International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 29 No. 2 Mar. 2017, pp. 87-95

http://www.ijisr.issr-journals.org/

A new time-spatial method for the evaluation of groundwater contamination beneath a MSW sanitary landfill: A case story

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ABSTRACT: Waste sanitary landfilling is generally opposed by public opinion as responsible of aquifer contamination even when other possible contaminating sources exist in the area. A new tool based on time-spatial evaluation of groundwater contamination is presented, capable of appreciating the direct responsibilities of a MSW sanitary landfill when the aquifer becomes polluted. A successful application of the tool to the case of a medium-size Italian city is discussed.

KEYWORDS: solid waste disposal; aquifer pollution; responsibility assessment among various players.

1 INTRODUCTION

Groundwater provides irrigation (60%), industrial (20%) and drinking (20% on the average) water sources to immense population in rural, industrial and metropolitan areas in developing and developed countries of the world like in the Greatest Milan area (Italy), while 50% of U.S. citizen served by public water supplies rely on the aquifer [1]. The "*circular economy*", predicted since the 1940s [2] and today mandatory in fast growing nations like China [3], aiming at 100% recovery and recycling in waste management (*zero waste*), still requires back-up sanitary landfilling in the mid-term years and for unavoidable occasional plant shutdown. Although other sources, including septic systems, pesticides, underground storage tanks etc., can often contribute significantly, aquifer contamination by uncontrolled dump sites and even by engineered sanitary landfills tends to attract the greatest concern from Regulatory Authorities and consumer associations as numberless incidents where leachate polluted the underlying groundwater aquifer or nearby water bodies are being reported worldwide.

The physio-bio-chemical characteristics of leachate are highly variable depending on several factors, e.g., waste composition, site hydrology, local meteorology, waste compaction, cover design, landfill design and operation etc. [4]. Many models have been proposed so far to evaluate the transport of contaminants throughout the soil profile, with dubious success [5]. Leachate produced from municipal solid waste (MSW) landfills, in particular, is generally heavily contaminated and consists of complex wastewater that is very difficult to deal with, being intrinsically heterogeneous and exhibiting huge temporal and seasonal variations [6],[7]. In some cases, furthermore, the contamination effect of leachate leaking the landfill linen system may become evident months or even years after the leak has occurred, depending on the flow velocity and flow direction of the groundwater, quite often moving continuously, but very slowly (few meters per year), through the open spaces in soil and rock. When a landfill contaminates groundwater, a plume of contamination occurs: wells in that plume will be polluted, while other wells, even closer to the landfill, may be unaffected if they are not in the plume.

Close, long term, monitoring and the knowledge of local direction of groundwater flow are accordingly mandatory for early warning and detection of the leachate leaking. This was the case of the MSW sanitary landfill of Andria (NW of Apulia Region, South Italy), initially blamed for contaminating the underlying aquifer and finally cleared of the accuse after a specific time-spatial evaluation of the problem was carried out, as described in this paper.

2 MATERIALS AND METHODS

2.1 STUDY LOCATION

The MSW sanitary landfill is 9.5 km South of the Adriatic Sea coastline, 100÷110 m above the sea level and 3 km W-NW of Andria, the 100,000 inhabitants capitol of the BAT Province (Fig.1). The MSW landfill was built in 1993 from an open-pit calcareous quarry with sub-vertical walls, using the best pertinent European engineering norms (full waterproofing by 1m compacted clay with $1x10^{-7}$ cm/s permeability plus a welded-on-site polyethylene synthetic linen, automatic drainage and treatment of leachate, in situ biogas collection and combustion, groundwater monitoring wells etc.). The plant consists of 2 adjacent quarries with levelled depth of 15 m, divided by a natural limestone rock wall into Sections A and B (Fig.2). With an overall net capacity of 1.4 Mt MSW, the upper section (A) received ≤0.1 Mt/year from a 300,000 inhabitants area around Andria until it was exhausted in 2010 after 17 years of continuous operation (Fig.3).

