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WATER RESOURCES MANAGEMENT IN A VULNERABLE ENVIRONMENT FOR SUSTAINABLE DEVELOPMENT

Degradation Risk Owing to Contamination and Overdraft for Apulian Groundwater Resources (Southern Italy)

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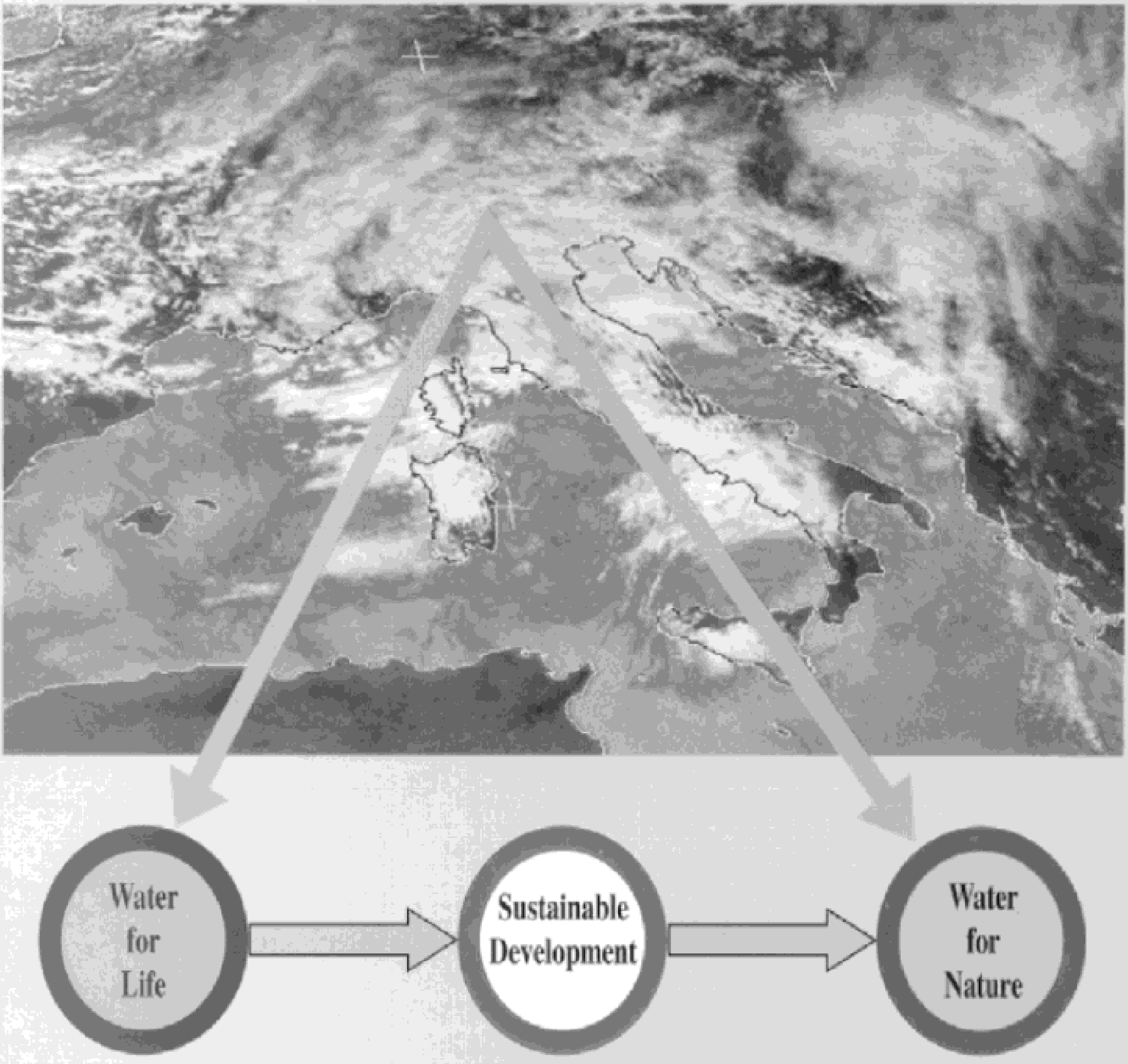

Degradation Risk Owing to Contamination and Overdraft for Apulian Groundwater Resources (Southern Italy)

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Abstract.

