CHARACTERIZATION OF IONIAN-LUCANIAN COASTAL AQUIFER AND SEAWATER INTRUSION HAZARD

Maurizio POLEMIO, **Pier Paolo LIMONI**, **Donatella MITOLO**, **Francesca SANTALOIA**

CNR-IRPI sezione di Bari, c\o Politecnico di Bari,
Via Orabona 4, 70125 Bari, ITALY
Email: polemio@area.ba.cnr.it
Fax: +39 080 5567944

ABSTRACT

The paper deals with the seawater intrusion hazard along the Ionian coastal plain (Southern Italy), between the mouths of Sinni and Bradano Rivers. Subjected to intense agricultural activities, the good quality of the tapped groundwater is seriously important for the economic growth of this coastal area. The stratigraphical and hydrogeological set-up of the area as the geochemical features of the groundwater arise from the data analysis of 1130 boreholes, widespread over the whole area and from 1.3 up to 423 meters deep. The contribution of seawater intrusion to salinization processes of the studied groundwater system is characterised. As pointed out by chemical-physical data, this phenomenon involves the studied coastal plain for a width of 1-1.5 km on average and it is less evident moving inwards where the altitude of the clayey bottom of the aquifer becomes progressively higher than the sea level. A preliminary seawater hazard map has been carried out through piezometric and aquifer geometrical data.

INTRODUCTION

The study area is located in the southernmost part of the Lucanian region (Southern Italy), along the Ionian coastal plain, known as *Piana di Metaponto*, stretching around the middle and the lower valleys of the Sinni, Agri, Cavone, Basento and Bradano Rivers.

The geological and hydrogeological set-up of this area and the chemical-physical groundwater characterization have been inferred from both the data analysis of 1130 boreholes and the hydrogeological survey. A regards the boreholes data, coming from different public sources, stratigraphic and hydrogeological data are available for 71.9% of the wells whereas chemical-physical and geotechnical data are available respectively for 13.9 % and for 5.6 % of the all wells.

The location, the altitude, the depth and the source of each well have been so gathered in detailed database where stratigraphic, piezometric, chemical-physical groundwater data have been also reported. Moreover, historical data have been also collected for estimating the groundwater use and the exploitation of groundwater (in this case utilising long piezometric time series.

After a preliminary study on the hydrogeology of the whole area, the attention has been focused on the shallow aquifer of the coastal plain which is the most interesting for practical utilization, as highlighted by Radina (1956), and the most subjected to the seawater intrusion. The features of this aquifer, such as its lithology, its bottom referred to the sea level, its saturated and unsaturated thickness have been also investigated. The piezometric heights above sea level and the results of many pumping tests have been analysed too. Total dissolved solids, major dissolved ions, salinity, electrical conductivity, pH and temperature of the groundwater have been also assessed.

The framework of the acquired knowledge highlights the availability and the quality of Ionian-Lucanian coastal groundwater which is influenced not only by seawater intrusion but also by river waters, upward groundwater, nature and salinity of the topsoil and of the soils, irrigation water surplus and high evapotranspiration rates, all factors of the salt mass return flow (Milnes & Renard, 2002). The paper is mainly focused on the seawater intrusion and the hydrological conditions, which justify the existence of the quality degradation hazard due to this factor. The described research has been partially developed for the research project “Crystallization technologies for prevention of salt water intrusion”, founded by European Community (V Framework Programme) which activity is still in progress.

GEOLOGICAL BACKGROUND

The study area is mainly located in the southernmost part of the Bradanic trough, which is the narrow Pliocene-Pleistocene sedimentary basin, with a NW-SE trend, placed between the southern Apennines and the Apulian foreland. This through is filled by a thick Pliocene to Pleistocene sedimentary succession (up to 2-3 km) whose upper part of Late Pliocene(?)-Late Pleistocene in age, widely outcrops in Southern Italy because of the intense Quaternary uplift occurred in the area (Ciaranfi et al., 1979; Tropeano et al., 2001).

The neotectonic uplift was driven by the arrival at the subduction hinge of the thick buoyant south-adriatic continental lithosphere, which caused a lower penetration rate of the slab and a consequent buckling of the lithosphere (Doglioni et al., 1996). It occurred previously in the northern sectors of the trough and afterwards in the southernmost ones. Moreover, it was higher in the western edge than in the eastern one, producing then a regional tilting towards the Adriatic sea of the geological formations, deposited in the Bradanic trough (Ciaranfi et al., 1983; Tropeano et al., 2001; 2002).

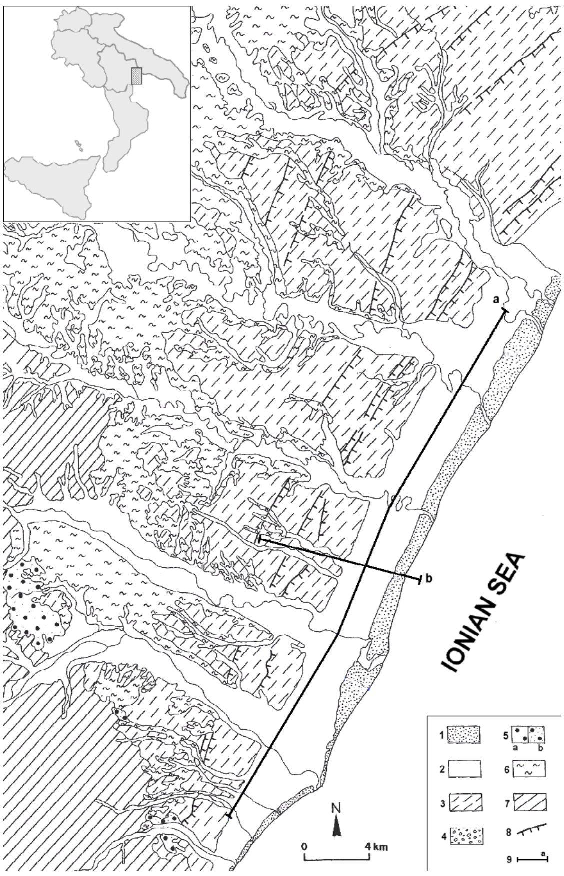

Figure 1 *Schematic geological map of the study area: 1) coastal deposits; 2) alluvial, transitional and marine deposits; 3) marine terraces; 4) Conglomerato di Irsina Formation; 5) Sabbie di Monte Marano Formation (a) and Sabbie di Tursi Formation (b); 6) Argille subappennine Formation; 7) allochthonous geological; 8) marine terraced scarps; 9) lithological sections lines.*

The progressive uplift is testified by the regressive trend of the sediments deposited in this trough since early Pleistocene which are represented by the following geological formation (Figure 1), from top to bottom: Marine Terraced Deposits (regressive deposits consisting of sands, conglomerates and silts of Middle-Upper Pleistocene in age, outcropping in the southern parts), Sabbie di Monte Marano and Conglomerato di Irsina Formations (sands and conglomerates of Early-Middle Pleistocene in age outcropping in the northernmost and central sectors) and Argille subappenine Formation (silty-clayey successions of Late Pliocene-Middle Pleistocene in age, widely outcropping).

