Oxygen isotope composition as a tool for aquifer assessment: the CAMI-Life project case

O. Flora[1], J. di Varmo[1], B. Stenni[1], L. Genoni[1] and A. Carniel[2]

[1] *DiSGAM, Università di Trieste, Italy*
[2] *ARPA FVG, Dipartimento di Pordenone, Italy*

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ABSTRACT The stable oxygen isotope composition of 11 wells, 4 pluviometers and 3 rivers are analysed and discussed in this paper in order to provide information on the recharge basin of aquifers and on the hydro-geological processes operating on groundwater. The studied area is situated in the northern part of Pordenone's plain (NE Italy) and includes the Cellina - Meduna fan and the "risorgive line". Samples were collected once a month with the exception of the main site at the Chions - Torrate locality where two wells, at a 50 and a 200 m depth, were sampled every two weeks. On the basis of the results, we identified three areas where aquifers are affected differently by meteoric water, when percolating through the unsaturated zone and the river water. In a few cases, only one of the two end members characterizes the groundwater.

1. Introduction

In the last few years, monitoring, analyzing, safeguarding and tutoring surface water and groundwater has become an important task related to the European environmental policy. In response to these E.C. directives, CAMI - Life project wants to develop an integrated method of investigation to study aquifers. Aspects typically investigated to assess groundwater resources include, the quantity of water available, its sustainable exploitation rate, and its quality.

Stable water isotopes are natural tracers present in the water cycle system, which can be used as an important tool of investigation. A precise knowledge of the isotopic composition of local precipitation and of the isotopic composition of groundwater and surface water provide essential information on the hydro-geological characteristics of aquifers including their origin, and aquifer interconnections (Gonfiantini *et al*., 1998). The knowledge of the mean weighted annual isotopic composition of precipitation over a catchment basin is pre-requisite to investigate the origin of the water feeding the rivers and the aquifers. The definition of the vertical isotopic gradients of meteoric waters are necessary to define the recharge area of aquifers as well as its mean altitude. Local rain will also contribute to the isotopic composition of shallow groundwater depending on the grain size of the material covering or forming the aquifer.

The stable oxygen isotope composition of precipitation, of rivers and of groundwater collected in the area, included in the CAMI project, will be presented in this paper. The aim is to define the recharge area and the occurrence of interconnections between rivers and aquifers by the isotopic characterization of these waters.

2. Study area, sampling and methods

The investigated area covers the northern part of the plain of Pordenone, located in north - eastern Italy (Fig. 1). The northern part is formed by the alluvial fan of the Cellina and Meduna Rivers and it is composed mostly of gravel and sands, forming an undifferentiated aquifer, belonging to a Pleistocene age system (Stefanini and Cucchi, 1977). The size of these sediments becomes smaller and smaller in the southern part of the fan where different layers of clay are interbedded. This part is separated from the southern one by the "risorgive line", where the intrinsic permeability of sediments decreases abruptly and water from the aquifers is forced to spring out (Cucchi *et al*., 1999). The investigated area is bounded to the east by the Tagliamento fan, whose aquifer merges gradually into the Pordenone plain and feeds part of its wells, and, finally, by the Livenza and Noncello Rivers to the west. The absence of surface hydrography and the high infiltration rate characterize the alluvial fan of Cellina and Meduna, whereas south of the line of the "risorgive" the plain is characterized by a low permeability and the river direction is oriented NE-SW (Fig. 1).

The location of the sampling stations (pluviometers, rivers and wells) is reported in Fig. 1. Four pluviometers were located at different altitudes in order to define the recharge areas and the vertical oxygen isotopic gradient. The southern one is placed at the main site (20 m a.s.l.) and another one is placed near the village of Vivaro, at an altitude of 142 m a.s.l. Two other pluviometers are located at an altitude of 468 and 558 m a.s.l., along the course of the Cellina River, which is the most important stream of the northern plain of Pordenone.