The remarkable and rapid socio-economic development over the past few decades has further stressed the Apulian hydrogeological system. The whole Apulian groundwater has undergone a twofold pollution, all originated by human action: saline pollution evolves progressively as it affects increasingly large portions of land; biological and chemico-physical pollution is gaining importance and is mainly concentrated around urbanised areas. The latter is due to the circumstance that the aquifers are increasingly bound to become a kind of ultimate "receptacle" for domestic and industrial waste waters. In order to characterise the features of human-related pollution, data was gathered by a monitoring network-encompassing 157 wells, some of which hundred meters deep, and 19 coastal springs. Periodical water samples were taken from the network to be submitted to chemical, physical and bacteriological analyses. The effects of human activity on groundwater pollution and depletion are so characterised.

1. Introduction

The rapid socio-economic growth, which has occurred in the past decades, has continued to stress the Apulian hydrogeological system in Southern Italy, thereby leading to different hazardous conditions. Groundwater for domestic, irrigation and industrial use has been withdrawn in large quantities over the years. The aquifers are increasingly becoming the ultimate "receptacle" for wastewater. Apulia is affected by two types of human-related pollution: salt contamination, which is spreading over large portions of land thus reducing the availability of good quality water (Cotecchia, 1981; Cotecchia & Tadolini, 1993; Cotecchia et al., 1981; Fidelibus & Tulipano, 1996), and chemico-physical and biological pollution, which is mainly confined to urban areas (Cotecchia & Polemio, 1998). In several areas groundwater salt contamination has reached such a level that many of the wells have been abandoned.

In Apulia there are four Hydrogeological Units (hereinafter HU, for brevity's sake). They exhibit varying geological, structural and morphological features (Figure 1). Apart from Puglia Tableland (hereinafter called *Tavoliere*), the remaining HU share some common features (Cotecchia & Magri, 1966; Ippolito et al., 1958; Cotecchia, 1977; Grassi, 1983; Zezza, 1975). They consist of large and deep carbonate aquifers (of Jurassic-Oligocene and mainly Mesozoic age), the predominant rock material of which is either limestone or limestone-dolomite. Aquifers are affected by karst and fracturing phenomena, also well below the sea level, whereas intruded seawater underlies fresh groundwater owing to a difference in density. In both the Gargano

Promontory (*Gargano*) and the low Murge Plateau (*Murgia*) aquifers are under pressure except on a restricted coastline strip. In the Salentine Peninsula (*Salento*), subsurface water flow under phreatic conditions is prevailing. The Salentine HU is the only unit which is lapped by the sea on both sides.

Max. piezometric heads are about 50 m asl in the Gargano, 200 m asl in the Murgia and 5 m asl in the Salento (Spizzico & Tadolini, 1997). Tavoliere HU consists of a large porous aquifer (Pleistocene-Holocene) within a conglomerate sandy-silty succession, less than sixty meters deep with a clayey impermeable bottom. Only in the vicinity of the coast is the aquifer deep enough to allow seawater intrusion. Groundwater flows under phreatic conditions in the most internal and upstream portion of the HU, whereas it flows under pressure in the remaining part of the unit; max. piezometric levels reach 300 m asl.