As regards the marine terraced deposits, eight orders of terraces have been recognised on the basis of morphological features. Their ages varies from 80.000 up to 650.000 years B.P. (Brückner, 1980). The flat top surfaces of these terraces are broken off both by the river valleys and by marked morphological steps, roughly parallel to the present coastline with a fairly fanwise trend, which should represent the ancient coastlines and so the phases of sea level standing (Carobene, 1980; Parea, 1986).

Near the Apennines, thick Lower Pleistocene delta bodies are located at different depth in the Argille subappennine Formation and they represent the Sabbie di Tursi Formation (Figure 1), constituted by sands with basal clayey intercalations and by sandstones with lens of polygenic conglomerates (Pieri et al., 1996). Moreover, the allochthon, cropping out in the westernmost sector of the study area, consists of marly-clayey, sandy-clayey and marly-calcareous successions, sandstones and limestones, belonging to different geological formations connected to the Apennines.

Besides the above-mentioned geological formations, alluvial, transitional, coastal and marine deposits outcrop widely in the coastal plain, which include the mouths and the deltaic systems of the Sinni, Agri, Cavone, Basento and Bradano Rivers, rising in the Apennines. Briefly, mainly silty-clayey layers and sandy strata constitute the alluvial and marine deposits with the lower sediments of a transitional environment. The sedimentation of these deposits, thick more than 60 m, has been deeply influenced by the glacio-eustatic fluctuation and the consequent coastline changes occurred since the end of Tyrrhenian (Cotecchia and Magri, 1967; Cotecchia et al., 1971).

Finally, the Ionian littoral is defined mainly by sandy beaches, from 10 up to 100 metres wide and average value of the particle-size between 500 and 300 micron, but moving towards the Sinni area, the Ionian beaches become gravely/sandy or sandy with pebbly lens (Cocco et al., 1975). The beaches are limited inland both by marshy areas and by coastal dunes. The latter, parallel to the coast, are made up of sands, packed and weakly cemented, and they may be as high as 12 m.

LITHOLOGICAL SET-UP

The analysis of the lithological logs has allowed elaborating the lithological set-up of the upper portions of the Ionian coastal plain and of the area where the marine terraces outcrop (Figure 2).

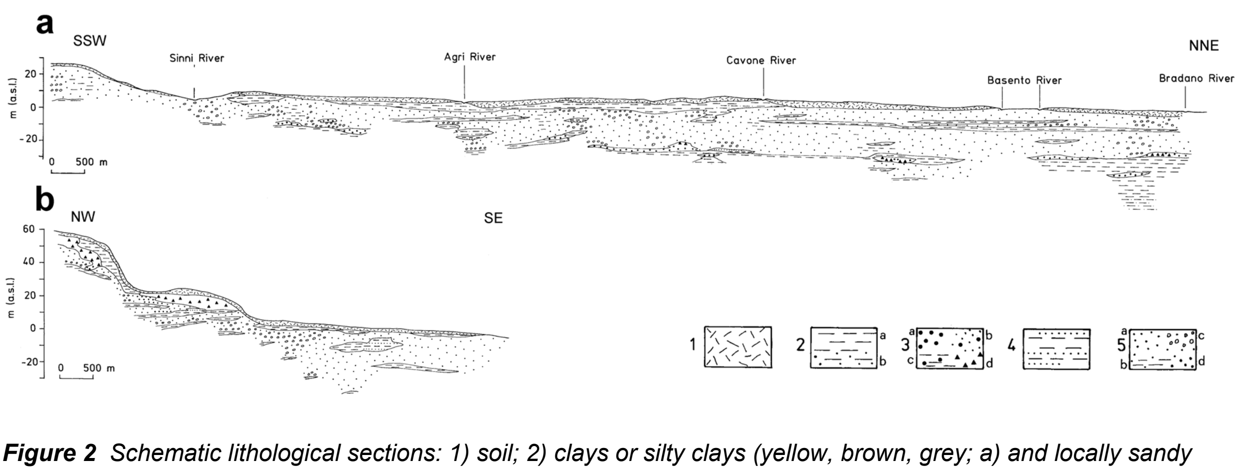

Figure 2 *Schematic lithological sections: 1) soil; 2) clays or silty clays (yellow, brown, grey; a) and locally sandy clays (b); 3) pebbles (a) in a sandy (b) or clayey matrix (c); pebbles locally cemented (d); 4) grey sands with clayey strata; 5) grey or yellow sands and silty sands (a), locally clayey sands (b) or with gravels (c), locally sandstone strata (d).*

As regards the area of the marine terraces, below the topsoil, three units have been identified (Figure 2). The upper unit is constituted by pebbles, locally cemented and dispersed mainly in a sandy matrix, and by sands and silty-clayey levels of different thickness. These lithotypes are arranged in the space in different ways and sandy, clayey or silty-clayey strata could substitute the gravelly intervals. The thickness of the pebbly intervals changes from a few metres up to around 10 metres. Below this unit, there is a sandy unit, thick up to around 40 m, and formed by fine-grained to coarse-grained sands. Different clayey and silty-clayey strata, sandstone levels and gravely lens are also widespread in this sandy unit. The thickness of these strata or levels changes from a few centimetres up to 10 m. The third unit is represented by a clayey and silty-clayey succession.

Referring to the Ionian coastal plain, below the topsoil (about 1-4 m thick), four principal units have been distinguished (Figure 2). The upper one consists of grey and/or yellow clays and exists above all, even if with a discontinuous trend, in the sector of the plain from the Cavone River towards the Sinni River, where it reaches the thickness of around 10 meters. Below the clayey unit a sandy unit is present. This unit shows an almost subhorizontal arrangement gently dipping towards NE. The maximum depth of the bottom is nearly 45-50 meters from ground level. It reaches the present-day sea level in the plain close to the coast in the Sinni sector and far from the coast in Basento and Bradano area. The bottom surface gently goes down from inland to the coast. The lithological features of this unit are rather heterogeneous with a typical arrangement of a transitional environment, where the rivers and sea interacting between themselves. Silty-clayey and clayey levels, gravely sands and locally cemented pebbly lens are widespread in this sandy unit, above all in the area lying from the Cavone River towards the Sinni River. Anastomosed by heteropic phenomena, the thickness of the levels or of the lens are deeply variable, from few centimetres up to less than 10 meters. The third unit consists essentially of grey silty-clays and clays. A few pebbly lens, locally cemented and less than 6 meters thick, are widespread mainly in the upper part of this unit and hardly ever inside it. Except for a few, the analysed boreholes have been stopped when they have reached this unit, therefore it is not possible to define accurately its thickness which changes approximately from some meters up over 30 meters. The greater thickness seems to exist in the Basento and Bradano Rivers area. Finally, the fourth unit, reached only by some boreholes, consists of grey sands, from fine-grained up to coarse-grained.