We identified two series of 4 and 6 pumping phreatic wells inside several aquifer layers which help us understand the origin of the groundwater, the infiltration areas, and see the indications of interconnections between different aquifers or between aquifers and rivers. They are located on two arcs, covering an angle of 130°-140°, and respectively 9-11 km and 20-24 km from the main site, located at Chions - Torrate. All the wells were sampled every month with the exception of the main site, which was sampled every two weeks at two depths of 50 and 200 m. The three rivers, Cellina, Livenza and Tagliamento, were sampled every month at Ravedis, Brugnera and Pinzano localities, respectively. The above-described research had to be carried out over a period of two years, in order to have a statistically meaningful data set. The sample collection was made by the ARPA FVG section of Pordenone. All the stable isotope measurements were carried out at the Isotope Geochemistry Laboratory of DiSGAM (University of Trieste). The water samples were measured for their oxygen isotope composition using the well-established technique of CO_2 water equilibration by means of an automatic equilibration device on line with the mass spectrometer (Epstein and Mayeda, 1953). A Delta Plus Advantage equipped with an HDO device by Thermo Finnigan was used.

The results are reported as delta units (δ) per mil (‰) against the V-SMOW isotopic standard. The analytical precision of $\delta^{18}O$ measurements (where $\delta^{18}O = \{[(^{18}O/^{16}O)_{sample}/(^{18}O/^{16}O)_{V\text{-}SMOW}] -1\} \times 1000$) are better than ±0.05‰.

3. Results and discussion

The $\delta^{18}O$ values obtained from the four pluviometers, sampled from January 2005 to December 2006, are reported in Fig. 2. The mean weighted annual $\delta^{18}O$ values calculated for