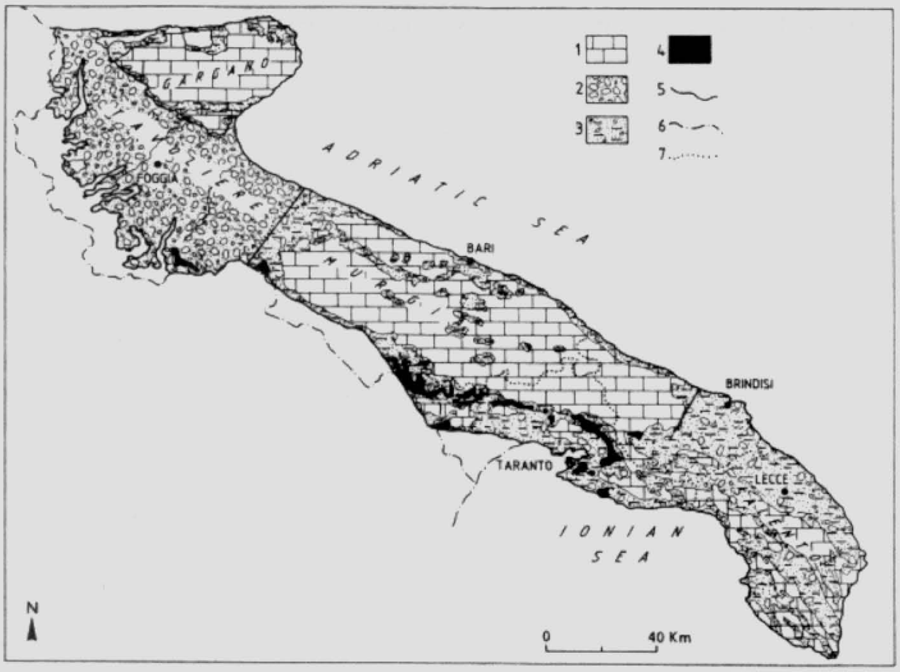

Figure 1 - Apulian hydrogeological units. 1) Carbonate rock outcrops of Gargano, Murgia and Salento (Salento) units; 2) Tavoliere unit, mainly conglomerate and sands; 3) shallow aquifers and permeable lithotypes, calcarenites, clayey sands, sands, gravel, or conglomerates; 4) low permeable lithotypes, blue marly clays; 5) hydrogeological unit boundary, dashed where uncertain; 6) regional boundary; 7) provincial boundary.

Along the borders between the Tavoliere and the Gargano or the Murgia, the sinking of the carbonate platform, which makes up these two last HU, is observed. A deep succession of clays, marly clays, sandstones and sands of Plio-Pleistocene age underlies the Tableland HU. NW-SE oriented oblong aquifers are predominantly reported in the sandy layers of this succession (Balduzzi et al., 1982). Groundwater flowing in these "intermediate" aquifers is generally of artesian nature and is subjected to high pressure due to the confining action of the clayey layers (Cotecchia et al., 1995). This succession overlies a third deep carbonate aquifer which is a sunken carbonate platform. Inland, the Tableland border corresponds to outcropping impermeable clayey formations.

The hydrogeological units are bounded by the coastline and by Pliocene or more recent tectonic lines (faults) (Ambrosetti et al., 1983). The borders are occasionally clear cut, as those between the Gargano and the Tavoliere and between the latter and the Murgia. The border between the Murge and the Salentine HU is unclear. A gradual shift from the typical Murge high depth to groundwater and low and mildly variable permeability to the Salentine varying types of water flows, permeability and depth can be observed. A number of surface, calcarenite and/or sandy aquifers some ten meters deep partially overlie the carbonate HU. Salt contamination of the Apulian groundwater - which flows within HU and overlies intruded seawater - is a well-known and thoroughly investigated phenomenon (Cotecchia, 1977). Nowadays, a strong connection between the increase in salt contamination and the lowering of piezometric levels, which can be ascribed to groundwater overdraft and/or a natural decrease in groundwater recharge, has been recognised in coastal aquifers.

Despite the massive import of water, the Apulian groundwater supply hardly meets 20% of the local demand for drinking water. Furthermore, groundwater is often the only resource available for diffuse water-demanding production processes in the area (Cotecchia & Polemio, 1998). Apulian groundwater contamination results mainly from the misuse of soil and subsoil, which have increasingly become the ultimate receptacles for waste products originated by human activities, and from the unbalance between the contaminants reported in the area and the cleaning capacity of the existing purifying plants. There is also evidence that most contamination remnants in the soil and subsoil due to incomplete purification are bound to contribute waste to groundwater as a result of the local hydrogeological properties. To add to the problem is the absence of major water streams, which has made underground disposal of sewage a common practice. The offshore diversion of waste water through submarine pipes to enough distant areas as to ensure fast dilution abatement is not always feasible owing to the high costs of this solution. Groundwater quality is also threatened by landfills and dumps, urban wastes being disposed until very recently in a chaotic and uncontrolled manner in abandoned caves.