HYDROGEOLOGICAL SET-UP

The features of climatic conditions along the Ionian coastal arch do not favour the build-up of water resources. The mean annual temperature ranges between 16°C and 17°C. As regards the rainfall regime, the mean annual rainfall value varies from 535 mm up to 591 mm, besides the minimum of mean monthly rainfall occurs in July and the peak is in November. An annual water surplus of 101 mm from December to March has been calculated on a basis of a water storage capacity of topsoil equal to 100 mm, using the traditional Thorntwaite-Mather method. The climate of the area is then semiarid.

In the study area 28 springs have been recognised and their flow rate is generally low but greater than 0.1 l/s. If the spring flow rate is considered, the unique interesting springs are located along the Sinni River. These springs are connected to the river water leakage and so they have substantially disappeared as an effect of the recent dam construction upward, finished on 1975.

The hydrogeological features of the study area are directly connected to its lithological and structural set-up, previously described. Therefore, the aquifers could be distinguished in two types. The former encloses aquifers constituted by marine terraces deposits and alluvial river valleys deposits. The marine terraces aquifers show hydraulic conductivity from medium to high but their continuity across the area is regularly broken by river valleys. The aquifers of river valleys show hydraulic conductivity from low to medium and do not permit the accumulation of relevant groundwater resources, except for Sinni River, where the hydraulic conductivity becomes from medium to very high. The second type of aquifer includes that one of the coastal plain deposits. It is the most interesting for practical utilization not for its hydraulic conductivity, which is not so high, but for its extension, thickness, continuity across the plain and for its location in an area where the water demand is higher.

As regards the coastal plain, the aquifer is more or less large 40 km and long no more than 10 km (along the main groundwater flow direction, almost orthogonal to the present-day coastline). Its transversal continuity is partially reduced by the deep riverbeds of the different rivers flowing into the Ionian Sea (Polemio and Ricchetti, 1991).

The groundwater of this plain flows in a multilayered aquifer due to the lithological set up of the area, where sandy and permeable strata are confined by impermeable levels of various extension and thickness, deposited in a marine and/or transition environment. In particular, the shallow sandy aquifer stratum, coinciding with the above-mentioned sandy unit lying below the upper clayey unit, is generally the only one exploited for any kind of hydrogeological practical utilization. The particle-size distribution in this sandy aquifer is extremely variable, as a matter of fact the gravel fraction is in the range 0÷11%, the sand fraction changes from 0 up to 96 % with a mean value of 48%, the silt fraction is in the range 4 ÷99%, with a mean value equal to 38% and finally the clay fraction varies from 0 up to 55%, with a mean value of 14%. Moreover, the sand fraction is higher for the samples collected in the coastal plain extended between the Cavone and Basento Rivers.

Neglecting silty or clayey levels, the total thickness of the effective pervious strata of the aquifer is generally higher than 10 m and it increases moving from inland to the coast with some exceptions, as in the sector between the Agri and Cavone River.

Coinciding with the sandy unit's bottom, the bottom of this aquifer is below the sea level near the coast (Figure 3), allowing so the occurrence of seawater intrusion. The gradient of this bottom surface is not null: the bottom altitude decreases gently from the Sinni to the Bradano River, from SW to NE. As a consequence, the seawater intrusion is progressively more favoured moving along the coast in the northeastern direction. Following the trend of the sandy unit's bottom, the width of the strip where the aquifer bottom altitude is below the sea level increases then from the SW to the NE sector, changing from 4 to 8 km. Moreover, considering the aquifer sections orthogonal to the coastal line and so about parallel to main groundwater flow lines (Figure 4), the bottom altitude generally decreases moving from inland to the coast. The trend of this drop is not everywhere regular: in a wide portion of the coastal aquifer, a huge drop of the bottom exists creating so a sinking, parallel to the coast, not easily recognisable in Figure 3 due to the small scale of the map.

The coastal aquifer does not outcrop everywhere due the widespread presence of the upper almost impervious stratum, constituted by silty-clays with a thickness of 3 up to 10 m. In particular, where this stratum exists the aquifer is confined otherwise it becomes unconfined. The latter type usually is more present nearby the coast and also in some areas around the Basento River.

This aquifer is then bounded downward (SE) by Ionian Sea and it passes upward (NW) to the aquifers belonging to the marine terraces or to the alluvial deposits of river valleys. The groundwater in the marine terraces is not confined everywhere, due to the not homogeneous distribution of the low hydraulic conductivity strata or levels existing in these deposits.

A recharge boundary between the coastal and the upper aquifers is not everywhere well defined. It becomes a discharge limit mostly near Policoro villages, where some springs are located at the foot of the slope, by the contact between the pebbly unit and the lower clayey strata, both of them belonging to the marine terraces.

Being the first 3 up to 10 m of soil characterised by a low hydraulic conductivity, the recharge of the shallow aquifer is mainly guaranteed by the discharge from the upward aquifers of the marine terraces and from the river leakage. As a matter of fact, as shown in Figure 2, the riverbeds are deep enough to cut outcropping soils of low hydraulic conductivity, where they exist. The existence and the relevance of a recharge effect due to upward groundwater are confirmed by the spatial trend of the piezometric contour lines (Figure 4). They are quite straight and almost parallel to the coastline and to boundary between the upper marine terraces and the coastal plain, where this boundary is crossed.

