Geological constraints on the location of industrial waste landfills in Salento karst areas (Southern Italy)

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Abstract

Landfills of industrial wastes constitute heavy potential sources of water pollution. The hazard is particularly high in the karst areas; it increases with time as a consequence of deterioration of bottom proofings. In order to reduce such hazard, EU Directive on landfills clearly states that any application for a location permit should contain, among other, plans for the closure and aftercare procedures. Some comments on geological constraints are given to better localize the industrial waste landfills in karst areas, on the base of Salento sub-region (southern Italy) experiences.

1 Introduction

The italian law (D.L. 5/2/97 n. 22 and D.L. 8/11/97 n. 389), following UE Directive (91/156/CEE, 91/689/CEE and 94/62/CEE), draws a distinction between municipal and special wastes. The two categories are further distinguished in dangerous and not dangerous.

Industrial wastes are considered special. The related danger is evaluated by measuring presence, concentration and quantity of specific substances, that are detrimental to the public health or to the environment. Especially when dealing with heavy metals, it is customary to perform tests on the leachate which can pollute the unsaturated zone and the groundwater.

Similar problems stand also for some wastes which are completely checked before disposal. In fact, even if the concentration of dangerous substances contained in industrial wastes is in agreement with law parameters, it can turn very high in the leachate with time (Baccini & Henseler, [1]; Filippini, [2]).
Table 1: Annual production of industrial wastes in Salento (on the base of "Piano per la gestione dei rifiuti speciali della Provincia di Lecce - Plane for special waste management of province of Lecce", 1997)

<table>
<thead>
<tr>
<th>waste type</th>
<th>minimum ton/year</th>
<th>maximum ton/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>like municipal</td>
<td>15.000</td>
<td>50.000</td>
</tr>
<tr>
<td>dangerous</td>
<td>5.000</td>
<td>10.000</td>
</tr>
<tr>
<td>recyclable</td>
<td>15.000</td>
<td>35.000</td>
</tr>
<tr>
<td>other</td>
<td>60.000</td>
<td>550.000</td>
</tr>
<tr>
<td>total</td>
<td>95.000</td>
<td>645.000</td>
</tr>
</tbody>
</table>

The danger connected to such situations increases when the leachate is trapped into the landfills, forming in-between and bottom stagnations (Serra, [3]). On the other hand, every bottom landfill proofing tends to spoil with time (Jappelli et al., [4]), in most cases within dozen of years. The causes are the reduction of tightness capacity of the geosynthetic clay liners (Banini et al., [5]; Magagni & Boschi, [6]; Majone et al., [7]; Ruhl & Daniel, [8]) and the tears in the geotextiles and geomembranes. These tears, even if small, can trigger very fast leachate emissions (Giroud & Bonaparte, [9]; Giroud & Cazzuffi, [10]). As a consequence, EU Directive on landfills clearly states that any application for a location permit should contain the proposed plans for the closure and aftercare procedures as well as the proposed operation, monitoring and control plans.

Location of industrial waste landfills is a strategical problem, especially in order to safeguard water resources of highly vulnerable zones like karst areas, which extend over 25% of the lands above sea level. In Salento sub-region (southern Italy), where karst areas are predominant, industrial waste landfills are absent, in spite of the hundreds of thousands of tons of wastes produced every year (Table 1).

Metal working, leather tanning and textile industries concentrate in Salento sub-region. The lack of industrial landfills favors the proliferation of unauthorized landfills and, as a consequence, groundwater pollution is actually a dramatic problem (Table 2). Therefore it is necessary to identify areas suitable to industrial wastes landfills, before that an irreversible groundwater pollution takes place.

2 Salento geological setting

The units forming the Salento stratigraphic series are generally separated by erosive limits. This is due to the geological history, that has been characterized by emersions alternate with submergences by the sea, owing to tectonic or eustatic phenomena. Cretaceous-Paleogene highly karstified limestones
<table>
<thead>
<tr>
<th>locality</th>
<th>pollutants</th>
<th>years of recognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burgesi</td>
<td>hydrocarbons, PCB, IPA, phenols</td>
<td>2000</td>
</tr>
<tr>
<td>Corigliano</td>
<td>hydrocarbons, phenols</td>
<td>1997</td>
</tr>
<tr>
<td>Galatone</td>
<td>hydrocarbons, phenols</td>
<td>1997</td>
</tr>
</tbody>
</table>

Table 2: Some of the more recent cases of water pollution in Salento

Figure 1: Geological sketch of Salento. 1 - Quaternary and Pliocene; 2 - Miocene; 3 - Paleogene and Cretaceous; 4 - Stratigraphic limit; 5 - Main fault
Units/cm/s