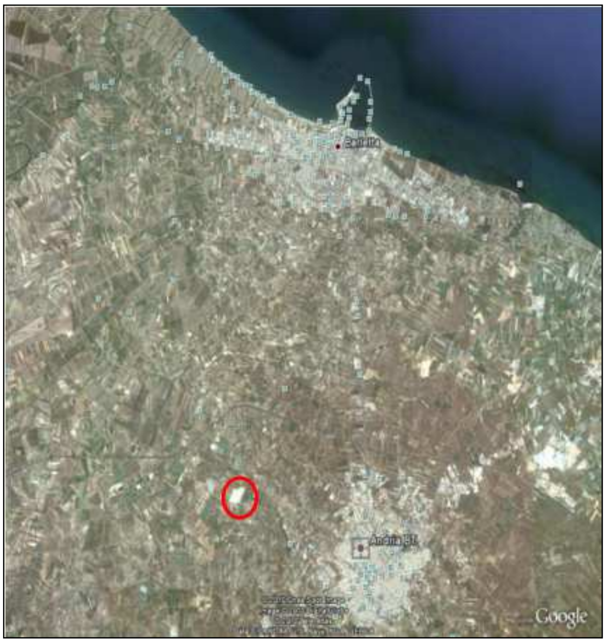


Fig. 1. Site location of Andria MSW sanitary landfill

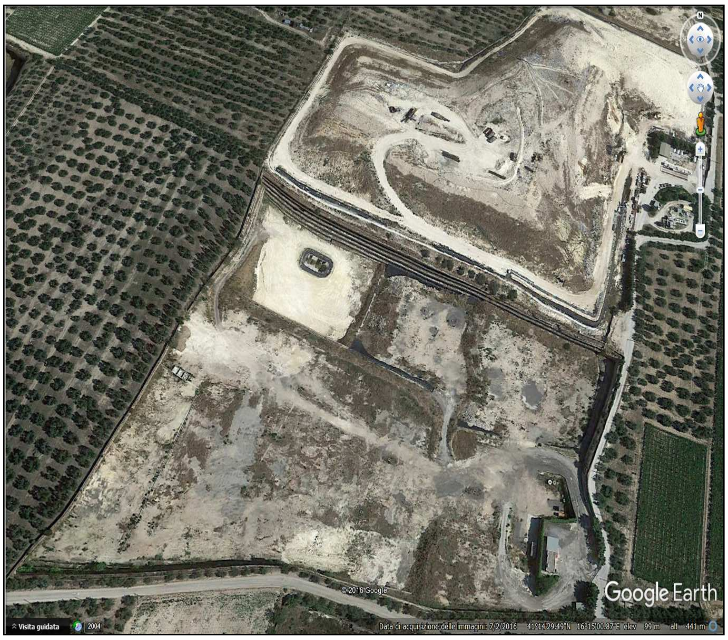
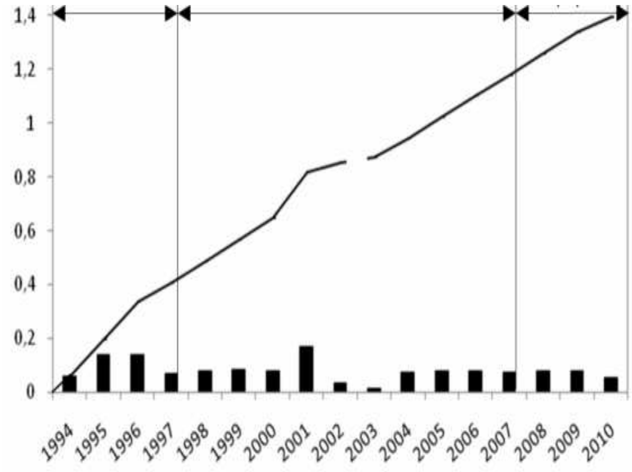


Fig.2. Upper (A) and lower (B) sections of Andria sanitary landfill

Fig.4 shows the layout of the landfill with the exhausted upper Section A (white-grey) and lower Section B split in 3 sub-sections (blue border), aimed with its net capacity of 0.7 Mt at complementing the nearby brand-new MSW bio-mechanic-chemical treatment plant (down at left). Section B) is equipped with 6 new monitoring wells $PN_{1÷6}$ in addition to the 4 monitoring wells $P_{1÷4}$ that served Section A) (in fact, PN3 substituted P2, for 10 monitoring wells overall), plus the existing $P_{acquaviva}$ well at the SE border.