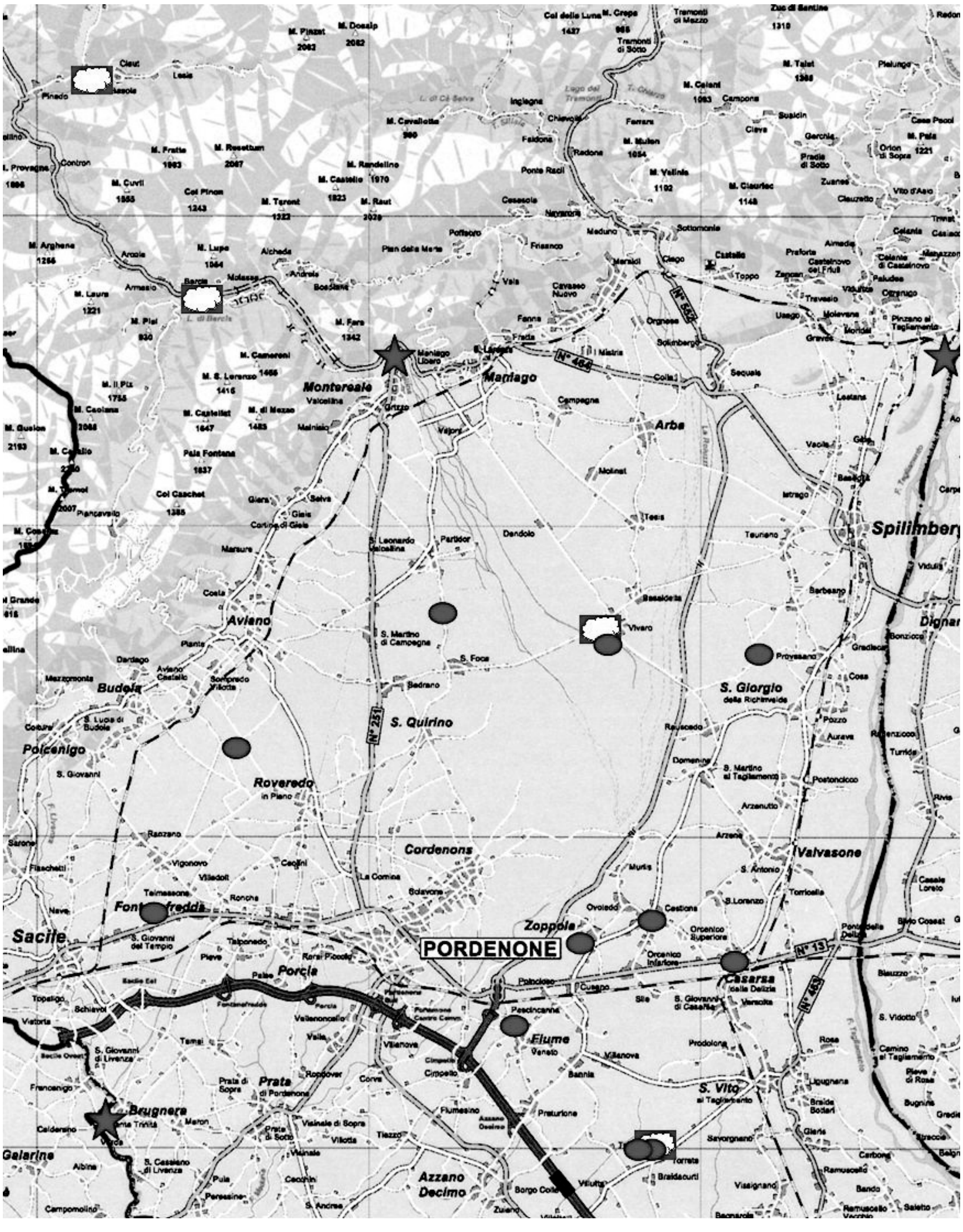

Fig. 1 - Map of the investigated area. Location of the sites where well, pluviometer and river samples are collected, is indicated with a dot, cloud and star, respectively.

Chions, Vivaro, Barcis and Claut pluviometers are -7.27, -7.17, -8.87 and -9.61‰, respectively. More negative $\delta^{18}O$ values are found, as expected, from the higher elevation sites, Claut and Barcis. In fact, the $\delta^{18}O$ of the precipitation is essentially related to the condensation temperatures (Dansgaard, 1964). At the higher elevation sites, a decrease in the $\delta^{18}O$ of the precipitation will

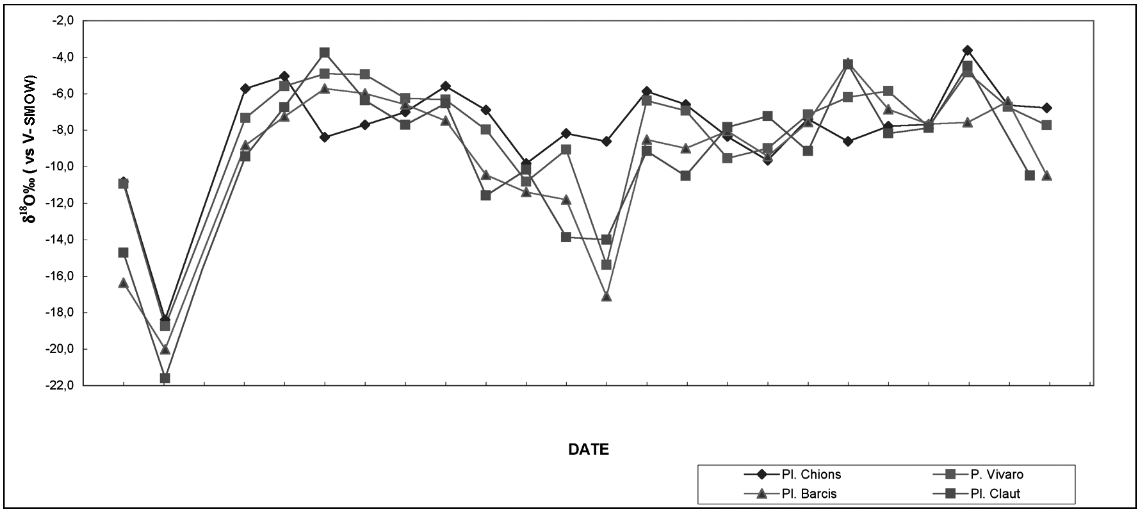

Fig. 2 - Oxygen isotopic composition of mean monthly samples at the four pluviometer stations, located in Chions – Torrate (20 m a.s.l.), Vivaro (142 m a.s.l.), Barcis (468 a.s.l.) and Claut (558 m a.s.l.).

be the obvious consequence of moisture depletion in heavy isotopes as the air mass expands, cools and rains out; this is known as the "altitude effect" (Dansgaard, 1964). Another consequence of the temperature dependence of the isotopic composition is the seasonal variations of $\delta^{18}O$ values, with more negative values in winter and less negative ones in summer. However, some particularities arise if we look at the pattern of the isotopic curves during the year. A strong negative $\delta^{18}O$ minimum is observed in February 2005 in all the pluviometers. On the other hand, relatively high values in February 2006 are observed. The $\delta^{18}O$ minimum could be related to just a few snowfall events in February 2005. The pluviometer at Chions shows an anomalous seasonal pattern with a higher monthly variability. If we look at the temperature data, available from ARPA - Osmer FVG, at Chions, relatively lower temperatures occur when compared to the Vivaro site located at a higher elevation.

