production of grape and, in part, of olives and almonds. It is noteworthy to consider that the cultivation of the famous "Grape Italy" has surely represented the social and cultural passage from a rural economy to a modern one, supported from modern techniques of business conduction of industrial type.

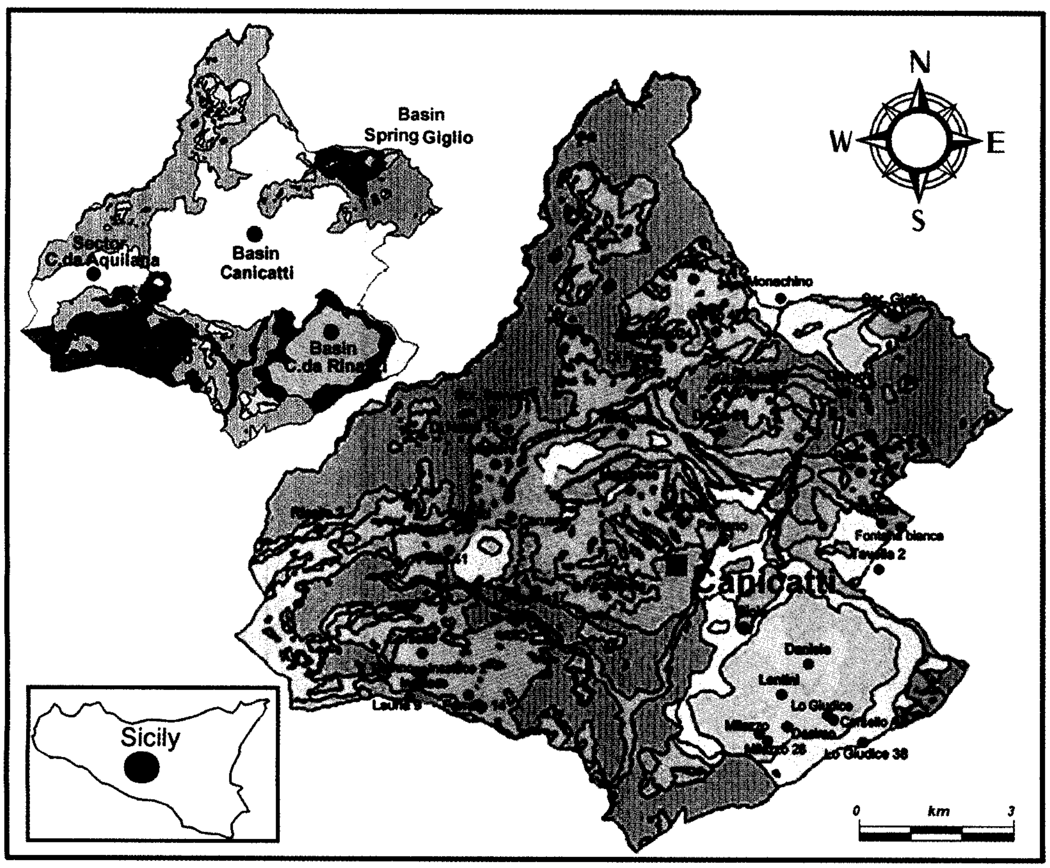
Problems related to the presence of nitrates in groundwater or agricultural soils have been arising for several years from the regional organization controlling this aspect.

Nitrate is the most typical chemical compounds which groundwater chemistry and cycling has been significantly perturbed by agricultural activities. It is highly soluble and rapidly leaches to groundwater and this reflects into high nitrate concentrations in natural waters flowing in the subterranean environment. Discharge of nitrate rich groundwater to surface waters may also reduce surface-water quality for drinking and aquatic life, and induce eutrophication of water table, due to increased availability for organism activities. Once $NO_3$ has entered the largely and aerobic unsaturated zone, it will behave as a conservative anion and its geochemical behavior will be similar to Cl. Subsequent variations in the concentrations of $NO_3$ will be modified by physical processes (evapotranspiration) or biochemical transformation in the soil. According to Edmunds et al. (1997), sources and sinks of nitrate and its evolution through the unsaturated zone may be followed conveniently using the $NO_3/Cl$ ratio, even though the presence in this area of the evaporitic series or clays makes it not suitable.

Potassium is often associated with nitrate in fertilizers (DATTA et al., 1997) but, even when fertilizers are deposited or applied simultaneously on the land surface, because of their different chemical behaviour, there may be a considerable time lag between their movement rate in the unsaturated zone and subsequent arrival to the saturated zone, causing an anomalous variation in their ratio.

## GEOLOGGICAL AND HYDROGEOLOGICAL FRAMEWORK

The geology of the area is allocable, regionally, to the center of the " Caltanissetta Basin " which is to consider as a wide tectonic depression filled by plastic marine sediments and gravitative lows of age comprised between Miocene sup. and the Quaternary, for a thickness which is thought to reach a maximum of 7,500 m between Agrigento and Licata. This is a structural depression located outside the Sicilian chain, above the layers covering the foredeep originated by the collapse of the African foreland (LENTINI et al., 1987).
The terrains constituting the study area are essentially referable to the "Terravecchia" Formation (Tortonian med.), clayey-marly substratum widely extended along the margins north-west and south of the municipal territory and in C.da Buccheri in the eastern part (FLORES G.,1959; SCHMIDT DI FRIEDBERG P., 1964), hence there is, stratigraphically, the "gessoso-solfifera" series (Messinian) whose sequence is often not represented by all the terms, and whose thicknesses are variable (CATALANO R.,1986; DEEVME A. et al.,1971). The calcilutites and marls (locally named "Trubi") close the deposition of the evaporitic series, covered in discontinuity by clays and sandy clays (Pliocene med.) on which the sands formation (Plio-Pleistocene) close the regressive series. They are visible in extended outcrops in C.da Rinazzi and, in minor dimension, in C.da Giglio and




**Legend**

- **Heterogeneous Complex**
  Lacustrine, alluvial, detric-eluvial, deposit.
  (Low permeability due to porosity)
- **Sandy-calcarenite complex**
  Yellowish calcarenites, sometimes jointing with sandy lenses.
  (Medium-high permeability due to porosity)
- **Sandy-clay and marl complex**
  Marls at globigerine and sandy-clay.
  (Absent permeability for porosity and very low for jointing.)
- **Calcareous and gypsum complex**
  Limestone and gypsum of the evaporite series. They are dislocated giving no hydraulic continuity.
  (porosity very low and high permeability for jointing and karst).
- **Clayey and clayey sandy complex**
  Slightly stratified with powerful thickness.
  (Impermeable)

FIG. 1 - *Hydrogeological map of the study area. The smaller one shows the identified basins.*
***Carta idrogeologica dell'area studiata. La carta più piccola mostra i bacini idrogeologici identificati.***

C.da Gulfi (D'Onofrio S., 1964; Roda C.,1967). Finally, there are limited recent deposits of swampy and lacustrine sediments constituted by sandy silts; alluvial deposits in correspondence of the main rivers and detritic-eluvial ones, extensively present in all the territory, constituted by screes; colluvial and eluvial deposits, mostly originated by the silty-clayey levels present within the "Calcare di base" sequence. All this material, along with the crushed limestone formation, has produced fertile soils, suitable for special agriculture development.