<table>
<thead>
<tr>
<th>Units</th>
<th>cm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary calcarenites</td>
<td>$10^{-2} \div 10^{-4}$</td>
</tr>
<tr>
<td>Quaternary clay</td>
<td>$10^{-6} \div 10^{-8}$</td>
</tr>
<tr>
<td>Pliocene calcarenites</td>
<td>$10^{-2} \div 10^{-4}$</td>
</tr>
<tr>
<td>Paleogene-Miocene marls and calcarenites</td>
<td>$10^{-4} \div 10^{-5}$</td>
</tr>
<tr>
<td>Cretaceous-Paleogene limestones</td>
<td>$10^{2} \div 10^{-2}$</td>
</tr>
</tbody>
</table>

Table 3: Orders of permeability value

are in the bottom of the series (Figure 1). Paleogene-Miocene marls and calcarenites, Pliocene moderately karstified calcarenites, Quaternary clay and moderately karstified calcarenites follow.

The main factor of shaping the landscape in Salento is the tectonic style. The relief is mainly formed by Cretaceous units, while Miocene, Pliocene and Pleistocene units mainly crop out in the level lands. This is interpreted as due to a "horst and graben" structure, with the relief which had to be blocks structurally uplifted, while the level lands should had to be lowered blocks (Delle Rose, [11]). Blocks are separated by main faults that had been active during several phases, from Upper Cretaceous to Quaternary. As a consequence, lithological features and thickness of the stratigraphic units change suddenly in few meters near the main faults.

Karst caves are frequent, especially into Cretaceous-Paleogene limestones. They are present also into Pliocene and Quaternary, whereas only few karst caves are known in the Miocene. Lithological and speleological features of the units change so much and this circumstance entails a vast range of permeability values (Table 3).

Salento contains several aquifers; the greater - and the deeper - is formed by Cretaceous units and it is the only drinking water resource available in the sub-region. The others aquifers are formed by some Tertiary and Quaternary units; they are used only for limited irrigation. Groundwater contained in the Tertiary and Quaternary units (superficial aquifers) feeds, in large portion, the deeper aquifer, generally through karst systems which are connected by means of tectonic structure networks (Beccarisi et al., [12]) (Figure 2).

It is necessary to remark that the discovery and reconnaissance of a karst system depend mainly on the activity of speleological groups. The location of all the karst systems is not completely note, being the speleological activity a voluntary work.

In Salento, karst cave groups are usually arranged along some sub-horizontal levels, being the sea level the main bottom karst level (Delle Rose et al., [13]). Inside karstified units, water flows in pipe-like conduits as well as through fractures. Due to the randomness of the geometry of the network of fractures and conduits, the flow circulation and the transport of
Figure 2: Hydrogeological scheme showing the influences of fault and karst systems on flow

Solute are predictable in a statistical sense by means of a discrete fracture network methodology (Delle Rose et al., [14]).

3 Prescriptive aspects

Improper location of hazardous waste landfills in karst areas is frequently cause of lawsuit (LaMoreaux et al., [15]). A great problem of the safeguard of environment Italian law is the lack of agreement between the waste classification and the landfill type (the latter are establish by D.C.I. 27/7/84). Five kinds of landfills are defined, three of them can be used for industrial wastes.

A serious hazard derives if the wastes that produce dangerous leachate are stored in landfills for which the law provides for less constrained requirements (i.e. the second category type B). In fact, Italian law does not provide for any restrictions in karst areas and as to environmental safety, it allows location of this type of landfill when the distance between the bottom and the water table is more than 1 meter.

Owing to the above-mentioned serious law deficiencies, water pollution prevention trusts to the local water authorities activity. From this point of view, an important administrative resolution is the Environmental Impact Assessment (EIA) of the landfill project. Nevertheless, also EIA procedure has some shortcoming. In fact, one out of three of the industrial landfill projects, that were located on Salento karst areas with high groundwater vulnerability, has been considered positive (Table 4).
Table 4: Industrial landfill projects and EIA judgment

<table>
<thead>
<tr>
<th>Locality</th>
<th>Cropping out unit</th>
<th>EIA</th>
<th>Water table depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Eleuterio</td>
<td>cretaceous limestones</td>
<td>negative</td>
<td>170 m</td>
</tr>
<tr>
<td>Fierandina</td>
<td>cretaceous limestones</td>
<td>negative</td>
<td>1 m</td>
</tr>
<tr>
<td>Ghetta</td>
<td>cretaceous limestones</td>
<td>positive</td>
<td>1 m</td>
</tr>
<tr>
<td>Ugento</td>
<td>plio-pleistocene clay and calcarenites</td>
<td>?</td>
<td>80 m</td>
</tr>
</tbody>
</table>

It is remarkable that for S. Eleuterio and Fierandina projects, the high groundwater vulnerability ranking led to the negative judgments. As to S. Eleuterio the judgment given that "there is karst system, whose hydraulic characteristics determine unlimited permeability in limestones". In Fierandina "quarry has high permeability due to fractures and karst dissolution", so to "favor fast percolation and, for all that, groundwater is exposed to pollution hazard".