In a general way, all these effects could be due to the fact that the $\delta^{18}O$ precipitation values are not only affected by temperature but other effects are also driving the variations of this parameter. Moisture origin, trajectory of air masses and precipitation amount are some of them. However, a study on the climate situation, of the subject area on a small scale, is not the priority of this paper and will be the subject of another publication.

The vertical gradient (variation of $\delta^{18}O$ of the precipitation with elevation) calculated among all the pluviometers is -0.45‰/100 m, which is quite a high value when compared to other data found in the eastern part of the Friuli-Venezia Giulia Region (D'Amelio *et al*., 1994) and in Italy (Longinelli and Selmo, 2002). This could be related to local temperature effects depending on the particular morphological situation of the Cellina Valley. This is in agreement with the temperature gradient of -0.12°C/100 m between the site of Vivaro and the high elevation sites of Barcis and Claut (Fig. 3).

The $\delta^{18}O$ values obtained from the rivers are reported in Fig. 4. The Tagliamento River shows

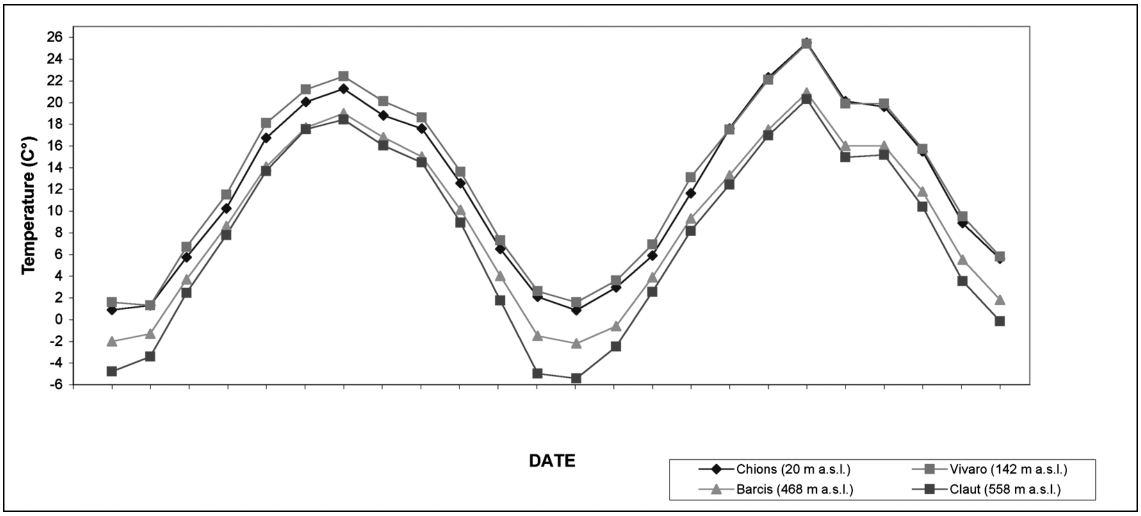

Fig. 3 - Mean monthly temperatures observed at the four pluviometer stations located in Chions – Torrate (20 m a.s.l.), Vivaro (142 m a.s.l.), Barcis (468 a.s.l.) and Claut (558 m a.s.l.). The data are from the ARPA - OSMER FVG.

higher $\delta^{18}O$ values compared to the Livenza and Cellina ones. The two curves of the Cellina and the Livenza cross each other and show a marked peak in September 2006.