The hydrogeological study has allowed: a) to identify the basin limits, b) to reconstruct the flow directions of the aquifer and to identify the hydrogeological complexes. In particular, three hydrogeological basins have been recognized:

Basin of Canicattì, which has an aerial extension of about 84 km², where the aquifer flows on the impermeable substratum represented by the clayey complex (Tortonian sup.), within the calcareous-gypseous complex (Messinian sup.).

Tab. 1 - *Values of the major and minor constituents in the analyzed waters. Concentrations expressed in mg/l.*
***Valori dei costituenti maggiori e minori nelle acque analizzate. Concentrazioni espresse in mg/l.***

| Sample | Temp. (°C) | Conductivity (mS/cm) | pH | Li | Na | K | Mg | Ca | F | Cl | Br | NO3 | SO4 | HCO3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pantano | 17.8 | 2.1 | 7.4 | 0.1 | 62.3 | 11.6 | 39.6 | 356.0 | 13.4 | 104.9 | 0.0 | 76.6 | 782.0 | 182.8 |
| Taverna | 16.0 | 1.6 | 7.0 | 0.0 | 39.5 | 2.8 | 28.2 | 199.2 | 0.7 | 244.1 | 1.3 | 23.0 | 265.5 | 149.4 |
| Marchese | 16.8 | 2.5 | 7.0 | 0.0 | 72.7 | 2.2 | 40.2 | 439.5 | 1.2 | 185.9 | 0.8 | 325.5 | 900.1 | 127.5 |
| Lo Giudice 38 | 15.8 | 2.5 | 7.0 | 0.1 | 300.4 | 19.5 | 94.8 | 152.5 | 4.3 | 410.7 | 3.2 | 46.8 | 324.6 | 577.8 |
| Guarneri 48 | 16.7 | 1.6 | 7.1 | 0.0 | 51.3 | 1.3 | 31.7 | 250.1 | 0.9 | 134.3 | 0.6 | 40.7 | 383.3 | 382.7 |
| Lauria 9 | 16.0 | 1.3 | 7.3 | 0.0 | 49.3 | 2.2 | 39.5 | 173.0 | 0.9 | 99.3 | 0.4 | 166.7 | 230.1 | 251.5 |
| Failla 41 | 17.2 | 1.2 | 7.5 | 0.2 | 91.3 | 8.5 | 55.3 | 82.5 | 4.6 | 98.0 | 0.9 | 4.6 | 171.4 | 377.7 |
| Lo Verme 17 | 16.7 | 1.9 | 6.7 | 0.1 | 75.1 | 7.2 | 51.6 | 297.3 | 1.5 | 77.8 | 0.5 | 16.4 | 650.1 | 469.7 |
| Lo Verme 12 | 17.2 | 2.4 | 6.9 | 0.1 | 164.5 | 14.0 | 97.2 | 251.8 | 2.0 | 235.3 | 0.9 | 2.5 | 651.4 | 440.7 |
| Lauricella 24 | 16.3 | 1.6 | 7.2 | 0.0 | 88.5 | 4.1 | 44.3 | 186.3 | 1.7 | 124.0 | 1.1 | 61.1 | 493.9 | 170.7 |
| Milazzo 28 | 18.7 | 2.5 | 6.6 | 0.0 | 91.3 | 3.0 | 33.0 | 383.1 | 1.2 | 330.3 | 1.3 | 725.3 | 277.1 | 103.7 |
| Corbo 47 | 18.5 | 2.3 | 7.0 | 0.1 | 117.0 | 1.3 | 76.7 | 268.3 | 2.4 | 243.8 | 1.9 | 105.5 | 524.5 | 361.3 |
| Bennici | 16.9 | 2.5 | 6.8 | 0.0 | 87.1 | 2.6 | 98.7 | 370.2 | 1.6 | 333.1 | 1.5 | 259.9 | 454.5 | 309.6 |
| Tavella | 15.9 | 2.0 | 6.9 | 0.0 | 84.1 | 3.8 | 41.1 | 242.1 | 1.6 | 260.8 | 1.7 | 195.0 | 320.6 | 25.8 |
| Tavella 2 | 16.3 | 2.4 | 7.2 | 0.1 | 48.9 | 9.5 | 40.6 | 478.2 | 13.0 | 84.3 | 0.0 | 68.7 | 1258.4 | 65.5 |
| Rinallo 2 | 16.5 | 1.0 | 7.2 | 0.0 | 40.7 | 1.9 | 28.7 | 150.8 | 0.7 | 77.1 | 0.3 | 39.0 | 120.8 | 370.4 |
| Failla 50 | 18.1 | 3.1 | 7.2 | 0.1 | 273.2 | 17.5 | 70.8 | 297.6 | 3.8 | 442.0 | 3.5 | 5.9 | 704.2 | 414.6 |
| Ferraro 14 | 17.1 | 3.7 | 7.0 | 0.0 | 308.6 | 9.8 | 67.6 | 372.0 | 4.2 | 693.4 | 3.0 | 191.1 | 519.2 | 350.7 |
| Di Natali 15 | 16.8 | 1.4 | 7.3 | 0.0 | 60.3 | 3.4 | 42.6 | 170.5 | 0.9 | 124.3 | 0.6 | 16.7 | 219.6 | 359.6 |
| Drago 26 | 16.4 | 1.6 | 7.1 | 0.0 | 123.5 | 5.5 | 29.2 | 163.6 | 2.0 | 231.1 | 1.8 | 27.7 | 224.1 | 323.2 |
| Corsello 43 | 16.8 | 1.8 | 7.2 | 0.0 | 139.4 | 6.6 | 45.3 | 194.6 | 2.0 | 221.0 | 1.3 | 55.6 | 293.0 | 353.6 |
| Caruano | 16.2 | 2.3 | 7.3 | 0.1 | 258.7 | 18.9 | 80.1 | 110.3 | 4.0 | 303.6 | 2.1 | 6.2 | 443.6 | 320.0 |
| Di Rocco | 16.5 | 3.4 | 7.2 | 0.1 | 214.8 | 22.3 | 89.3 | 393.1 | 3.1 | 401.2 | 1.5 | 313.8 | 931.5 | 211.9 |
| Sor. Giglio | 16.9 | 1.0 | 7.0 | 0.0 | 24.0 | 1.3 | 6.4 | 179.9 | 0.3 | 74.6 | 0.5 | 129.3 | 177.0 | 227.2 |
| Sor. Savuco | 16.1 | 1.4 | 7.4 | 0.0 | 58.7 | 4.2 | 47.7 | 176.3 | 1.2 | 143.5 | 0.5 | 67.6 | 264.0 | 274.2 |
| Lupo | 16.5 | 1.1 | 7.1 | 0.1 | 60.8 | 4.8 | 34.1 | 116.5 | 2.1 | 92.6 | 0.4 | 13.3 | 171.5 | 364.3 |
| Tiranno | 16.4 | 3.0 | 6.9 | 0.0 | 126.7 | 2.6 | 62.4 | 446.4 | 1.8 | 356.6 | 2.3 | 468.6 | 641.5 | 263.8 |
| Migliore | 17.1 | 1.2 | 7.3 | 0.0 | 90.8 | 6.8 | 42.8 | 113.1 | 1.6 | 130.5 | 0.7 | 45.6 | 147.5 | 321.3 |
| Corsell A. | 17.7 | 0.8 | 7.6 | 0.0 | 39.9 | 4.3 | 18.8 | 91.8 | 0.7 | 53.8 | 0.0 | 1.2 | 75.3 | 321.3 |
| Insalaco | 14.6 | 2.4 | 6.8 | 0.0 | 105.6 | 1.0 | 48.8 | 371.3 | 1.3 | 281.4 | 1.1 | 206.7 | 544.3 | 361.4 |
| Insalaco 2 | 15.3 | 2.2 | 7.3 | 0.0 | 103.2 | 2.2 | 43.8 | 288.4 | 1.4 | 248.2 | 1.1 | 188.3 | 458.3 | 297.2 |
| Lentini | 18.9 | 1.7 | 6.8 | 0.0 | 78.4 | 4.7 | 38.9 | 268.2 | 1.1 | 152.1 | 0.5 | 5.3 | 385.8 | 516.9 |
| Decimo | 16.6 | 0.8 | 7.4 | 0.0 | 21.1 | 3.8 | 16.1 | 113.5 | 0.4 | 42.0 | 0.2 | 2.6 | 63.5 | 366.9 |
| Fontana Bianca | 16.4 | 1.4 | 7.4 | 0.0 | 64.9 | 3.9 | 23.2 | 209.3 | 1.2 | 104.8 | 0.4 | 62.4 | 357.4 | 312.3 |
| Facciponte | 18.0 | 1.1 | 7.3 | 0.0 | 63.1 | 3.4 | 38.0 | 123.5 | 1.1 | 78.9 | 0.5 | 55.7 | 193.2 | 287.4 |
| Milazzo | 18.2 | 1.0 | 7.1 | 0.0 | 30.1 | 1.0 | 4.8 | 158.5 | 0.5 | 62.4 | 0.2 | 97.4 | 118.7 | 268.3 |
| Ottavo | 17.3 | 2.3 | 7.1 | 0.0 | 89.8 | 69.2 | 42.0 | 307.2 | 1.3 | 169.1 | 1.0 | 239.9 | 643.7 | 263.7 |
| Di Gioia | 16.3 | 2.0 | 7.4 | 0.1 | 181.5 | 15.0 | 98.6 | 146.4 | 2.9 | 189.4 | 1.1 | 13.1 | 479.3 | 377.8 |
| Monachino | 19.5 | 2.2 | 7.0 | 0.1 | 76.3 | 8.4 | 84.8 | 376.1 | 2.6 | 103.3 | 0.4 | 2.3 | 1221.9 | 228.7 |
| Daniele | 17.0 | 1.1 | 7.2 | 0.0 | 45.1 | 6.3 | 23.5 | 140.2 | 0.7 | 67.3 | 0.2 | 2.2 | 117.0 | 418.9 |
| Lo Giudice | 15.9 | 1.2 | 7.0 | 0.0 | 48.0 | 2.7 | 6.3 | 181.5 | 0.5 | 97.3 | 0.0 | 115.8 | 127.7 | 293.8 |
| Nicosia | 17.0 | 1.7 | 7.0 | 0.0 | 46.7 | 2.7 | 23.9 | 262.0 | 0.8 | 122.6 | 0.3 | 149.2 | 428.1 | 141.8 |