Regarding Ghetta landfill project, groundwater pollution hazard has not been considered with the same ranking. This is due to the differences in the documentation that the local civil services use for their judgments. In the fact, documentation can be incomplete, being usually a civic committee (formed by people living near the landfill in project), that requires a detailed assessment about public welfare and environmental hazards. Nevertheless, usually the community does not know the landfill projects. As a consequence it is necessary for the water authorities to get safe instruments for the evaluation of the projects.

4 Evaluation landfills projects referred to the groundwater pollution

Systems for evaluating groundwater pollution potential, like DRASTIC (Aller et al., [16]) and SINTACS (Civita, [17]) can be utilized only for a first screening of the suitable areas to industrial waste landfills (Civita, [18]). They use, first of all, hydrogeologic setting (type of saturated and unsaturated zone; water table depth; permeability). Also some morphological (slope, network of canals) and meteorological features (rainfall) are considered.

Quality maps are the outcome of quality and interpretation of data. As a consequence these methods can be useful where the geological setting is uniform (i.e. vast alluvial plains). In karst areas the above-mentioned systems have only restricted utility and groundwater vulnerability maps can be only instruments for a general planning (Cucchi et al., [19]).

In any case, these methods are not able to certify the suitability of specific subsoil to contain potential source of water pollution. The use of groundwater vulnerability maps on a large scale to solve detailed problems
Figure 3: Theoretical time (in seconds) of percolation of hypothetical leachate, evaluated for the subsoil of the four industrial waste landfill projects of Table 4, four municipal landfills (Fondo Rio, Castellino, Burgessi and Cavallino) and three comparison sites (Lecce, Spedicaturo and Lustrelle, see Figure 1). G.P.H. = Groundwater Pollution Hazard

like a location of landfill, can lead to catastrophic results (Boumans et al., [20]), especially in karst areas where geological setting can quickly change in narrow spaces.

Furthermore, the methods for evaluating groundwater pollution are based on generic hypothesis about the characteristics of the pollutant, while the subsoil pollutant mitigation has a strong influence on some pollutants and no influence on others (Civita, [18]). Therefore, there are serious risks if groundwater vulnerability maps have used in decision-making activity by public administrator unprepared to recognize the limits of the methods.

For a judgment on the suitability of specific subsoil in karst areas to contain source of pollutants, at least three levels of geological analysis should be performed. First of all, one has to take into account rainfall, thickness and permeability of the geological units forming the unsaturated zone, to calculate the time of percolation. Simulations can be made based on the
kind of leachate, which depends on the initial fluid of the waste, fluid derived from waste decomposition and washing away. The evaluation of subsoil pollutant mitigation (Robinson & Lucas, [21]; Kjeldsen, [22]; Serra, [3]) must be considered also, on the base of the chemical characteristics of the leachate.

In a second phase, surroundings features must be checked, as slopes, network of canals, tectonic fracture systems, distances and connections to karst systems and main faults. Finally, a careful three-dimensional reconstruction of subsoil must be performed.

Owing to the homogeneous meteorological features of the Salento (Zito et al., [23]), a preliminary evaluation, based on a hypothetical leachate with water-like density and viscosity, can be made (Figure 3).

By means of this first evaluation, one can choose a safer place in order to safeguard groundwater resources. In particular, for industrial waste landfill projects and for municipal landfills the estimated time of percolation ranges from few minutes to years and from tens of minutes to tens of years respectively, while for comparison sites it is of the order of hundreds of years.

Nevertheless, near karst systems and faults, real time of percolation can be smaller than the theoretical time. In fact, based on the results of the second phase of geological analysis (Figure 4), the representative points in Figure 3 of Burgesi, Ugento and Spedicaturo sites move to the lower part, corresponding to a high groundwater pollution hazard.
5 Conclusions

Different levels of geological analysis can overcome the limit of groundwater vulnerability maps for the judgement about the suitability of sites for industrial waste landfills. In Salento the need for a better understanding of the geological structure is due to the existence of karst cavities where fluid and contaminant can move faster. The local authorities trust usually the maps obtained by the application of parametrical methods, like DRASTIC or SINTACS for example, that obliterate such geological features.

The author points out that a good geological investigation is not particularly expensive, especially if compared to the high social costs of a groundwater contamination.

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References