The Tagliamemto and Cellina Rivers show a lower variability than the Livenza one. The mean values over the two-year period are -8.8, -9.4 and -9.5‰ for the Tagliamento, Cellina and Livenza Rivers, respectively. The lower variability of the Tagliamento River is related to its higher

Table 1 - Mean oxygen isotope composition for monthly samples collected at the 11 wells. The depth of the wells is also reported.

Sampling site	**Depth well (m)**	**$\delta^{18}O$‰ (V-SMOW)**
Chions - Torrate (Well 1)	50	-8.54
Chions - Torrate (Well 2)	200	-8.95
Fiume Veneto	170	-8.36
Zoppola	81	-8.54
Castions di Zoppola	80	-8.48
Casarsa	40	-8.44
Fontanafredda	300	-8.49
Roveredo in Piano	147	-8.35
Montereale - Valcellina	174	-7.90
Vivaro	120	-7.34
S. Giorgio della Richinvelda	25	-8.78

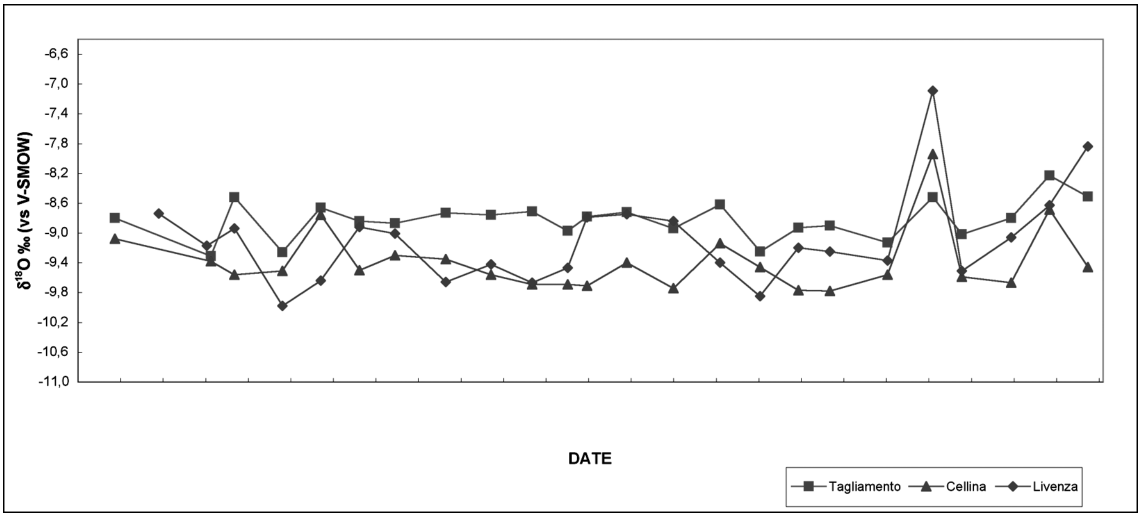

Fig. 4 - Oxygen isotopic composition of monthly samples collected at the Tagliamento, Cellina – Meduna and Livenza Rivers.

catchment basin which is also different from the ones of Cellina and Livenza. The positive peak found in September 2006, which is particularly marked for the Livenza River, could be related to the well-known higher temperatures observed during summer 2006, which should have affected the $\delta^{18}O$ of the precipitation in the respective catchment basins.

The $\delta^{18}O$ values obtained by all the sampled wells are reported in Fig. 5 against time while their mean values are reported in Table 1. A low isotopic variability characterizes all the wells but we can divide them into different groups according to both their $\delta^{18}O$ values and their geographical location.

Less negative isotopic values are found in the Vivaro and Montereale-Valcellina wells with mean $\delta^{18}O$ values of -7.34 and -7.90‰. These are located on the Cellina-Meduna fan where the permability is very high, allowing a high infiltration by local rain. In fact, the isotopic values are near the mean $\delta^{18}O$ value observed in the precipitation of the area; taking into account a vertical gradient of -0.45‰/100 m (this study) and a mean $\delta^{18}O$ value of -7.27‰ (Vivaro pluviometer), we can suppose that the recharge area of this aquifer is located at a mean elevation ranging between about 150 and 300 m (piedmont area). However, we cannot observe seasonal variations because the downward velocity of the water is statistically distributed around a mean value causing a high dispersion rate of the seasonal signal.