Basin of C.da Rinazzi, and the basin feeding the Giglio spring, with an extension of 6 $km^2$ and 1 $km^2$ respectively, whose waters flow on an impermeable substratum of clayey-sandy and marly complex (Pliocene inf.) within the calcarenites (Pliocene sup.).

To esteem the hydrological balance of the area, data from Regional Hydrographical Technical Service (STIR) have been used. The thermo-pluviometric stations considered are: Campobello di Licata (349 m a.s.l.), Canicattì (475 m a.s.l.), Castrofilippo (349 m a.s.l.) and Racalmuto (475 m a.s.l.). It was taken into account a total interval of 20 years, from 1980 to 2000.

The analysis of the historical pluviometric data of the territory showed a climate going from the barren warm to moderate one, with a rainfall between 500-600 mm/year. The course of the precipitation evidence a decrease of the annual precipitations in coincidence to an increase of intense rainy events, this is a clear sign of a trend towards crescent aridity conditions. The heavy rainfall events have had, in the last century, a frequency of 10 years but in last two decades the regularity of these precipitation has been of 2-3 years, with rainfall amount above 200 mm, within few hours and after long drought periods. The contribution is correspondent to about 30-40% of the annual total amount. Thus, it can be thought that there is a change in the climate condition, unfavorable to feed the aquifers and favorable to surface water accumulation.