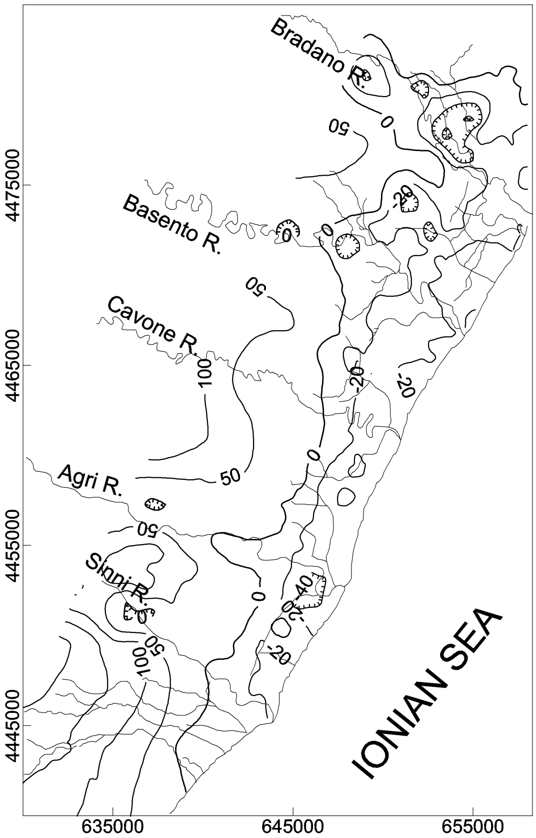

Figure 3 *Approximate trend of sandy unit's bottom (m a.s.l.).*

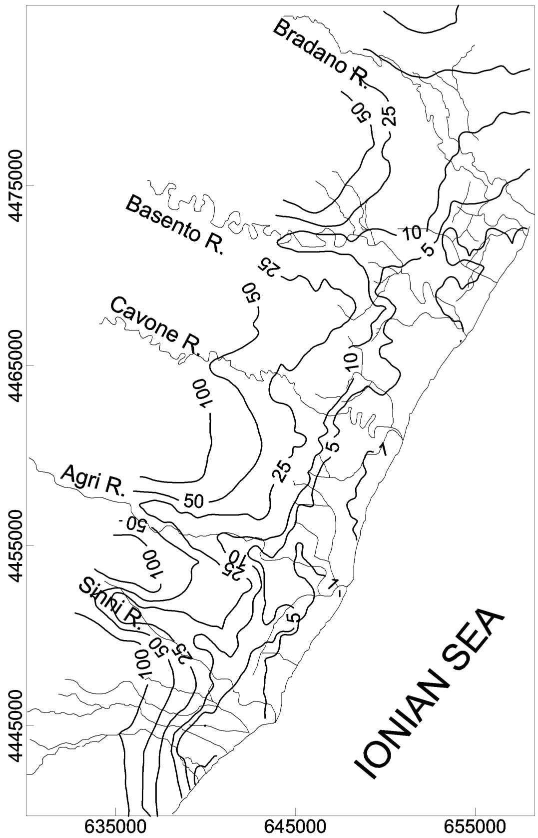

Figure 4 *Piezometric map (m a.s.l.)*

Moreover, the piezometric surfaces are also clearly influenced by the river paths upward: this effect is particularly evident for the Basento and the Agri Rivers (Figure 4). In any case, as for the Sinni River, the downward concavity of the piezometric contour lines is not exactly superimposed on the present riverbed but it could be correlated to the buried riverbed. The drainage effect of the rivers on the river valley aquifers (Figure 4) gradually decreases, ceases or is inverted in the area where the rivers start to flow in the coastal plain. According to the point considered, the altimetric relation existing between the river water height and the piezometric height changes but it can be also influenced by the river flow stage, characterised by a high seasonal effect.

The minimum hydraulic conductivity value of the study coastal aquifer, obtained by the analysis of different wells, is equal to 3.47*10-6 m/s which is due to a well yield equal to 0.8 l/s as a drawdown effect of 25.9 m. On the contrary, the mean value is equal to 2.28*10-4 m/s and the median one is 6.53*10-5 m/s. The maximum value of the hydraulic conductivity is equal to 5.69*10-3 m/s, connected to a well yield equal to 2.3 l/s as a drawdown effect of 0.2 m. The hydraulic conductivity decreases not regularly moving both from inland to the coastline. The decrease of this parameter does not seem to be enough considerable to the effect of seawater intrusion hazard reduction.

CHEMICAL-PHYSICAL FEATURES OF THE GROUNDWATER

As regards the chemical and physical characterization of the groundwater, data have been inferred from laboratory analyses performed on different groundwater samples: n. 47 tapped by marine terraced deposits and n. 162 by alluvial and coastal deposits. All these samples have been taken from 158 wells uniformly distributed within the study area. A statistical summary of main chemical-physical parameters is reported on Table 1.

	Statistics	A	B	C	D	E	F	G	H	I	L	M
Terraced marine deposits	min	16,0	6,7	271	348	20	0,3	0,5	0,3	0,2	0,2	0,2
	max	22,0	8,6	2310	4000	805	20,6	7,3	3,2	3,3	2,5	4,3
	average	19,3	7,2	868	1333	167	2,4	2,9	1,1	1,0	1,0	0,9
Alluvial deposits	min	16,3	2,9	179	211	17	0,4	0,2	0,1	0,2	0,2	0,2
	max	22,3	8,8	3410	9031	2645	59,7	21,7	32,7	4,9	11,2	8,0
	average	19,3	7,6	940	1786	268	4,2	2,0	1,4	1,1	1,2	1,2
Coastal deposits	min	19,0	6,8	261	446	30	0,8	0,5	0,1	0,5	0,4	0,3
	max	20,2	8,3	1487	15052	3000	12,7	6,0	3,7	2,2	2,4	6,6
	average	19,5	7,7	805	3190	661	3,8	2,4	1,2	1,1	0,9	1,6

Table 1 *Statistical outline, listing the minimum, the maximum and the mean values of each chemical parameter and the classification according to the outcropping lithotype. Legend: A) T (°C); B) pH; C) TDS at 110°C (mg/l); D) Groundwater Electrical Conductivity at 25°C (μS/cm); E) Cl^- (mg/l); chemical characteristic as epm ratio F) Na^+/Ca^{++}; G) Ca^{++}/Mg^{++}; H) Ca^{++}/SO_4^{2-}; I) SO_4^{2-}/Cl^-; L) Na^+/Cl^-; M) $(Na^+ + K^+ + Cl^- + SO_4^{2-})/(Ca^{2+} + Mg^+ + HCO_3^-)$.*

The groundwater temperature ranges between 12 °C and 20 °C and it increases towards the coastline. In detail, the changes of this parameter seems to depend on the gradual increase in temperature from the recharge areas, which are located inland where the terraced marine deposits collect rainfall, to the receiving areas such as the springs, the mouth of the rivers and the sea.