2. Groundwater Resource Quality

The results of 700 laboratory analyses, carried out on samples taken from 19 coastal springs and 157 wells, about 110 wells of which are stations of the Apulian groundwater monitoring network, managed by the *Ente per lo Sviluppo dell'Irrigazione e la Trasformazione Fondiaria in Puglia, Lucania ed Irpinia*, were processed. Samplings were performed from January 1995 to July 1997. The sampling was aimed at identifying significant vertical variations that require more frequent checking according to the space-time variability of the parameters under study.

Samples were taken under static conditions from springs and from wells, in the latter case using a "Kemmerer" water sampler which takes water at the selected sampling depth. A submersible pump was used to take samples under dynamic conditions (12.4 %) (hereinafter called "static samples" and "dynamic samples"). Static samplings help highlight the "natural" chemico-physical stratification of groundwater as well as the occurrence of hydrogeologically significant geological and structural features. However, little is known about the properties of the water which will be extracted from a given well or area. Withdrawn water is most likely to be that which is found where permeability is higher. Therefore, dynamic samples were also taken during the final stage, once the characteristics of the well were definitely known. Data inferred from dynamic samplings was used to complement and crosscheck data derived from static samplings. Samples taken under static conditions (2.8 % from springs) constitute about 87.6 % at depths ranging from 6 m to 600 m below ground level with about 12.4 % samples taken under dynamic conditions. The static samples were taken from each well at varying depths and at various times. A maximum of 15 samples per vertical axis or 5 measuring cycles were obtained.

Despite the effort made to gather and process data, the large size of the investigated HU, the natural lack of homogeneity and anisotropy, the frequent withdrawals and frequent use of aquifers for depositing waste water causes impacts that can only be described briefly in this paper. Hence, some parameters were selected in order to assess broadly the quality of groundwater and detect the areas most at risk. While processing data for mapping purposes, the average concentration of samples taken at the same depth was considered; samples of consecutive depths and very similar averages were unified. Then, in each well, the maximum and minimum mean concentration was selected (hereinafter called the worst and best concentration of the well). Therefore, the selected values provide a more cautious description of the

phenomena in progress.
In order to establish a benchmark for groundwater quality, reference was made to the Italian Law (DPR n. 88/236) which includes the EEC directive n. 80/778 about the quality of water fit for human consumption, namely the Maximum Acceptable Concentration (hereinafter MAC) of drinking water.

2.1 Chemico-Physical Properties of Groundwater

Apulian groundwater (95% of data) can be classified as cold (< 20° C, according to Mouren), with an average temperature of 17°C. This is due to the temperature of the recharge water fed by winter rainfalls and to the absence of very deep groundwater pathways. Exceptions to the latter case are the bordering areas of the major HU where some peculiar hydrogeologic and structural conditions prevail. Samples taken from some wells (5%) proved hypothermal (between 20 and 35° C) with an average temperature around 22.3°C; these wells are mainly located at sites in the province of Foggia where peculiar hydrogeological characteristics load to such higher temperatures. Human activities can also affect this parameter following the release into the subsoil of hot fluids. The use of groundwater to exchange heat for industrial and urban activities is common and has major effects on groundwater, as reported for Bari urban area (Polemio, 1994) and for the wells located near Brindisi and Taranto, in keep with the finding of this research.

Apulian groundwater is generally alkaline. Two times out of three water exhibited a pH > 7, with a spatial variability along the same vertical axis and a time variability, though with no great variation from the mean pH, approaching 7.16. As far as hardness is concerned, water samples were rarely fresh (Desio, 1973), accounting for the minimum percentage. Slightly hard water was a little more common than fresh water, with a medium mineral content when taking TDS into account, and generally classifiable as fresh with regard to the chlorine content. Water was found hard in 36% of the samples. In terms of salinity, hard groundwater was low to high in mineral content and fresh to saline (Cl > 1000 mg/l) as to chlorine content. Only 19% of samples were medium hard. The most common occurrence was very hard groundwater (39%) that is medium-mineral to mineral and brackish to saline water.