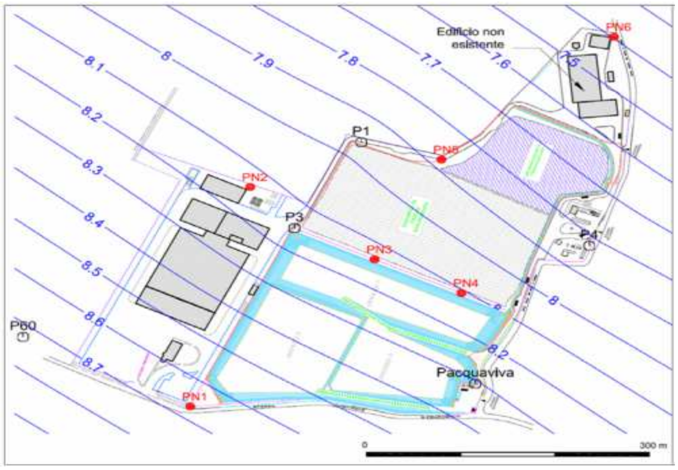
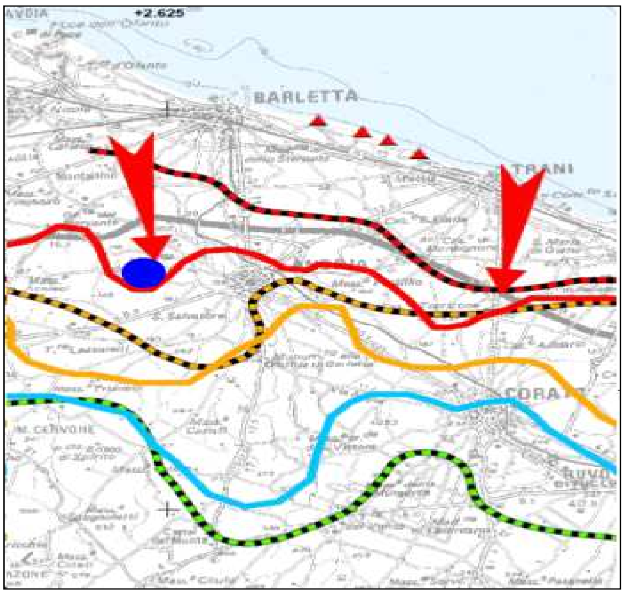


Fig.3. Operation chronogram of Andria Section A landfill *Fig.4. Layout of A (upper) and b (lower) MSW Andria landfill Sections*

After the assessment of heavy contamination of local groundwater in 2010, Section B was denied the construction permit.

2.2 AQUIFER DESCRIPTION

The aquifer consists locally of two water-tables, the unpressurized ("free") upper one, at 90÷100 m below ground level (20÷10 m above sea level), and the pressurized, much deeper, lower one. Land use maps show that the area is intensely cultivated, with crop irrigation allowed by tents of wells, largely private. This is causing increasing salinization of the aquifer, where a major saline intrusion cone (3.5g/l, red arrows) already reached the landfill (Fig.5). Detailed hydraulic measurements allowed to estimate accurately flow direction (SW → NE) of groundwater beneath the exhausted Section A of the landfill as shown in Fig.6, where the numbered solid lines indicate the groundwater table height (hydraulic head in meters above sea level), slowly decreasing towards the sea at N-NE.



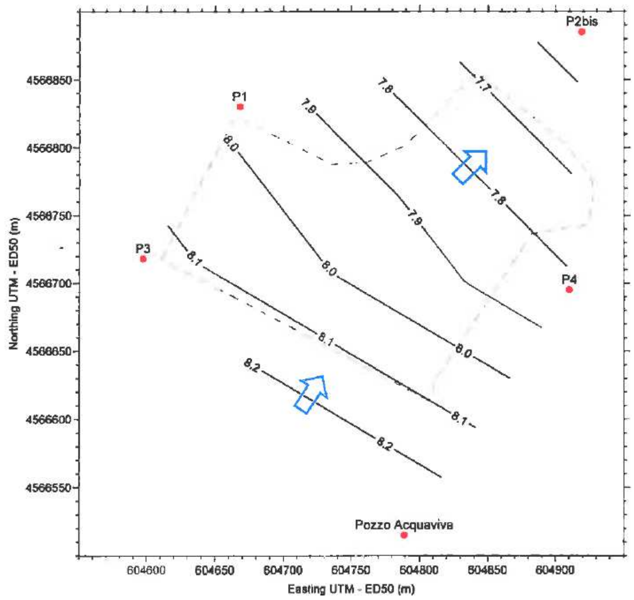


Fig.5. Aquifer isohaline (g/l) in the area (● Andria landfill) *Fig.6. Groundwater flow direction below Andria Section A) landfill*