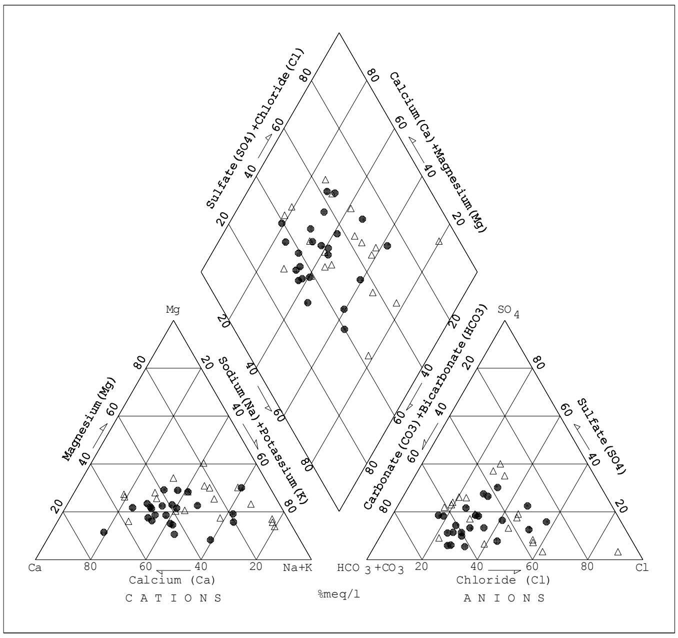

Figure 5 *Piper diagram. Legend: •) groundwater sample of terraced marine aquifer; ∆) groundwater sample of the coastal aquifer.*

The concentrations of the major ions are plotted in the Piper diagram (Figure 5), which shows an extremely high dispersion of the groundwater samples, with no clear-cut types nor traces of a marked mix of two or more types of water. Notwithstanding this, two dominant types of groundwater can be distinguished: the bicarbonate-alkaline-earthy type and the sulphate-chlorinate-alkaline type. The former is mainly typical of groundwater flowing in the marine terraces and in the alluvial deposits while the latter is characteristic for the samples taken in the coastal plain deposits (Figure 6). Another the bicarbonate-alkaline type and the sulphate-chlorinate-alkaline-earthy type is less frequent except for the area surrounding the Basento River. This type could be partially justified by to pollution phenomena detected in this area (Figure 6). The last type, the bicarbonate-alkaline type, is not statistically relevant.

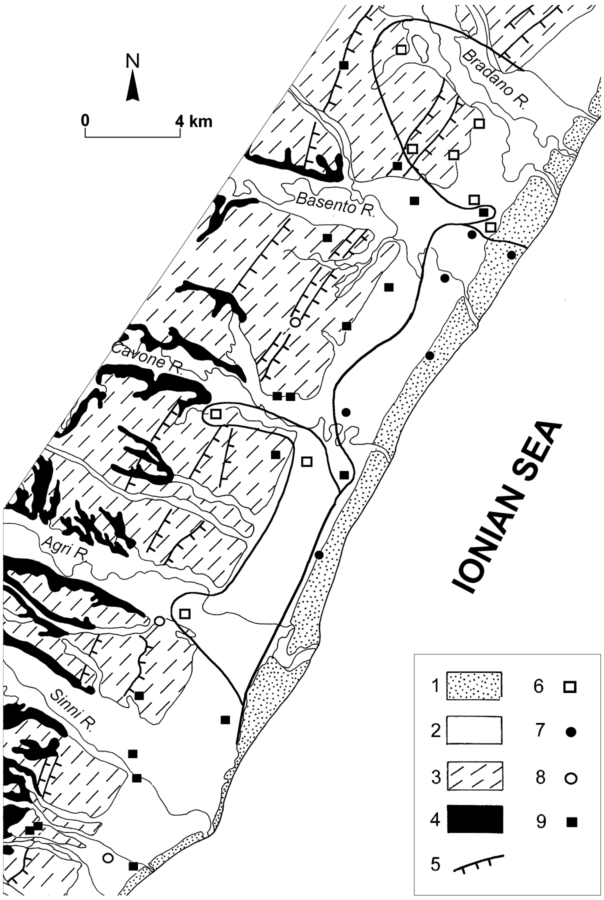

Figure 6 *Schematic geological map of the study area and chemical types of groundwater: 1) coastal deposits; 2) alluvial, transitional and marine deposits; 3) marine terraces; 4) Argille subappennine Formation; 5) marine terraced scarps; 6) sulphate-chlorinate-alkaline-earthy type; 7) sulphate-chlorinate-alkaline type; 8) bicarbonate-alkaline type; 9) bicarbonate-alkaline-earthy type.*

The wide concentration ranges of the major ions (Table 1) could not be simply explained as an effect of the different sources of public data, as the ranges remain substantially constant if a single source is considered. The reasons of this high variability should be related to some other factors, which are briefly summarised in the following.

First of all, the conditions, which have characterised both the depositional environment of the various geological units and the lithogenetic processes, should have influenced the geochemical composition of the different lithotypes constituting the aquifers. The different lithological distribution could have also influenced this high variability, for example the clayey interbeds are common in each aquifer but in marine terraces aquifer are more widespread and frequent so in this unit the ion exchange phenomena have been more active. At same time, the physical-chemical features of groundwater should have been affected by the grain size, which is not homogenous through each aquifer.

The electrical conductivity of groundwater and the salinity is not everywhere low. The marine and transitional origin of sediments, so the existence of a syngenetic salinity of soils should not to explain alone the high value of these parameters, also if groundwater flow is extremely lows somewhere.

Anthropic factors could be also inferred for explaining the high variability of the ion concentration. The first one is connected to the widespread irrational irrigation procedures and to the consequent water irrigation surplus. As a matter of fact, in the study area, characterised by a semiarid climate, this factor becomes important because of the high rate of potential evapotranspiration, equal to 860 mm as mean annual value (161 % as percentage of mean annual rainfall). The irrigation water is supplied by dams, built in the inner sectors of the main river basins (except of Cavone River) from the sixties. Before using aqueducts, supplied by dams, the irrigation water was tapped by wells and nowadays the same happens during the drought periods when the artificial lakes are substantially empty (as it is happening at the moment). In both cases, an increasing load of salt mass is added to the fresh groundwater system. During intensive groundwater exploitation, the irrigation acts distributing salt mass related, at least as a part, to seawater intrusion. This phenomenon is well known for semiarid areas, as described by many authors, as Milnes & Renard (2002). Other anthropic factors are related both to the mixing with polluted river water and to the increase of chemical products in agricultural activities (Polemio et al., 2002).

The above-mentioned high variability could be also related to the extreme low drainage capacity of the coastal plain, which is subjected to frequent and wide seasonal pounding due to river flooding. The evaporation of the pounded waters can be then another source of salts, added to the system as pointed out by Lopez et al. (1986). This situation is abruptly changed from the sixties, when reclamation works strongly reduced this problem.