When considering TDS, groundwater is rarely low in mineral content (TDS < 200 mg/l), as is the case in some wells located inland (Murge and Salento). The most frequent case is that of water with a medium mineral content (200<TDS<1000 mg/l) (51%). Less frequent is the case of mineral groundwater. When classifying water based upon chlorine content, fresh water (Cl < 100 mg/l) was reported in most samples (36%). The remaining samples exhibited brackish water (100 < 1000 mg/l; 32%) and saline water (TDS > 1000 mg/l; 32%). Fig. 2, which for brevity's sake reports only some significant wells in the Murge HU, shows chemical differences in groundwater. Sample no.7, taken at the maximum distance from the sea, exhibits a very low salinity and can be classified as bicarbonate-alkaline-earthy, just like samples 1, 2, 4 and 6. Samples 8, 5 and 3, the last with a salinity equal to 1/3 that of seawater, are contaminated increasing in the order by seawater intrusion and are much more similar to sample no.9 consisting of sea water. Samples 3, 5, 8 and 9 can be classified as sulphate-chlorinated-alkaline.

2.2 Results of human-related organic contamination

The occurrence of bacteria in the water does not necessarily indicate that water is contaminated above drinking standards as not all bacteria are equally harmful. The presence of bacteria in groundwater, which is quite hard to identify and interpret given the abundance of species and the array of factors that originate them, is widely accepted as an indication of the poor protection of the water body against the external environment and of the release into the soil and subsoil of increasing colonies of bacteria.

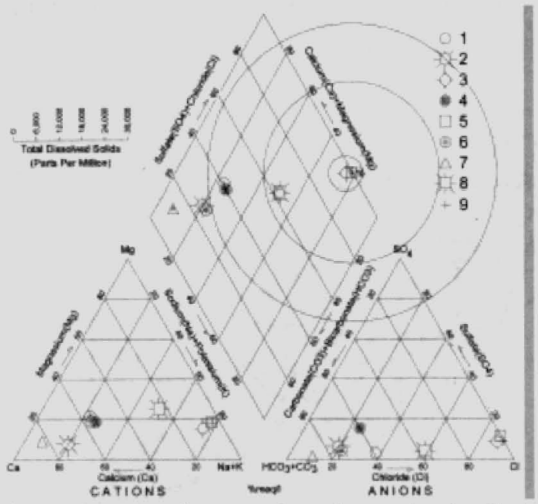

Figure 2 - Piper diagram of Murgia groundwater selected samples (wells in the Bari province). The circle radius is proportional to the TDS. Location of well, sea distance (Km) and depth from ground level (m): 1) Adelfia, 14, 179, 2) Terlizzi, 6, 256, 3) Trani, 1, 32, 4) Bitetto, 10, 190, 5) Polignano, 4, 131, 6) Monopoli, 10, 350, 7) Altamura, 36, 505, 8) Barletta, 8, 165, 9) Adriatic Sea.

When taking the worst well content, the peak bacterial mass detected at 37°C indicates that Apulian groundwater is characterised by a high concentration (Fig. 3). In extensive areas it exceeded 300/ml, after this value the count was interrupted. The main concern are the high values reported in the Gargano and Murge, even inland and in the Salento along the Ionian coast, with the exception of the central portion of the HU and the area bordering the Tavoliere and the Salentine Peninsula. Water samples taken in the above areas seemed inadequately protected as a result of the fast and abundant supply of infiltration water. The worst ammonia distribution in the region is quite uniform, mostly inland, where concentration approaches 0.1 mg/l, a value which is definitely lower than MAC (0.5 mg/l) for drinking-water standards (Fig. 4).