2.3 WATER QUALITY STANDARDS

As indicated, groundwater use for agriculture is largely prevailing in the area. However, there are no quality standards for irrigation water in Italy. In order to assess the contamination of the aquifer, hence, 5 different standards were considered in this study, namely:

1) The 1994 Food and Agriculture Organization (FAO) standards for agriculture [8]
2) Italy's Ministry Decree No.185/2003 for municipal wastewater reuse

3) Italy's Legislative Decree No.152/2006 for municipal wastewater discharge (Annex 5, Part 3, Tab.3)
4) Italy's Legislative Decree No.31/2001 for water to be used for potable consume
5) Italy's Legislative Decree No.152/2006 for groundwater to be classified "officially contaminated".

2.4 THE TIME-SPATIAL EVALUATION PROCEDURE

The assessment of the contamination of the groundwater beneath Section A convinced local Administrative Authorities to deny the permit to build the Section B landfill, serving as a backup for the new complex plant for reclamation of Andria MSW.

In order to ascertain eventual responsibility of Section A in the contamination of local groundwater during its 17 years of operation (1994÷2010), all the analytical results of quarterly controls of groundwater quality carried out systematically by the owner of the landfill and occasionally by the Regional Agency for Environment Protection (ARPA) on the samples taken from its 4 monitoring wells (P3, P1, P4 and P2*bis*) were considered in order to appreciate the evolution of the groundwater moving through and beyond the landfill during the years. Table 1 reports the technical characteristics of the 4 control wells.

Table 1. Technical characteristics of the 4 control wells of Section A) of the landfill

Well	Year	Position (m on s.l.)	Abs. level (m)	Rel. level (m on s.l.)	Drilling Φ (mm)	Coating Φ (mm)	Coating	Inner volume (m^3)	Flow rate (l/s)	Flow position
P3	1998	121	114.19	8.14	220	180	steel	0.8	1	upstream
P1	1993	121	112.36	7.97	160	120	PVC	0.4	1	midstream
P4	1998	133	101.53	7.82	220	190	steel	1.8	1	midstream
P2*bis*	1998	135	101.30	7.54	220	180	PVC	0.8	1	downstream

The analytical results for each water parameter in each sample of the 4 wells during the 17 years were plotted, so to have the time evolution of groundwater quality in each well. The 4 plots obtained for each parameter were then arranged spatially (i.e., the plots of downstream P2*bis* well followed those of the mid-stream P1 and P4 wells, following in turn those of the upstream P3 well) so to have the time-spatial evolution of groundwater quality beneath Section A landfill throughout its service life. Furthermore, each plot reports, by a solid line with different color, the benchmark limit for that parameter (if existing) according to the different standards shown at Paragraph #2.3: if exceeding the limit(s), the experimental value is in the corresponding color thus facilitating "de visu" appreciation of the time-spatial groundwater evolution for that parameter.

Tab.2 indicates the 45 groundwater parameters taken into consideration. For ease of representation, only the plots with groundwater parameters exceeding the limit(s) are reported in this paper.

All physical, chemical and biological analyses were carried out according to Standard Analytical Methods [9].

Table 2. Groundwater analytical parameters considered

Physical	TDS, temperature, electric conductivity, pH, oxidation capacity
Chemical (common inorganic species)	Na^+, K^+, Ca^{++}, Mg^{++}, HCO_3^-, Cl^-, F^-, $SO_4^=$
Chemical (polluting inorganic species)	NH_4^+, NO_3^-, NO_2^-
Chemical (toxic in/organic species)	Pb, Cr_{tot}, Cr^{+3}, Ni, Cd, B, Be, Fe, As, Co, CN, Sn, Cu, Hg, Mn, Se
Chemical (common organic parameters)	TOC, BOD, COD
Chemical (toxic organic species)	Benzene, Total Phenols, Chlorinated Solvents, Aromatic Solvents
Microbiological	Total Bacterial Count, Enterococci, Escherichia coli, Chlostridium Perfringens, Fecal Coliforms, Total Coliforms

3 RESULTS AND DISCUSSION

Tab.3 reports the results of a typical analysis of local groundwater carried out by ARPA (Nov. 2008), showing the variation range of the analyses among the 4 wells. The salinity exceeded the limit imposed by FAO (agriculture use), due to local intense groundwater exploitation for irrigation and to its consequent salinization, as previously explained.