The direct effect of seawater intrusion should be so inferred considering the whole effect of the hydrologic cycle, also due to anthropic contribution, and of soils-waters interactions.

SEAWATER INTRUSION EFFECT ON GROUNDWATER QUALITY AND DEGRADATION HAZARD

Owing to the occurrence of many years of drought and to the increase of agricultural activities, the seawater intrusion hazard for Ionian-Lucanian coastal groundwater has become a real problem for the social and economic development of this area.

The analysis of the concentration maps of some ions, abundant in seawater (potassium, sodium, sulphates and chlorine), has delineated the spatial trend of the area subjected to a seawater intrusion hazard, which seems to involve a strip of land close to the coastline.

The spatial distribution of the total dissolved solids (TDS), the groundwater electrical conductivity and the concentration of chlorides, all parameters particularly sensitive to seawater intrusion, have been sorted out. In particular, the highest concentrations of TDS, exceeding 1,000 mg/l, occur near the coast and along the Bradano, Basento and Cavone Rivers, with a few and poorly significant exceptions. This trend confirms the close relationship existing between the rivers and the groundwater system. The riverbeds, which overlie alluvial and coastal deposits during low water, might favour seawater intrusion as their elevation is below or close to that of the sea level. This phenomenon is particularly important when low river discharges, low atmospheric pressure, sea storm and winds of the second or third quadrant take place at the same time. Then, water progressively flows back to the aquifer. This recurring and frequent phenomenon gives likely rise to a salt build-up in some localised and depressed areas that lie significantly far from the coast. As regards to the electrical conductivity of groundwater and the chloride content, it is important to point out that the analysis is partly influenced by the inhomogeneous data distribution, as a matter of fact the data are more present in the coastal sectors of Bradano and Basento River. Notwithstanding this, it is possible to highlight an increase of the electrical conductivity (Figure 7), from 1,000 to 6,000 μS/cm, in a strip of land close to the coastline, reaching a peak value in the alluvial plain, especially around the Basento River. This spatial trend is confirmed by the chloride distribution (Figure 8), which reaches its peak values nearby the Basento River.

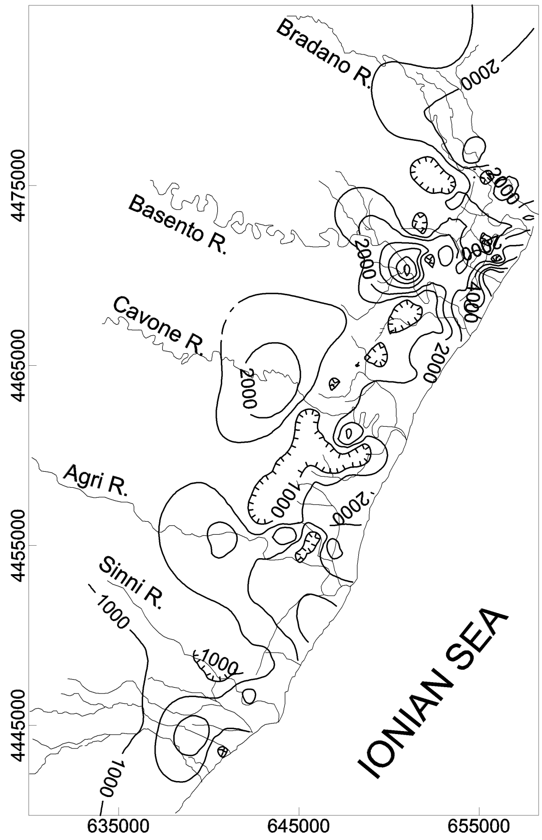

Figure 7 *Map of groundwater electrical conductivity (μS/cm at 25 °C)*

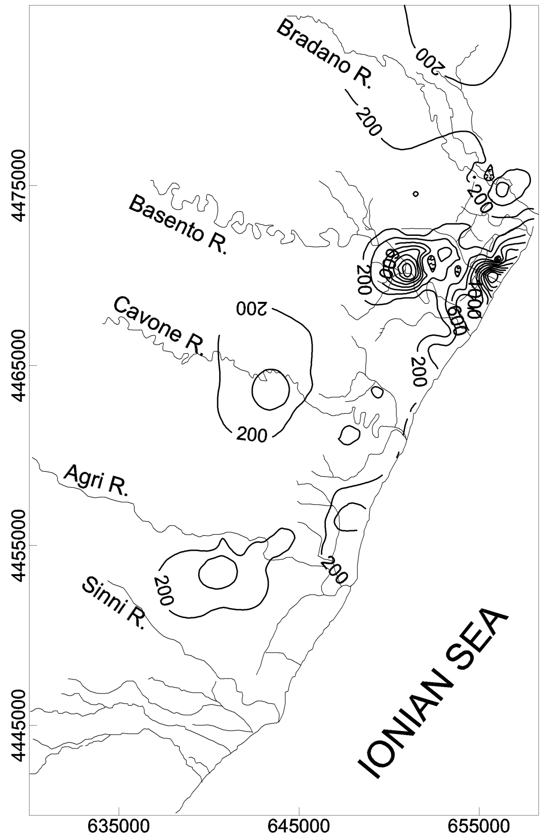

Figure 8 *Map of concentration of chlorides (mg/l).*

The combined analysis of the above-mentioned maps shows that the seawater intrusion hazard involves a coastal strip up to 2.5 km inland, with an average width equal to 1-1.5 km. The coastal areas with greater effects lie then between the Basento and Agri Rivers and probably on the right side of the Sinni River.

Moreover, some areas far from the coast, well beyond the coastal strip and generally near the rivers, have shown high values of the three above-mentioned parameters that could be connected to different factors. For instance, these high concentrations might be due to previously intruded seawater or to seawater intruded through riverbeds which has remained trapped owing to the geometry of the aquifer or to the morphological changes or shifting of the river mouths, occurred in the past. With regard to this, for example near the coastline, the Basento and Bradano Rivers appear to be slightly diverted toward the south-west, probably due either to a tectonic tilting (Guerricchio and Melidoro, 1986) or to the marine currents parallel to the coast and to the wave-motions (Boenzi et al., 1976).

In addition, as the shallowest portion of the aquifer close to the coast is below the sea level and many riverbeds are deeply incised close to the mouth, the river network could represent a seasonal way for the inland intrusion of the seawater.

Another contribution is due to the water infiltration (natural or not, if due to irrigation surplus) is most likely to dissolve by leaching and carry away the salts which have built up in the soil and in the unsaturated zone, as suggested by Lopez et al. (1986). Besides, the presence of clayey interbeds in localised zones, where the groundwater flow velocity is scarce or quite null, could affect higher salt content.