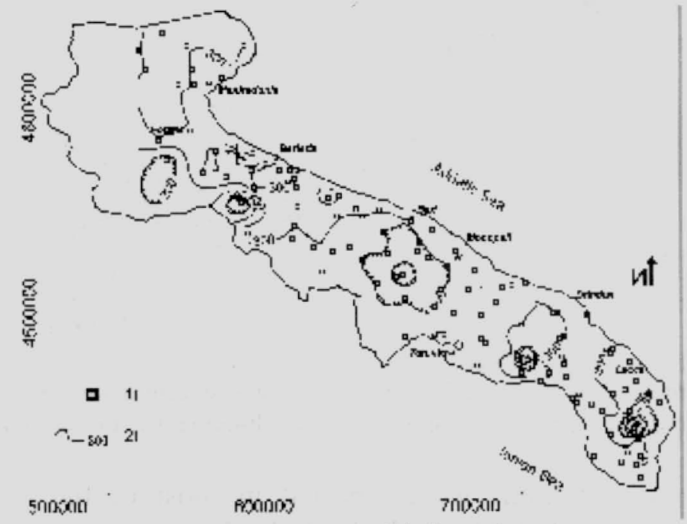

Figure 3 - Bacterial content at 37 °C map (1/ml), peak or the worst concentration along each well. 1) Well, 2) contour line.

An increased concentration was reported along the Adriatic coast, ascribable to the high population density and to waste disposal procedures. More alarmingly, the area between the two HU of Murge and Tavoliere crossed by the river Ofanto exhibited a progressive increase in the values from inland to the coast, with peaks exceeding 2 mg/l. The same applies to the area near Trani, where high values were reported, exceeding 3 mg/l. A similar situation was found in the surroundings of Brindisi, where concentration increased when approaching the coast and peaks were as high as 2 mg/l.

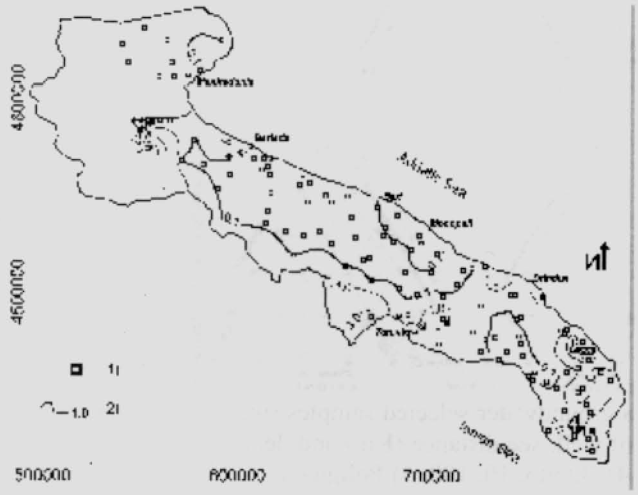

Figure 4 - Ammonia content map (mg/l), peak or the worst concentration along each well. 1) Well, 2) contour line (the line corresponding to the drinking water threshold is thicker).

Some ammonia values higher than 1 mg/l were detected in the far end of the Salentine Peninsula, in the vicinity of Presicce and Miggiano. As to nitrites(Fig. 5), their presence is significant in some confined areas where they exceed Mac (0.1 mg/l). The Gargano HU seems free from any nitrite contamination, whereas in the nearby Tavoliere concentrations can be as high as 5 mg/l.

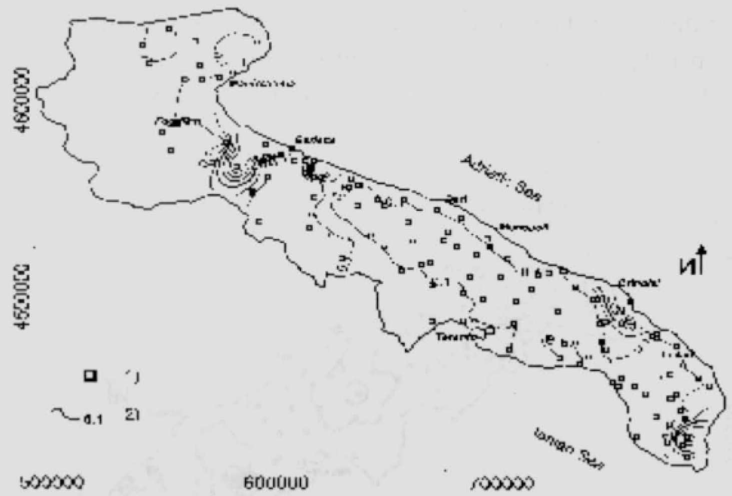

Figure 5 - Nitrite content map (mg/l), peak or the worst concentration along each well. 1) Well, 2) contour line (the line corresponding to the drinking water threshold is thicker).