Table 3. Concentration of major parameters in the groundwater (red values exceed FAO limits for irrigation)

Parameter	M. U.	P3	P1	P4	P2*bis*
Electrical conductivity	μS/cm	**4,680**	**4,400**	**4,600**	**4,600**
TDS	mg/l	**3,589**	**3,631**	**3,730**	**3,622**
Ca^{++}	mg/l	105	116	112	109
Mg^{++}	mg/l	81	85	81	85
Na^{+}	mg/l	**839**	**811**	**854**	**837**
K^{+}	mg/l	22	23	73	25
HCO_3^{-}	mg/l	385	395	410	400
Cl^{-}	mg/l	**1,300**	**1,265**	**1,255**	**1,308**
$SO_4^{=}$	mg/l	172	168	171	171

Fig.7 shows the time-spatial evolution of physical parameters of the groundwater travelling beyond the landfill Section A, measured each April (after the rainfall season) from 1994 to 2010. No variation of the parameters in groundwater referable to landfill activity could be appreciated throughout the 17 years. Interesting to note, the groundwater temperature suddenly underwent a noticeable variation (± 6°C) in April 2005, requiring over 1 year to be recovered. This was due to a moderate earthquake in that area, as revealed by local seismographic stations.

Fig.8 presents the time-spatial variation of the Nitrogenous ions (Ammonium, Nitrite and Nitrate) in local groundwater. It is evident that the concentration of NH_4^+, a most typical marker of leachate leaking from MSW landfills, is almost negligible, exceeding occasionally the drinking water limit and in 2 cases (April '99 in P1) also the FAO limit for irrigation. Same absence occurs for nitrites, exceeding only in one occasion the D.Lgs. No.152/06 limit for contaminated groundwater. Accounting also for the intrinsic Oxygen shortage in aquifers, the abundance of nitrates is clearly due to the intense use of fertilizers.

An alarming situation concerned the severe groundwater contamination by heavy metals and organic solvents, the main reason to deny permit to continue the landfilling by section B when section A went to its end. Time-spatial data exhibition in Fig.9, however, provided a double justification: first, the contamination interested exclusively the initial landfill operation as by 2005 all concentrations fit the standard; second, most important, the temporary groundwater contamination was already present upstream the landfill and it did not deteriorate further with groundwater moving along the landfill. The pollution was explained with the existence of uncontrolled polluting activities of a tanning factory upstream the landfill, closed in 2005.