Finally, the river contamination is able to modify the concentration of the above mentioned groundwater parameters, as in the Basento River area.

The role played by seawater intrusion and the exchanges occurring between the rivers and the groundwater system have been extensively confirmed by the values calculated for the most significant characteristic ratios, such as Na^+/Ca^{2+}, Mg^{2+}/Ca^{2+}, SO_4^{2-}/Cl^-, Na^+/Cl^-, $(Na^++K^++Cl^-+SO_4^{2-})/(Ca^{2+}+Mg^{2+}+HCO_3^-)$.

In particular, given the type of water and rocks belonging to the aquifers, the Na^+/Ca^{2+} ratio generally exceeds the unit, however it increases significantly closeness to the coast suggesting so a severe contamination with sodium-rich seawater. This phenomenon is particularly remarkable in the area between the Basento River and the Agri River.

The values of theMg^{2+}/Ca^{2+} ratio range between 0.5 and 3; the highest ones are reported along the coastal strip. Even the SO_4^{2-}/Cl^- and Na^+/Cl^- ratios show a spatial trend similar to that one of the above-mentioned ratios. Last but not least, the values of $(Na^++K^++Cl^-+SO_4^{2-})/(Ca^{2+}+Mg^{2+}+HCO_3^-)$ ratio (Cotecchia & Magri, 1966), exceeding the unit, suggests the existence of seawater intrusion along a strip of land, stretching for 2.5-3 km from the coast to the alluvial plain (Figure 9).

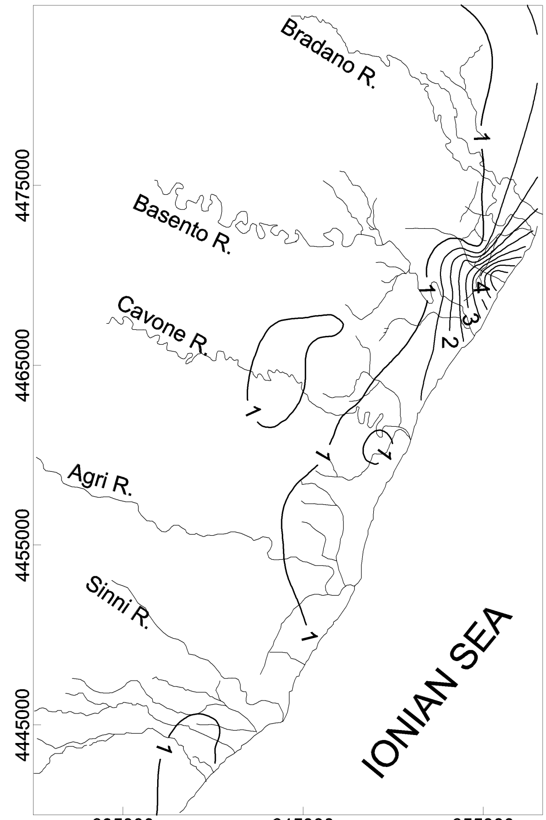

Figure 9 *Map of characteristic ratio ($Na^+ + K^+ + Cl^- + SO_4^{2-})/(Ca^{2+} + Mg^+ + HCO_3^-$) (as epm ratio).*

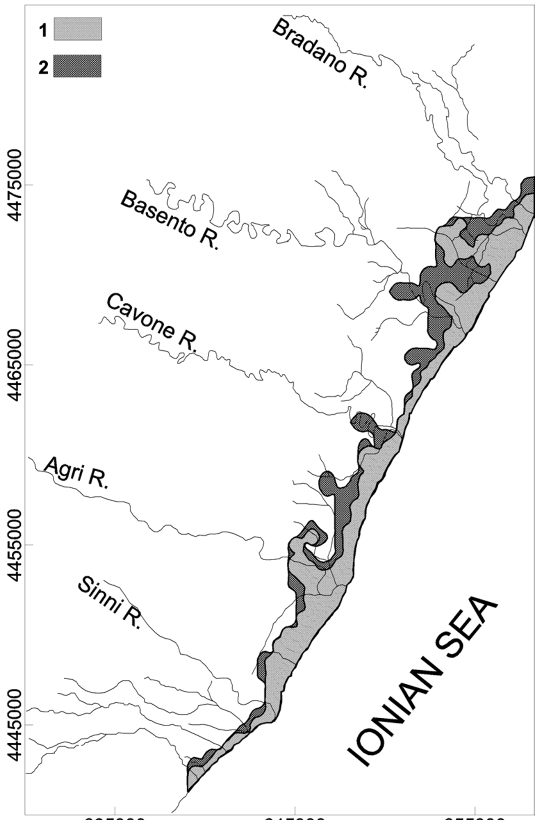

Figure 10 *Evaluation of seawater intrusion hazard based on Ghyben-Herzberg approach. 1) Principal Hazard Area (PHA); 2) Secondary Hazard Area (SHA).*

In the light of the spatial trends of the analysed ratio, it is possible to confirm that the effects of seawater intrusion are reasonable more evident along the coastline, as highlighted by previous studies, such as those carried out in the study area (Radina, 1956) and in the portion of the coastal aquifer between the Bradano and Cavone Rivers (Polemio and Mitolo, 1999). Besides, the width of the coastal strip, where the effects of seawater intrusion on groundwater quality are more evident, increases moving from the Sinni area to the Bradano one. In particular, the wideness is equal to 1÷1.5 km in the coastal area between the Sinni River and right bank of Cavone River, while it is about 5 km around the Basento River and in the coastal sector lying at the right bank of Bradano River (Figure 10).

A quantitative evaluation of the seawater intrusion hazard has been also drawn on the basis of Ghyben-Herzberg approach. The altitude of the sharp interface has been determined on the basis of a density factor equal to 37 on the basis of the piezometric map (Figure 4). Applying GIS methodologies, the sharp interface altitude has been evaluated for a squared grid 400 m wide and compared with the aquifer bottom altitude. The nodes in which the sharp interface is higher than the aquifer bottom should be considered as aquifer point exposed to seawater intrusion hazard. This assumption is base on the circumstance that in this area wells are generally drilled up to the aquifer bottom, without considering the seawater intrusion hazard of groundwater quality degradation. From this point of view, this hazard increases if the difference between the sharp interface and the aquifer bottom altitudes increases.

The area in which this condition occurs identifies the *Principal Hazard Area* (PHA) plotted in Figure 10. Moreover, in order to simulate an overexploitation of the groundwater resources, the same procedure has been applied considering a homogenous drawdown of the piezometric surface equal to 1 m. This drawdown has caused an enlargement of the area subjected to seawater intrusion (*Hazard Area for Overexploitation;* HAO). In Figure 10, a *Secondary Hazard Area* (SHA) is reported and it rises from the subtraction from the HAO of PHA.