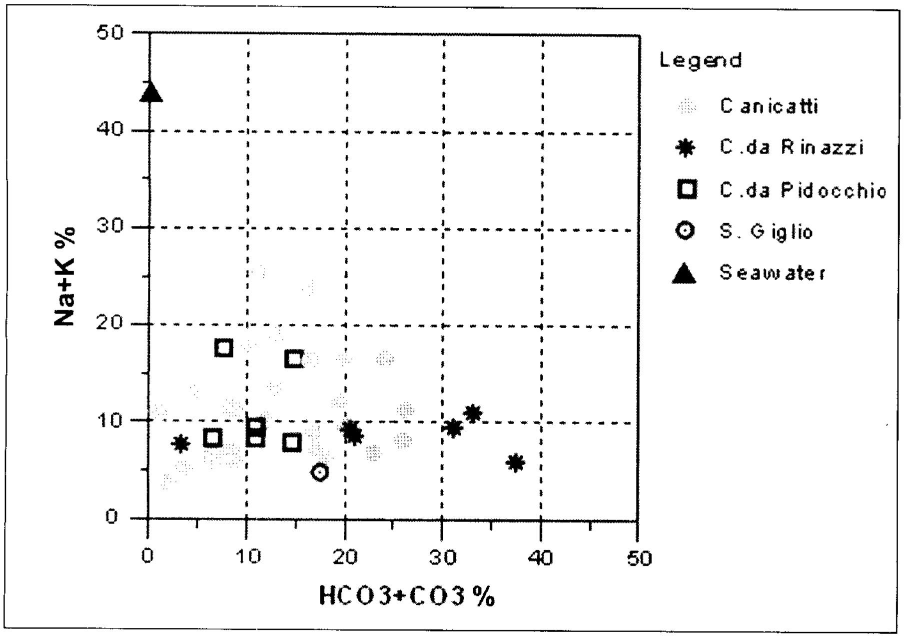



FIG. 2A - *The Langelier-Ludwig diagram. Values are expressed as reaction values, i.e.* $v_{Na+K} = (\Sigma C_{Na+K} / \Sigma C_{cations})$ *x50 and* $vH_{CO3+CO3} = (\Sigma C_{HCO3+CO3} / \Sigma C_{anions})$ *x50. The* $v_{Ca+Mg}$ *and* $v_{Cl+SO4}$ *are complementary.*

***Diagramma di Langelier-Ludwig nella versione generale. I valori sono espressi come "valori di reazione" cioè:*** $v_{Na+K} = (\Sigma C_{Na+K} / \Sigma C_{cationi})$ ***x50 and*** $v_{HCO3+CO3} = (\Sigma C_{HCO3+CO3} / \Sigma C_{anioni})$ ***x50. I valori*** $v_{Ca+Mg}$ ***e*** $v_{Cl+SO4}$ ***sono complementari.***

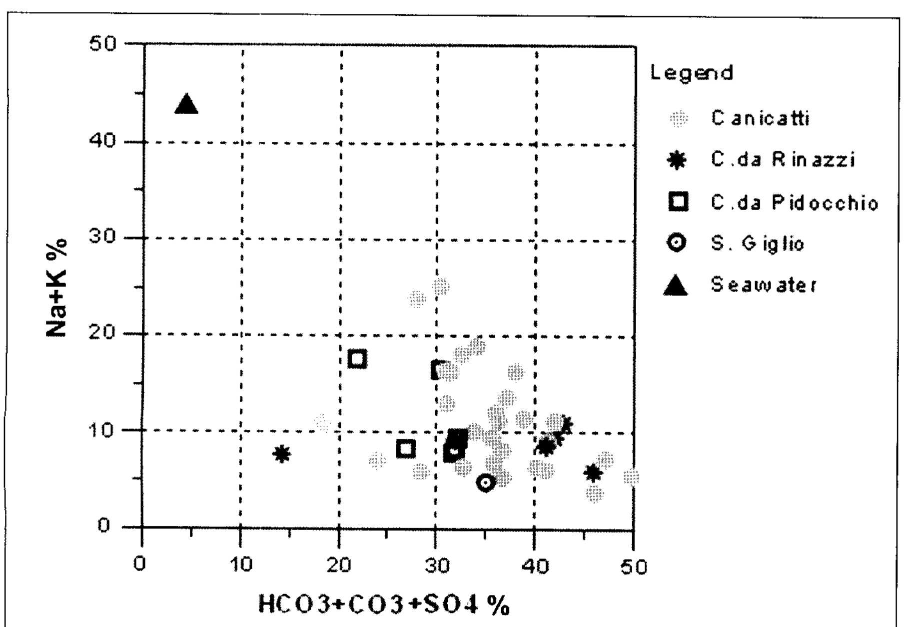



FIG. 2b - *The Langelier-Ludwig modified version.*

***Diagramma di Langelier-Ludwig nella versione modificata.***

The following formula has been used to calculate the mean precipitation: $P_m = \Sigma P_i \cdot A_i / A_t$ (where: $P_i$ = mean value in 20 years precipitations measured in the i-station, $A_i$ = the influence area of the i-station and the $A_t$ = total area of the territory) (CASTANY G., 1982). The evapotranspiration (E) was computed using the Turc's method (1954), modified by SANTORO (1970) for the Sicilian climate. Effective infiltration ($I_E$) has been determined through the potential infiltration coefficient (P.I.C. = $I_E$/D x 100; where D= total amount runoff). A P.I.C. of about 47% has been used to compute the effective infiltration for the total study area. This is the result of a weighted mean value considering the different litologies present in the area.

The hydrogeological balance has been computed using the following values: $P_m$= 527 mm/y (mean annual precipitation), $T_p$=12°C (weighted average temperature), E = 392 mm/y (Evapotranspiration), D=135 mm/y (annual mean total amount runoff), $I_E$=63 mm/y (effective infiltration), V= 5.8 $10^6$ $m^3$/y (water potentiality of the aquifer).

From ISTAT (Institute of Statistics) data for the 2000, it has been possible to estimate the cultivated surfaces for each kind of cultivation, thanks to which has been possible to make an esteem of the water amount requirement, which is about 5 $10^6$ $m^3$/y. Moreover, always from ISTAT data, it has been also possible to estimate the water requirement for civil uses, considering a mean value per person of 250 l/day, equal to 0.5 $10^6$ $m^3$/y. Therefore, the aquifer exploitation resulted about 5.5 $10^6$ $m^3$/y, approximately 94 % of the water potentiality of the municipal territory.