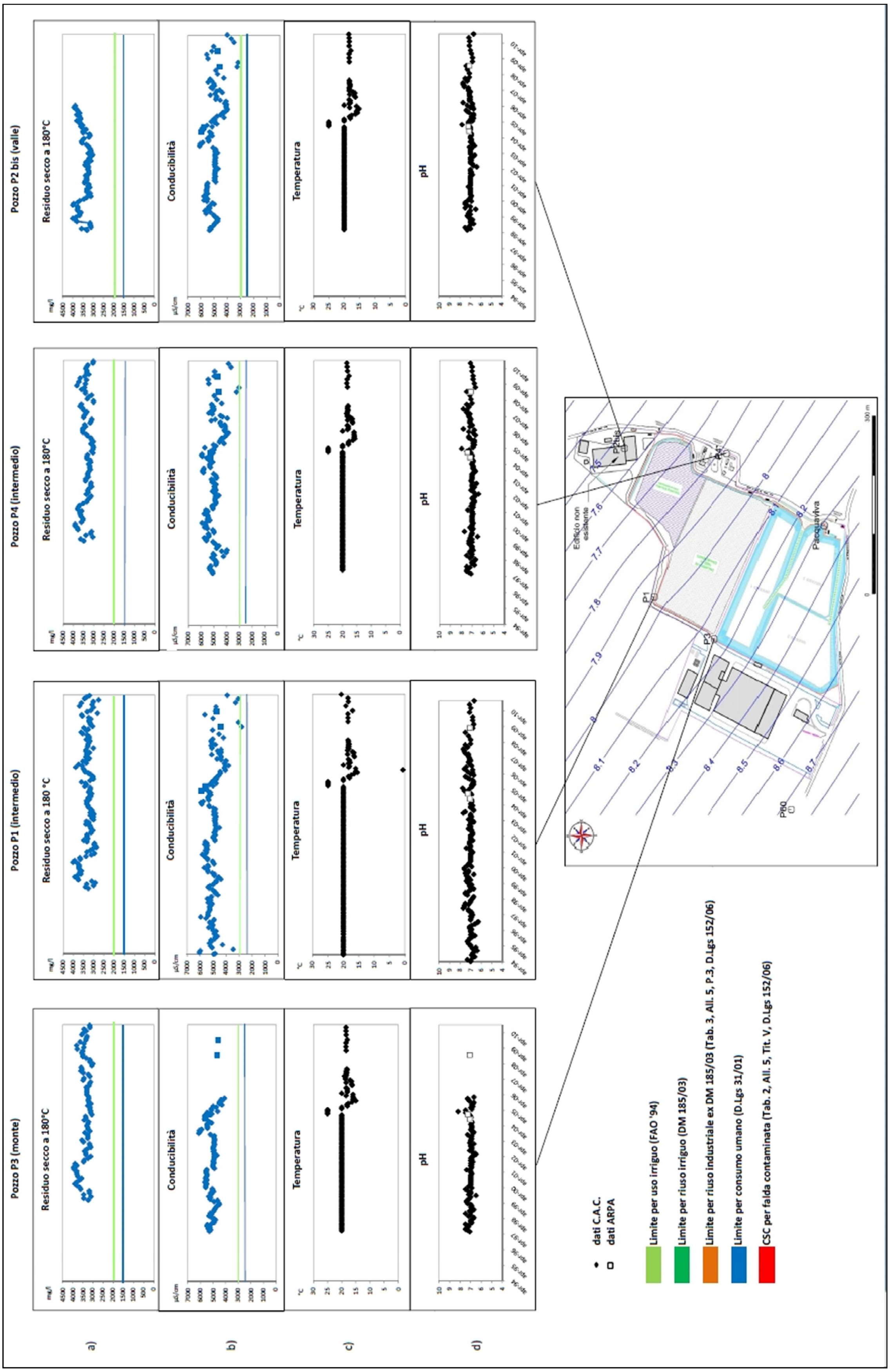


Fig.7. Variation of physical parameters of the groundwater moving along Section A) of Andria MSW sanitary landfill

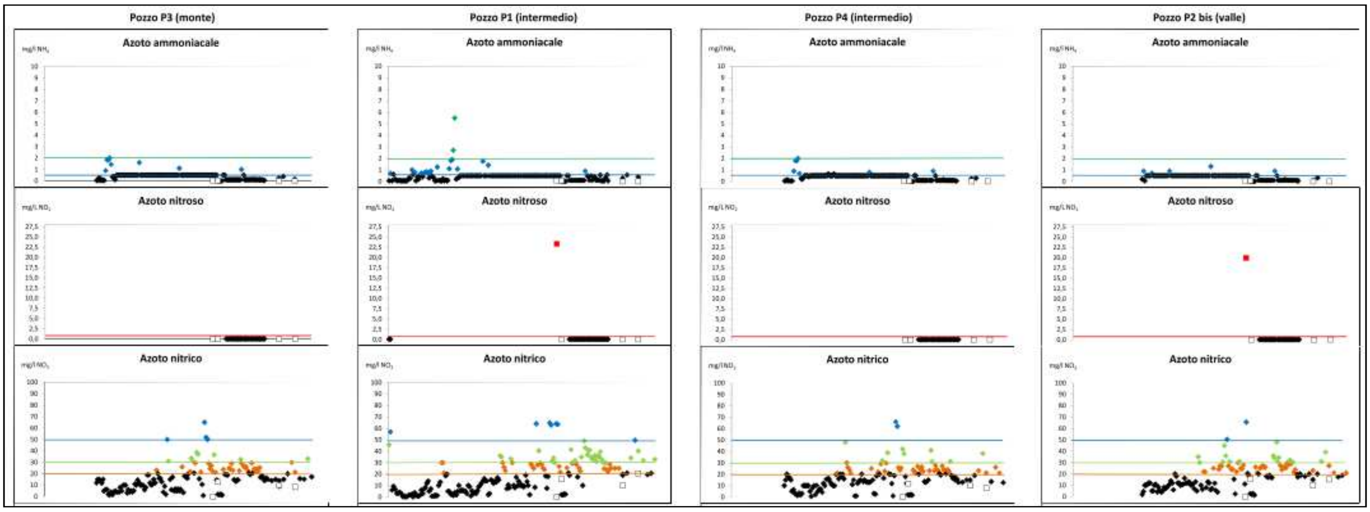


Fig.8. Variation of Nitrogenous ions in the groundwater moving along Section A) of Andria MSW sanitary landfill