Finally, comparing the latest results, determined only considering the piezometric surface and the surface of aquifer bottom, with the spatial trends of the considered chemical-physical parameters, a good overlapping occurs, in spite of simple nature of Ghyben-Herzberg approach.

Each parameter analysed confirms then the nature of effects and the role of seawater intrusion on quality degradation of coastal groundwater of Ionian-Lucanian plain; at same time, the good relation existing between detected groundwater quality and preliminary hazard evaluation map bears out this map as a first tool for starting a careful management of these water resources.

CONCLUSION

Hydrogeological aquifer features and main characteristics of groundwater flow have been carried out for a wide coastal area lying in the Southern Italy, subjected to a semiarid climate and dramatically degraded by drought at the present time.

The results obtained by the analysis of the hydrogeological, chemical and physical data coming from all the boreholes collected in the area have suggested the existence of quality degradation risks for groundwater of the coastal plain due to the seawater intrusion. The width of the coastal strip, subjected to a highest seawater intrusion effect, seems to increase moving in the NE direction, so from about 1÷1.5 km, between the Sinni River and the right bank of Cavone River, up to about 5 km, in the coastal sector around the Basento riverbed and in the area to the right Bradano River.

A preliminary hazard evaluation map of the seawater intrusion effects on groundwater quality has been proposed.

REFERENCES

Boenzi F., Palmentola G. & Valduga A. 1976. Caratteri geomorfologici dell'area del Foglio "Matera". *Bollettino Società Geologica Italiana*, 95, 527-566.

Brückner H. 1980. Marine Terrassen in Süditalien, Eine quartärmorphologishe Studie über das Küstentiefland von Metapont. *Düsseldorfer Geographische Schriften*, 14, 1-235.

Carobene L. 1980. Terrazzi marini, eustatismo e tettonica*. Geografia Fisica e Dinamica Quaternaria*, 3, 35-41.

Ciaranfi N., Ghisetti F., Guida M., Iaccarino G., Lambiase S., Pieri P., Rapisardi L., Ricchetti G., Torre M., Tortorici L, & Vezzani L. 1983. Carta Neotettonica dell'Italia meridionale*. Progetto Finalizzato Geodinamica del CNR*, 515.

Ciaranfi N., Maggiore M, Pieri P., Rapisardi L., Ricchetti G., & Walsh N. 1979. Considerazioni sulla neotettonica della Fossa bradanica. *Progetto Finalizzato Geodinamica del CNR*, 251, 73-95.

Cocco E., Cravero E., Di Geronimo S., Mezzadri G., Parea G. C., Pescatore T., Valloni R., & Vinci A. 1975. Lineamenti geomorfologici e sedimentologici del litorale alto ionico (Golfo di Taranto*). Bollettino Società Geologica Italiana*, 94, 993-1051.

Cotecchia V. & Magri G. 1966. Idrogeologia del Gargano. *Geologia Applicata e Idrogeologia*, 1, 1-86.

Cotecchia V. & Magri G. 1967. Gli spostamenti delle linee di costa quaternarie del Mar Ionio fra Capo Spulico e Taranto. *Geologia Applicata e Idrogeologia*, 2, 3-28.

Cotecchia V., Dai Pra G. & Magri G. 1971. Morfogenesi litorale olocenica tra Capo Spulico e Taranto nella prospettiva della protezione costiera. *Geologia Applicata e Idrogeologia*, 6, 65-78.

Doglioni C., Tropeano M., Mongelli F, & Pieri P. 1996. Middle-Late Pleistocene uplift of Puglia: an “anomaly” in the Apenninic foreland. *Memorie Società Geologica Italiana*, 52, 457-468.

Guerricchio A. & Melidoro G. 1986. Problematiche di geologia applicata lungo la fascia costiera ionica del golfo di Taranto. *ENEA, Convegno "Ricerche Energia della Trisaia", Evoluzione dei Litorali, Problematiche relative al golfo di Taranto*, Rotondella, Policoro-Matera, 3-29.

Lopez G., Ascione S.& Marrone G. 1986. Caratteri fisico - chimici dei suoli e delle acque di falda di un ambiente del litorale ionico lucano. *Annali Istituto Sperimentale Agronomico*, 17, 49-65.

Milnes E., Renard P. (2002). Assessment of seawater intrusion vs. mass return flow from irrigation in the Kiti coastal aquifer system (Southern Cyprus) based on filed investigations and three-dimensional finite element simualtions. Prociding 17th SWIM, Delfth, May 2002.

Parea G. C. 1986. I terrazzi marini tardo-pleistocenici del fronte della catena appenninica in relazione alla geologia dell’avanfossa adriatica. *Memorie Società Geologica Italiana*, 35, 913-936.

Pieri P., Sabato L. & Tropeano M. 1996. Significato geodinamico dei caratteri deposizionali e strutturali della Fossa Bradanica nel Pleistocene. *Memorie Società Geologica Italiana*, 51, 501-515.

Polemio M. & Mitolo D. 1999. La vulnerabilità dell’acquifero della piana costiera di Metaponto. In: Proc. “Il rischio idrogeologico e la difesa del suolo”, Accademia Nazionale dei Lincei, 423-428.

Polemio M. & Ricchetti E. 1991. Caratteri idrogeologici dell'acquifero della piana costiera di Metaponto (Basilicata). *Ricerca Scientifica e Istruzione Permanente*, 93, 417-426.

Polemio M., P.P.Limoni, D. Mitolo. & F. Santaloia. 2002. Nitrate content characterization of ionian coastal groundwater. Proc. of IAH Eurometing, Nitrate in Groundwaters in Europe, Wisła, 4-7 of June 2002.

Radina B. 1956. Alcune considerazioni geoidrologiche sulla fascia costiera jonica compresa fra i fiumi Bradano e Sinni. *Geotecnica*, 1, 3-11.

Tropeano M., Sabato L, & Pieri P. 2001. The Quaternary “Post-turbidite” sedimentation in the South-Apennines Foredeep (Bradanic Trough-Southern Italy). *Bollettino Società Geologica Italiana*, in press.

Tropeano M., Sabato L, & Pieri P. 2002. Filling and cannibalization of a foredeep: the Bradanic Trough, southern Italy. In: Jones S.J. & Frostick L.E. (eds) Sediment Flux to Basins: Causes, Controls and Consequences, Vol. 191, Geological Society of London, Special Pubblications, London, 55-79