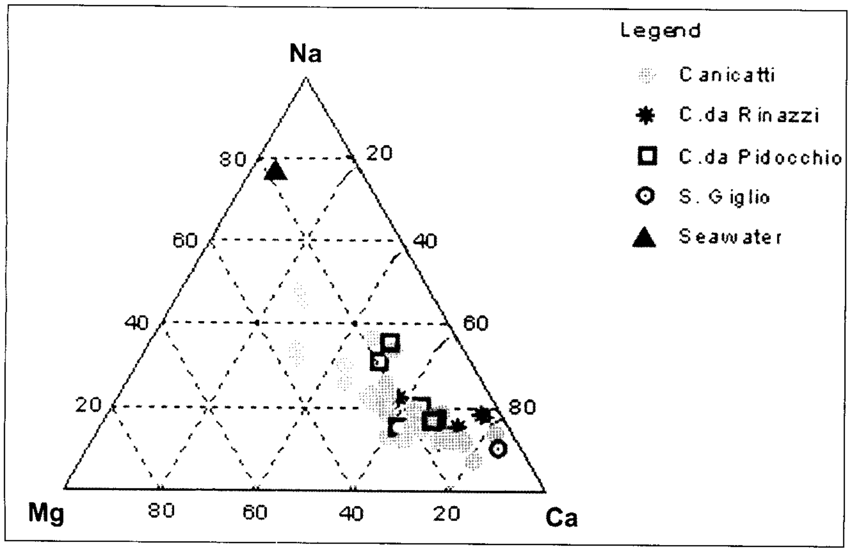



FIG. 3a - *Cation ternary diagram. Concentration expressed in %.*
***Diagrammi ternari. Concentrazioni espresse in %.***

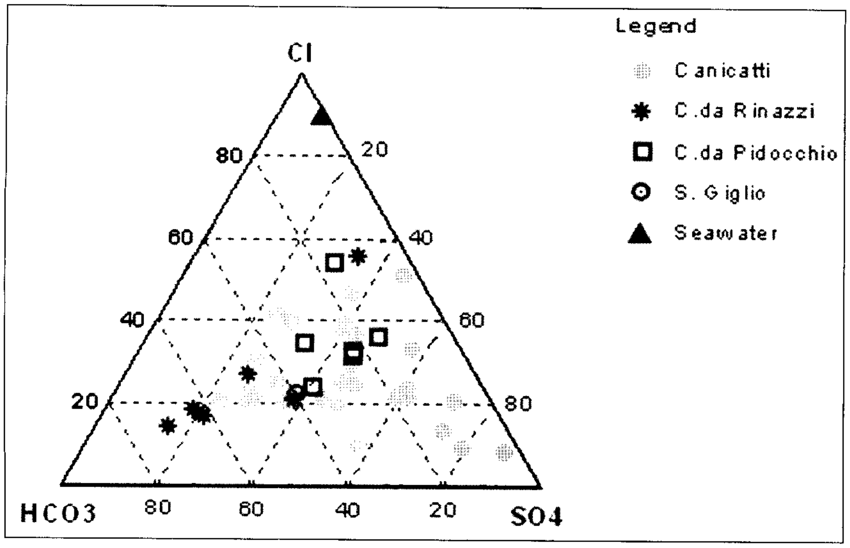



FIG. 3b - *Anionic ternary diagram. Concentration expressed in %.*
***Diagrammi ternari. Concentrazioni espresse in %.***

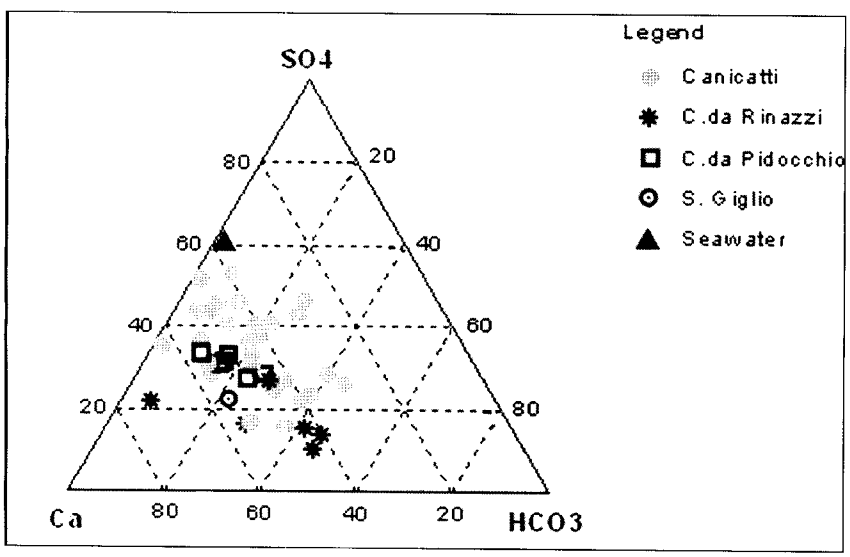



FIG. 4 - *$SO_4$-Ca-$HCO_3$ diagram. Concentration expressed in %.*
***Diagramma $SO_4$-Ca-$HCO_3$. Concentrazione espressa in %.***

## MATERIALS AND METHODS

Sampling campaigns have been carried out in the study area. Water samples were collected from wells and springs and chemical-physical measurements (T, Cond., pH, Eh) were performed in the field. The location of the sampling points (reported in Fig. 1) was controlled using a GPS detector (resolution ± 3 m). The collected samples were filtered through a membrane of 0.45 μm and acidified with $HNO_3$. The alkalinity was measured by titration with HCl 0,1 N. The laboratory analyses were carried out by means of high efficiency liquid chromatography (H.P.L.C.) for the determination of the major and minor elements.
The results are reported in Tab.1.

## DISCUSSION

The samples, reported on the following diagrams, are differentiated on the base of the belonging hydrogeological basin and sectors:
a) basin of Canicattì comprises two sectors: C.da Aquilana sector (in the diagrams see C.da Pidocchio sector) and C.da Pidocchio one;
b) basin of C.da Rinazzi;
c) basin feeding the Giglio spring.

In the basin of Canicatti two sectors have been considered since, although they are separated by the same impermeable substratum, they have similar hydrogeological characteristics.
The Langelier - Ludwig diagram (1942) (Fig. 2a) shows that 89% of the points fall into the family of chloride-sulfate-earth alkaline waters, while only 11% fall into the quadrant of the bicarbonate-earth alkaline ones. In the modified Langelier - Ludwig diagram (Fig. 2b), where the sulfate member is added to the bicarbonate one, there is a general shift of all the points towards right, pointing out a preponderant interaction with evaporitic rocks mainly rich in gypsum. The cation ternary diagram (Fig. 3a) shows a unique alignment towards the $Ca^{2+}$ - ($Na^{+}$/ $Mg^{2+}$) direction. A careful analysis, considering the outflow directions, evidences a water evolution of the Canicattì basin from sodic to calcic type, while waters from C.da Pidocchio sector show an exactly inverse trend, difference probably due to a different way that the waters flow through the interested litologies. Instead, from the anionic diagram (Fig. 3b) only waters from C.da Rinazzi show a prepon-