The wells that reach their $\delta^{18}O$ values around -8.5‰ (from -8.35 to -8.78‰) are probably affected by the influence of the Tagliamento River (-8.8‰) and local rain. The San Giorgio della Richinvelda (-8.78‰) well shows an isotopic profile similar to the Tagliamento River one with practically the same mean $\delta^{18}O$ value. However, on the base of their geographical location (see Fig. 1), the two wells of Fontanafredda (-8.49‰) and Roveredo in Piano (-8.35‰) cannot be fed by the Tagliamento River and, as already suggested by other authors (Mereu, 2000), they are probably under the influence of the more north-western mountainous area (Cansiglio Platean).

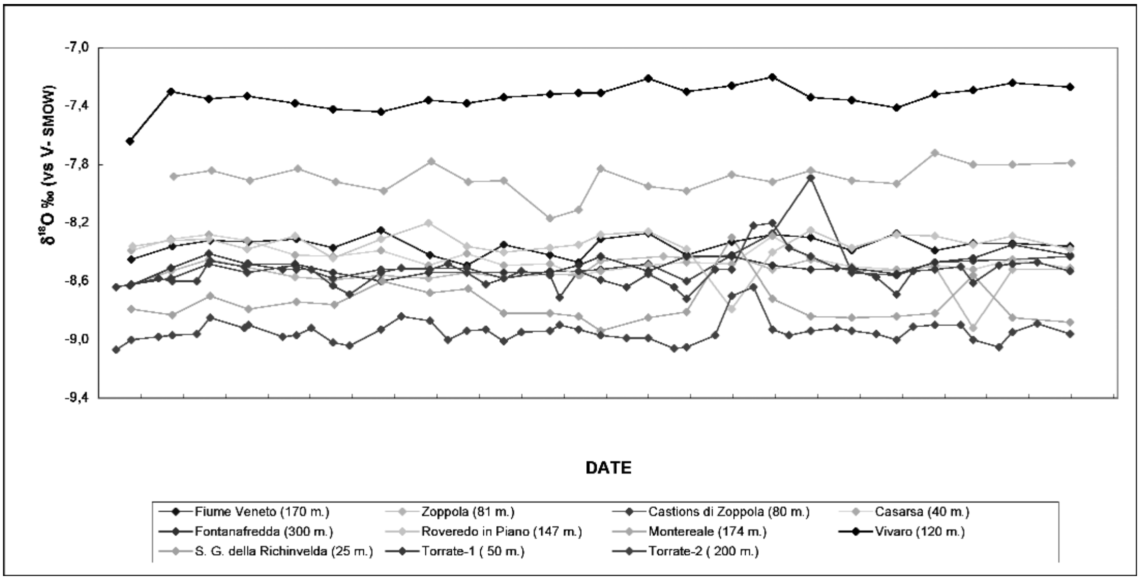

Fig. 5 - Oxygen isotopic composition of monthly samples collected at the 11 wells. The two wells situated in the main site of the Chions – Torrate locality are sampled every two weeks.

The more negative $\delta^{18}O$ value, found in the well of Chions-Torrate 2 (-8.95‰) at a depth of 200 m, may also be influenced by the Tagliamento River, but, differently to the previous group, in an area situated at a higher elevation and not affected by local rain.

4. Conclusion

The stable isotope data presented in this paper, in the framework of the EU-funded CAMI-Life project, suggest that the study area can be divided into three main sectors. A main one which is under the influence of the Tagliamento River and local rain, located in the area adjacent to the course of the river; a second one, situated in the middle part of the investigated area, on the Cellina-Meduna fan, influenced more by local conditions, and finally, a more western part under the influence of the Cansiglio platean.

This study suggests complex interconnections among aquifers, rivers and local rain and only a comparison with data collected by other partners in the same project will help disentangle this complicated hydrogeological situation. This will also allow us to define a multidisciplinary research methodology that can be applied in other hydrological contexts.

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Corresponding author: Onelio Flora
Università degli Studi di Trieste
Dipartimento di Scienze Geologiche, Ambientali e Marine
Via E. Weiss 6, 34127 Trieste, Italy
phone: +39 040 5582159, fax: +39 040 5582152; e-mail:flora@units.it