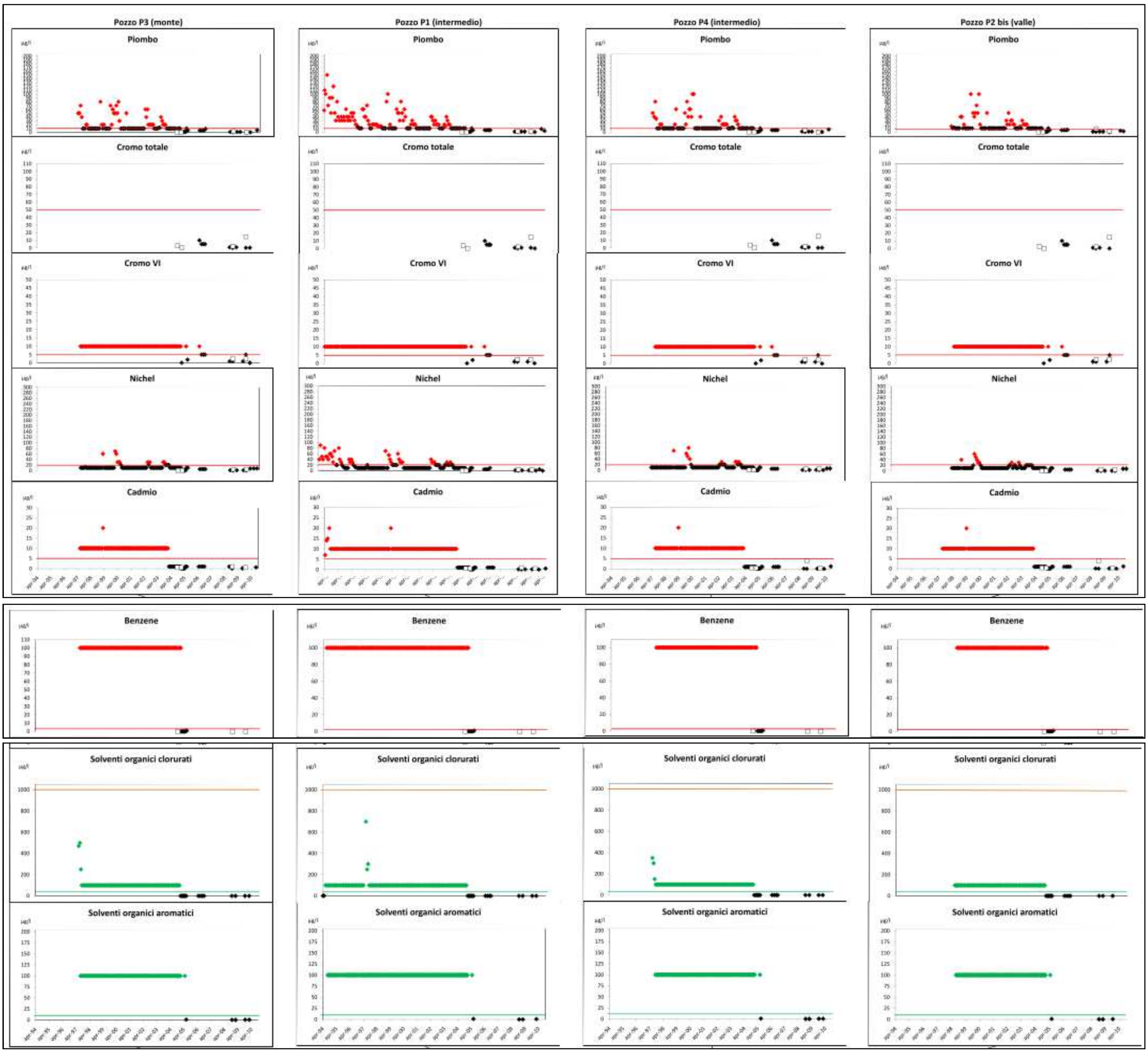


Fig.9. Variation of toxic species concentration in the groundwater moving along Section A) of Andria MSW sanitary landfill

Finally, Fig.10 shows that the concentration of Fecal and Total Coliforms, typical indicators of MSW landfill leachate, was almost and permanently negligible. Their occasionally presence (still below all the ongoing limits) in the groundwater was detectable since upstream, thus excluding conclusively that Andria landfill should be blamed upon deteriorating the aquifer.