derant bicarbonate member, while all the others evidence a relevant sulfate one, thus we can assume that two main processes are involved: carbonate rocks dissolution, in C.da Rinazzi, and preponderant gypseous rocks dissolution and, subordinately, carbonate rocks in the other basins. On the other hand, from the ternary diagram ($SO_4^{=}$- $Ca^{2+}$- $HCO_3^-$) (Fig. 4), a general evolution of all the points from terms rich in $HCO_3^-$ to terms rich in $SO_4^{=}$ is apparent. In particular, while the waters of the basin of Canicattì and those of the C.da Pidocchio sector become richer in salts, maintaining the same $Ca^{2+}/(SO_4^{=} + HCO_3^-)$ ratio, samples from the C.da Rinazzi basin show a similar evolution, but with different ratio, leading to greater enrichment in $Ca^{2+}$, index of higher interaction with carbonate rocks. The $Ca^{2+}/SO_4^{=}$ (Fig. 5) diagram shows that only the 12% of the points, all belonging to the Canicattì basin, have a ratio for a typical gypsum dissolution, while approximately 86% of the points have a calcium excess related to different processes.

The $Na^+$-$Mg^{2+}$ and $Na^+$-$Ca^{2+}$ species have, generally, a positive correlation while for some samples, belonging to the Canicattì basin, this is negative. This fact can be explained through an ion-exchange process, especially for those points with high concentrations. The $Cl^-/Br^-$ diagram (Fig. 6), besides confirming the presence of a typical marine sediment ratio, also shows that 47% of the samples have a bromide excess, index of anthropic processes due to use of fertilizers rich in $Br^-$. The $K^+/NO_3^-$ diagram (Fig. 7) shows as 34% of the points are aligned along a typical ratio for fertilizers more used in this area (NPK 11/22/16). The potassium excess, shown in all the other samples, is very likely due to ion - exchange with clays and, subordinately, dissolution of last stage K-bearing minerals of evaporitic sequence.

From the $NO_3^-$ histogram (Fig. 8) it is apparent that only 14% of sampled waters have a content less than 5 ppm, limit for drinkable waters (government decree 18/08/2000 no. 258), while the waters having a concentration being able to be made drinkable (from 5 to 50 ppm) are approximately 31%. All the others cannot be suitable for drinkable purposes. One deduces that the use of chemical fertilizers influences the water quality, but the nitrate presence in the aquifer is not only caused by the fertilizers use, probably it is also due to wastewaters contamination.

In order to define the water quality for

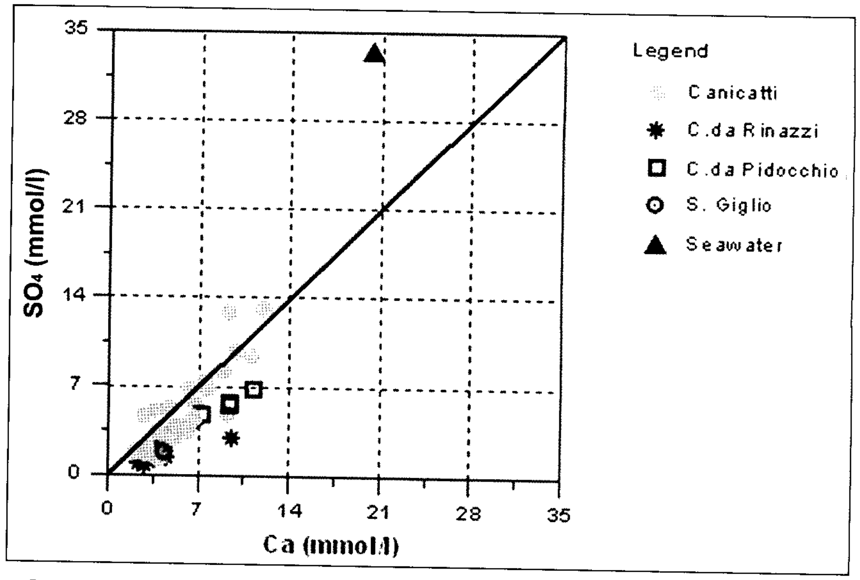



FIG. 5 - *Ca-$SO_4$ plot. The line represents the $SO_4/Ca=1$ ratio.*
***Diagramma Ca-$SO_4$. La linea rappresenta il rapporto $SO_4/Ca=1$.***

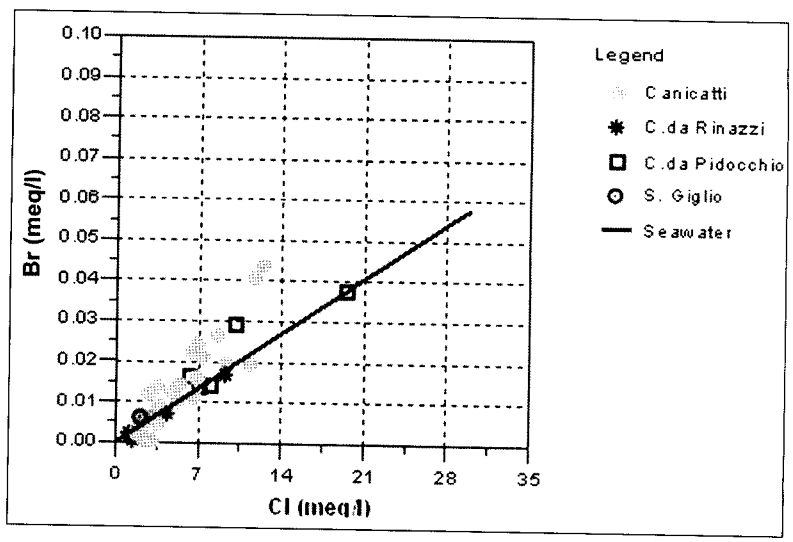



FIG. 6 - *Br-Cl plot. The line represents the seawater ratio.*
***Diagramma Br-Cl. La linea rappresenta il rapporto nell'acqua marina.***