No significant concentrations were reported in most of the Murge, except for the surroundings of Brindisi and Grottaglie and along the Ionian strip between Mottola and the coastline. By contrast, contamination is high in the Salento mostly along the Adriatic coast between Lecce and Otranto and at the far end of the Peninsula with peaks which not infrequently exceed 10 mg/l. Nitrates are rather uniformly distributed across the region (Fig. 6), with peaks in the Tavoliere and in some Murge areas. In a few cases MAC was exceeded (50 mg/l). Nitrate concentration in the Gargano ranges between 15 and 25 mg/l, with maximum values in the north, in the vicinity of the lakes of Lesina and Varano and, to the south, near Manfredonia. Higher nitrate concentrations were reported in the Tavoliere (25-35 mg/l) as a result of widespread farming activities. In the vicinity of the river Ofanto, the concentration was increasingly higher (35 to 45 mg/l).

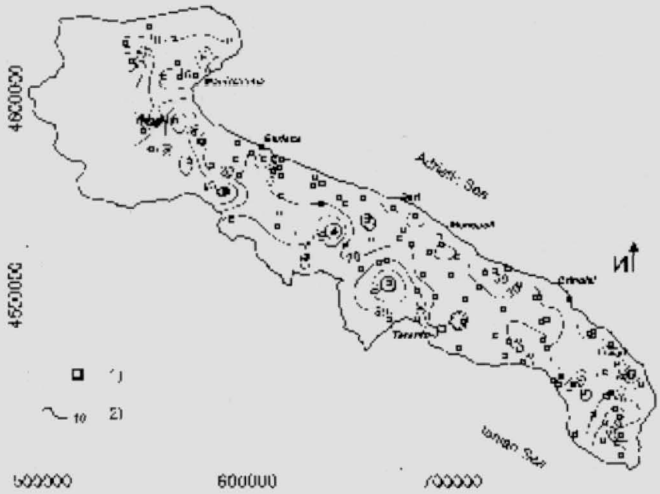

Figure 6 - Nitrate content map (mg/l), peak or the worst concentration along each well. 1) Well, 2) contour line (the line corresponding to the drinking water threshold is thicker).

Along the Murge coastline, from Trani (located between Barletta and Bari) to Fasano (between Monopoli and Brindisi) (Fig. 6), the distribution of nitrates with an average value of 15 mg/l was quite uniform and more significant in highly populated areas. However, the most severe cases were found inland, along the Ionian side with peaks exceeding 50 mg/l. The central part of the Salento HU exhibited average values (15 mg/l) whereas the highest concentration, exceeding 25 mg/l, was reported along the coast. The Adriatic coastline, between Lecce and Otranto, is affected by a diffuse contamination with maximum concentrations.

The above analysis suggests a significant concentration of nitrites in some confined areas, a rather widespread occurrence of nitrates across the region and the concentration of ammonia along the coast. Alarming concentrations (> MAC) are confined to some areas only. However, nitrates were constantly reported in all water samples, including those taken inland and in more sparsely populated areas, with values exceeding the limits set by the Italian Government (D.P.R. 236/88). The worst scenario was reported along the river Ofanto and in most of the Tavoliere HU, where the three parameters were often found at high concentrations. The same applies to the area between the Murge and the Salento and to the Adriatic coast and southern portions of the Salentine Peninsula.