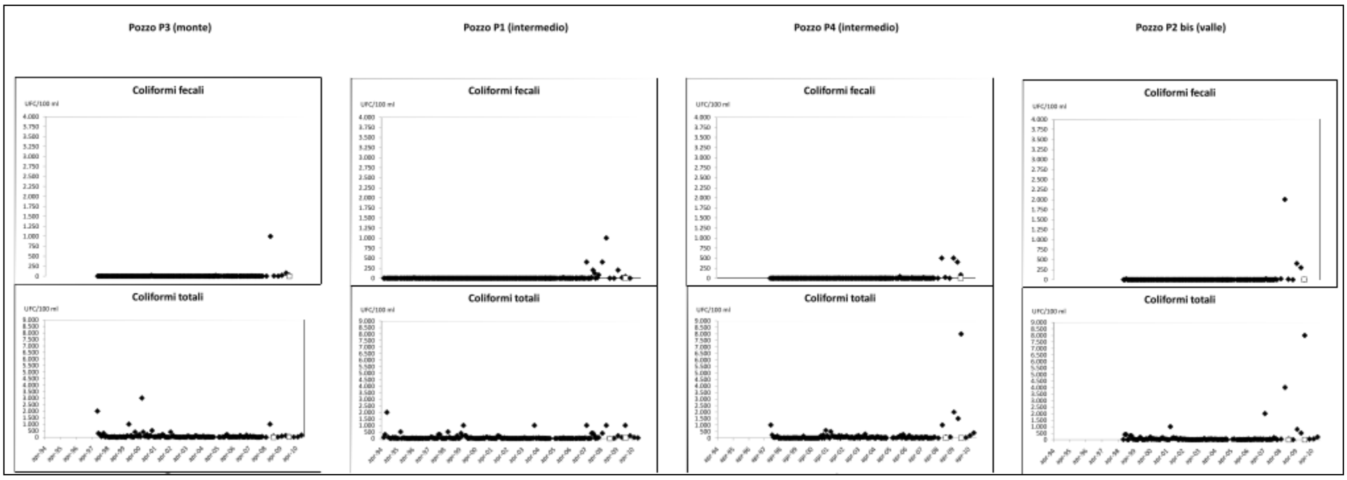


Fig.10. Variation of microbial concentration in the groundwater moving along Section A) of Andria MSW sanitary landfill

All the other 27 species analyzed in the groundwater (more heavy metals, toxic chemicals, TOC, COD, BOD etc., see Tab.2) respected, during those 17 years and along the landfill, all the 5 different standards considered as reference in this study.

On the ground of the results of this time-spatial evaluation of the potentially polluting performance of Andria Section A) MSW sanitary landfill, the new MSW complex bio-mechanic-chemical treatment plant has been approved and constructed. Now the plant is regularly operating, including the back-up Section B sanitary landfill, almost exhausted yet (Fig.11).

Fig.11. Present situation of Andria MSW bio-mechanic-chemical treatment plant with Section B) landfill almost exhausted (bottom left)

4 CONCLUSION

The “*zero waste*“ economy aiming at 100% recovery and recycling in waste management, still requires back-up sanitary landfilling for the unavoidable occasional plant shutdown. However, sanitary landfilling technology is largely refused by Civic Administrations and by the public opinion, being blamed as the exclusive polluter of the aquifer even when other activities, potentially producing the same contaminants, are active in the area. A method capable of discriminating the pollution responsibilities among various players, accordingly, is often required.

This study introduced a new tool to this aim, based on time-spatial evaluation of eventual groundwater contamination near a MSW sanitary landfill, allowing to appreciate who and when eventually caused the pollution of the beneath aquifer.

Applied for the first time to the case of Andria (Italy) MSW sanitary landfill, the new tool permitted to face positively the local opposition to a new modern plant for MSW reclamation that included a back-up sanitary landfill after the previous one was exhausted. No further complaint was raised after the new plant, now marking its 5th year of continuous operation.

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