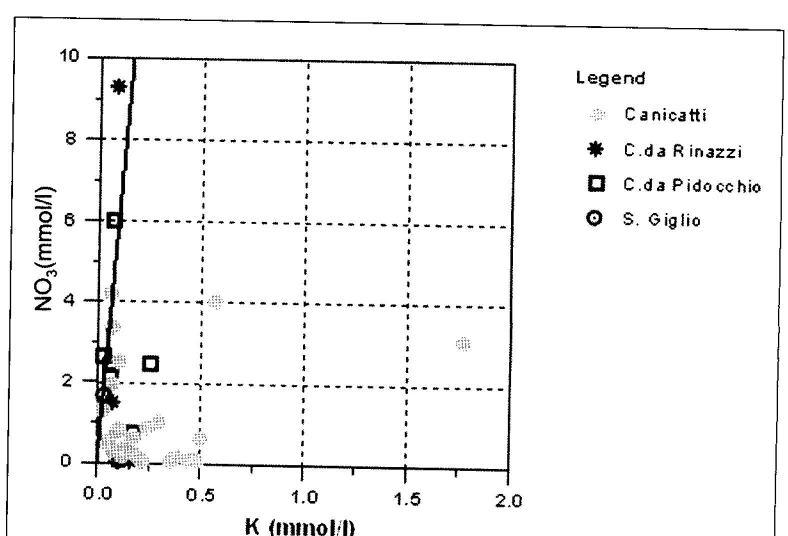



FIG. 7 - *$NO_3$-K plot. The line represents the $NO_3/K$ ratio of fertilizers used in the study area.*
***Diagramma $NO_3$-K. La linea rappresenta il rapporto $NO_3/K$ presente nei fertilizzanti usati nell'area studiata.***

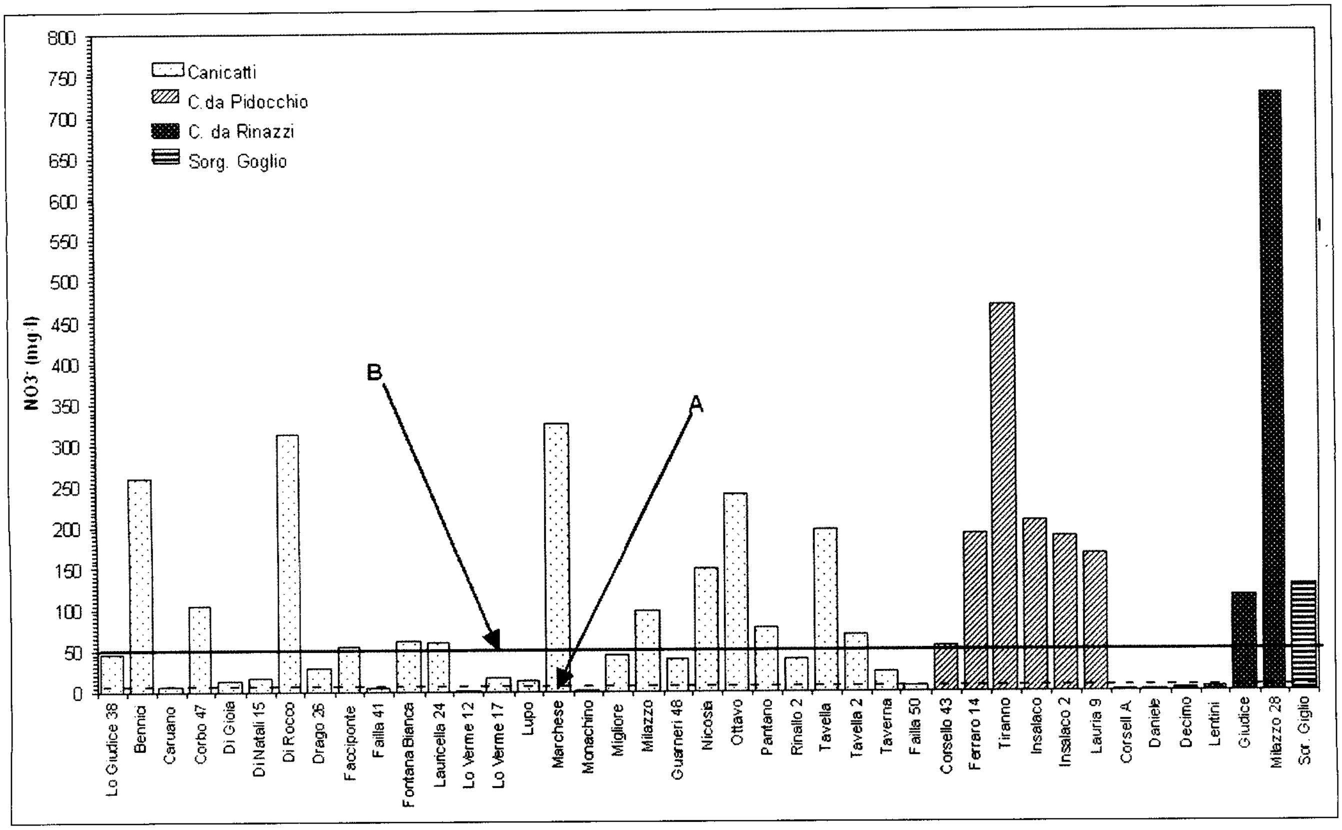



FIG. 8 - *$NO_3$ histogram. A= limit for drinkable waters, B= limit for potentially drinkable waters (after purification).*
***Istogramma della specie $NO_3$. A= limite per le acque potabili, B= limite per le acque potenzialmente potabili (dopo purificazione).***