As far as Salento and Murge are concerned, organic and bacterial contamination was higher in the vicinity of urban areas, where waste water is discharged into the subsoil, and close to the coast. Contamination was lower where groundwater flow and recharge were more active. As a whole, this type of pollution appears to be more extensive but less severe in Salento, unlike Murge. Note that the values for the typical human-related organic pollution parameters may have been underestimated by static samples, largely used for this study. However, as the most significant values for practical purposes are those established under dynamic conditions, similar to those for the common withdrawal of groundwater, the drawback was offset by a great level of caution and by taking the worst concentrations recorded at each well. These considerations and the maps they refer to proved consistent with the findings of previous investigations in the HU, mostly those of Murge and Salento (Tadolini & Ferrari, 1990; Tulipano & Fidelibus, 1995). Coastal spring water was thoroughly analysed. Almost no pest control products were found. By contrast, bacterial contamination was widespread consisting of total and fecal choliforms. No fecal streptococcus was found. Nitrogen-based compounds, mostly nitrates, were prevailing. Some contaminants, new for Apulian groundwater, mainly metals, some of which particularly toxic were found in samples taken under static conditions, along the water column of the wells at various depths.

Iron, lead and mercury were selected among the parameters most likely to correlate to inorganic human-produced pollution. Pollution due to iron is rare in the Gargano, Tavoliere and Murgia HU, having a MAC of 0.2 mg/l (Cotecchia & Polemio, 1998). By contrast, the Salentine HU exhibits a widespread iron occurrence in groundwater; the maximum concentration found was 178 mg/l. The threshold is exceeded in a large area away from the coast where groundwater recharge is concentrated. When considering the best concentrations, the situation is slightly improved. Hence, iron concentration is found more widely but it is lower on the Ionian side of the Salento. The excessive iron content is a source of nuisance. It worsens the taste of water, plugs the pipes and promotes the growth of iron bacteria which line the internal walls of the pipes with a sort of slime. However, such drawbacks generally result from concentrations > 0.3 mg/l. As to the concentration of the toxic lead ion, having a maximum acceptable value of 0.05 mg/l, the situation is similar to that of iron. Metal-pollution detected in some areas of the Gargano, Tavoliere and Murgia is attributable to widespread industrial and other commercial activities. Mercury, by contrast, was never found in the samples at concentrations exceeding MAC.

The most serious and severe cases of inorganic human-produced pollution are found in the Salento, in the Lecce area. The investigated parameters showed significant changes over time, mostly owing to the regime of the natural aquifer recharge. At almost all the sampled sites, the highest concentration of contaminants occurred in autumn when rainfalls following the summer drought feed the water table after leaching unsaturated and contaminated soils. The subsequent rainfalls then tend to dilute the contaminants which have reached the water table, thus reducing the concentration. This model may serve as an hypothesis, given the short time of the sampling and should not be taken as absolute as it is strictly related to the rainfall regime and to the local hydrogeological conditions.

3. Conclusion

The historical salt contamination due to seawater of Apulian groundwater is enhanced by human-related pollution. Contamination resulting from human agency was observed, contaminants of various types are being discharged into the water table. Except for nitrites, which are found in alarmingly high concentrations only in confined areas, excessive nitrates were reported across the region and ammonia along the coast. The three contaminants were found in concentrations which might give concern in some areas only. However, the constant presence of nitrates in all water samples, including those which flow inland, should not be underestimated. Values generally exceeded the standard set by the Italian Government (D.P.R. 236/88).

The human-related pollution is not only organic and bacteriologic. The occurrence in groundwater of toxic metals, like lead, which are generally absent or found in low quantities, elsewhere calls for a wiser management of water resources. A higher contamination level was observed in the vicinity of some urban and industrialised areas and near the Adriatic coast where population density is higher and groundwater more vulnerable. Contamination was lower wherever water flow and recharge were more intense. Good quality groundwater in some areas of the Gargano and in vast portions of the Murge calls for sound management measures in order to protect groundwater resources and create parks to preserve the natural wealth of the region. Besides the need to rigorously regulate groundwater withdrawals in order to reduce the increasing salt contamination, actions should be taken to properly manage and dispose of wastewater which is still discharged onto the soil and into the subsoil following inadequate purification treatments.

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