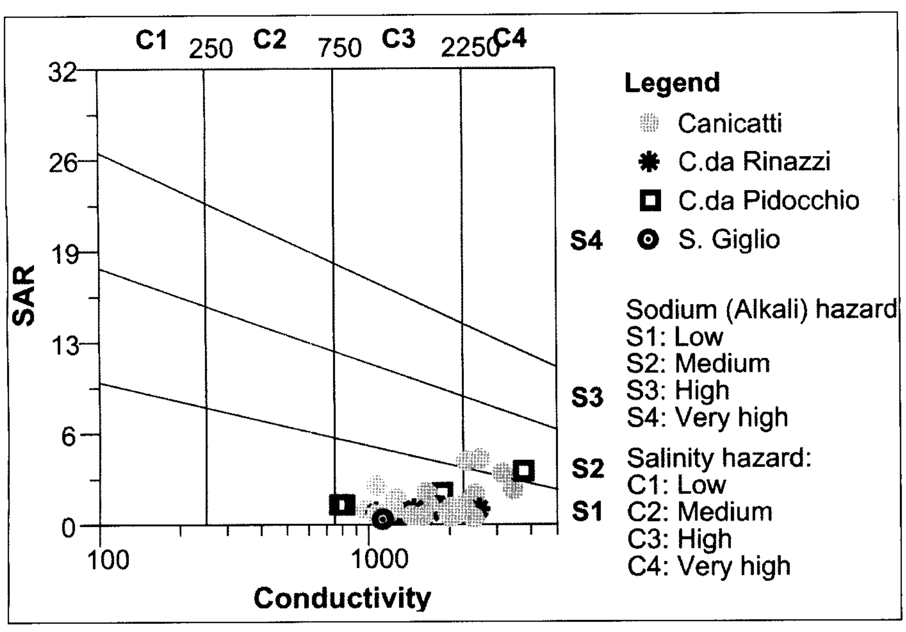



FIG. 9 - *SAR-Conductivity diagram.*
***Diagramma SAR-Conducibilità.***

irrigated use, it has been taken in consideration the SAR index (Sodium Adsorption Ratio), which allows estimating the alkalinization risk for soil, and the salinity content. Waters with SAR values higher than 10 would not have to be used. Comparing the SAR index with the salinity, express as conductivity, (U.S.D.A., 1954) (Fig. 9) can be noticed how 78% of waters fall in the field C3-S1, with high salinity risk and low sodium risk, 12% fall in the field C4-S1, introducing a salinity risk much higher while the sodium risk remains low, while 10% fall in the field C4-S2 with a salinity risk very high and a medium sodium risk.

The conductivity map (Fig. 10), similar to the SAR one, evidences high values in the C.da Pidocchio sector and the basin of Canicattì, while lower values are found in the basin of C.da Rinazzi. Taking into consideration the classification proposed by the U.S. Environmental Protection Agency (USEPA, 1976), which proposes limits based on the TDS (total dissolved solids) values, it turns out that 31% of the sampled waters are comprised in the range between 500-1000 mg/l, suggesting to adopt a monitoring only for the irrigation of sensitive cultivations, 52%, between 1000-2000 mg/l, demanding a controlled irrigation praxis for all the types of cultivations to avoid damaging effects, the remaining 17%, between 2000-5000 mg/l, for which it is advised the use only for tolerant cultivations in permeable soils and adopting, however, a controlled irrigation praxis. From the obtained information, it can be deduced as the best-irrigation waters are found in C.da Rinazzi and Giglio spring, the worse ones in C.da Pidocchio while those intermediate are found in the Canicattì basin. However, the use of these waters demands a careful control of the irrigation praxis in order to avoid some undesired effects on the cultivations.

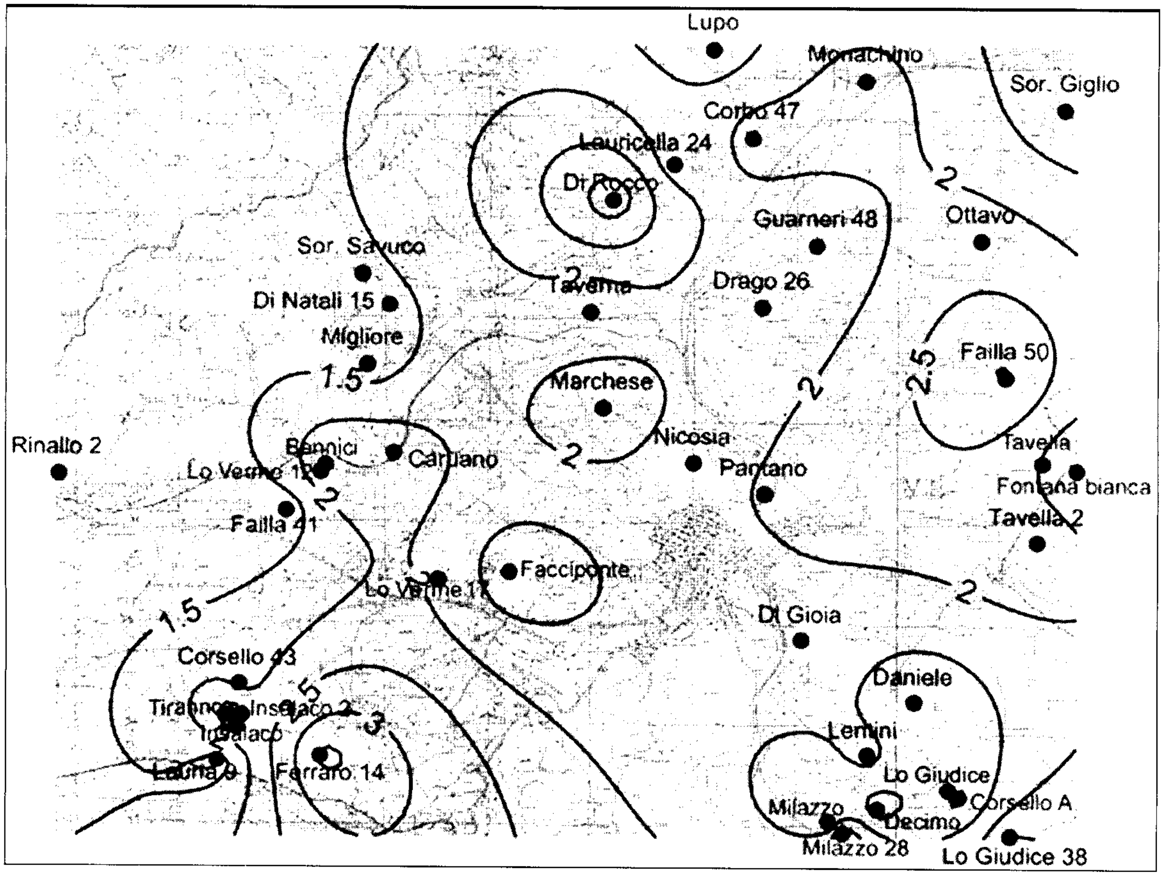



FIG.10 - *Conductivity contour map of the study area. Values expressed in mS/cm at 25°C.*
***Carta di iso-conducibilità dell'area investigata. I valori sono espressi in mS/cm a 25°C.***

## CONCLUSIONS

This research has shown that the hydrological balance is still active, even if with an estimated requirement of about the 94 % of the water potentiality of the territory. From a geochimical point of view, it is not possible to make a clear distinction among the various hydrogeological basins. The chemistry of these waters is essentially controlled by the interaction with evaporitic rocks (both gypsum or carbonate ones) except for C.da Rinazzi where a clear higher interaction with carbonate rocks is apparent. Moreover, the waters with higher salinity also show a cation-exchange phenomenon with clayey sediments. The waters of the municipal territory of Canicattì can be defined suitable for an irrigation use, on condition that opportune and controlled irrigation praxis are adopted, but the same cannot be said for drinkable purpose because the nitrate levels are above the limits established by the G.D. 18/08/2000 no. 258.

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