CHEMICAL ENGINEERING TRANSACTIONS
VOL. 28, 2012
Guest Editor: Carlo Merli

**ISBN** 978-88-95608-19-8; **ISSN** 1974-9791

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

DOI: 10.3303/CET1228008

# Risk Analysis of a Disused Landfill as Support Tool for Defining Strategy and Priority of the Remediation Actions

Eleonora Palmeri[a], Giuseppe Mancini*[a], Antonella Luciano[b], Paolo Viotti[b]

[a] Department of Industrial Engineering, University of Catania, Viale A. Doria 6, I-95125, Catania, Italy
[b] Department of Civil, Building and Environmental Engineering, “Sapienza” University of Rome, Via Eudossiana 18, I-00184, Rome, Italy
gmancini@dica.unict.it

Landfills have been the most common form of waste disposal, and old landfills are present or in close proximity to most communities. Many old landfills, built before the environmental laws could properly regulating waste disposal, often not lined, are now considered potentially contaminated sites and can represent a severe environmental issue posing a long-term risk to health and the environment. In this paper a risk analysis procedure aimed at investigating the long-term risk of groundwater contamination posed by old Municipal Solid Waste (MSW) landfills was applied in combination with LandSim (Landfill Performance Simulation) model with the aim of obtaining an integrate tool to assist decision makers establishing priorities for remediation action. A case study was carried out at an old landfill site filled with MSW, the oldest of which dated back to 1970. Risk analysis was carried out according to international and Italian guidelines. The risk for groundwater was considered by comparing the concentration at the compliance point with the Italian regulatory limits (CSC contamination concentration threshold), whereas the risk for humans was based on maximum chronic population exposure. The adopted risk analysis approach, for old landfills, appears to be a key tool to assist decision makers in establishing priorities for remediation action.

## 1. Introduction

Landfills have been the most common form of waste disposal, and old landfills are present or in close proximity to most communities. Prior to environmental laws that regulated waste disposal, landfills were no more than holes in the ground where trash was dumped in, often burned, and finally covered with dirt. Many of these landfills were not lined, and not properly set up. As a consequence most of the landfills, constructed in this fashion, now represent a severe environmental issue that can pose a long-term risk to health and the environment, with particular reference to the possible emission of leachate and biogas. The use of the risk analysis procedure for investigating the long-term risk of groundwater contamination posed by old MSW (Municipal Solid Waste) landfills, can represent an affordable approach for local administrations especially when the economic resources are poor. Within American Society for Testing and Materials (ASTM) and Risk-based corrective action (RBCA) programs, fate and transport modeling is one of the tools used to establish exposure point concentrations and their corresponding risk-based screening and cleanup levels. Various formulations of fate and transport models have been used for more than twenty years to assess and predict movement and behavior of chemicals in the environment. Over time, more sophisticated fate and transport models have been developed but numerical models were limited to Tier 3 analyses. In RBCA Tier 2 for risk site specific

Please cite this article as: Palmeri E., Mancini G., Luciano A. and Viotti P., 2012, Risk analysis of a disused landfill as support tools for definig stategy and priority of the remediation actions, Chemical Engineering Transactions, 28, 43-48 DOI: 10.3303/CET1228008

analysis (procedure adopted in Italy), analytical model are used avoiding the time variation of chemical concentration at the source.

In this paper LandSim vers.2 was used to estimate the fate and transport of chemicals through the engineering and natural barriers, and in the unsaturated and aquifer pathway, up to the exposure point (POI), taking into account time variability of leachate production and composition using a declining source terms. The risk for the groundwater and for humans (inhalation) was then evaluated according to international guidelines (USEPA, 2005). A case study was carried out at old landfill site containing mainly municipal solid wastes (MSW).

## 2. Case study

The Cozzo Vuturo landfill site covers an area of 12 ha located at about 3.8 km from the city of Enna (Sicily, Italy). The landfill zone include an old landfill of 4.5 ha containing about 250,000 $m^3$ of urban old waste), operating from 1975 to 1999. The landfill is located in a hilly area, geologically made up of Numidian Flysch of Holigocene lower age, marly and sandy brown clay of medium Miocene age, and river alluvium of Holocene age. The superficial layer is made of a mixture of humus and clay (1 – 2 m deep) within the area of the landfill and a clay layer of about 30-40 m below it. The average permeability of the clay layer varies in the range $2x10^{-9}$ - $7x10^{-9}$ cm/s. The humus layer is an aquifer but the recharge area is very small and the groundwater can be found only for a short time in the aquifer. Apart from that layer, there is another low flow aquifer, 30-40 m below the surface, situated below the clay layer. The landfill was not provided with engineering barriers, drainage systems and superficial capping. A characterization survey, (performed in 2006) showed exceeds of the threshold limits of Italian regulation (Decreto Legislativo 16 Gennaio, 2008) for some chemical parameters in groundwater (Aluminium, Arsenic, Iron, Manganese, Lead, Benzene). Climatic data on the Enna area were provided by the Sigonella Meteorological Station. The mean daily temperature in the Enna area is about 14 °C and the average annual rainfall value is 623 mm/y.

## 3. Methodology

Preparing a robust conceptual model is a critical element in successfully evaluating environmental risks (Vianello and Maschio, 2011). The conceptual site model should describe potential environmental impacts associated with the site and it should contain a detailed description of a) the characteristics of the sources a) migration pathway and their characteristics, c) targets. Because of the high age of the landfill the impacts associated with biogas emission were neglected and only the risk associated with leachate was evaluated. The concentrations trend of the chemicals ($Ci_{POE}$ (t)) at the exposure point (POE i.e. where the risk are calculated) were evaluated using LandSim v.2, a computer simulation model tool for risk assessment of landfills (Drury et al., 2003; Hall et al., 2006). LandSim enables a variety of different landfill scenarios. It uses a contaminant-specific declining source term based on the results of standard upflow percolation leaching tests and the Laplace transform technique to solve the advection-diffusion contaminant transport equation. Biodegradation and longitudinal dispersion can be modelled in all pathways, retardation in both the unsaturated zone and the aquifer, and attenuation in the mineral component of liners. The various parameters combine to model the amount of leachate generated, concentration of selected contaminants in the leachate, behaviour within the landfill, likelihood of release through the engineered barrier, and transport within the subsurface to an aquifer. The model simulation runs for 20,000 years, providing a long-term forecast of landfill leachate behaviour at each stage of plume migration from source (i.e. within the landfill body), through to the base of the clay liner, the base of the unsaturated zone, and at the off-site monitoring well.

Once the trend of the i-contaminant is obtained at the point of exposure ($Ci_{POE}$ (t) the maximum and the current risks are evaluated. The risk for groundwater was considered comparing the $Ci_{POE}$ (t) with the regulation (Decreto Legislativo 16 Gennaio, 2008) limits and assuming the exposure point to correspond to the compliance point (i.e where the groundwater quality must respect the concentration limits). The inhalation risk from groundwater was evaluated by calculating the inhalation concentration for the receptor at POE, starting from the concentration in groundwater at the compliance point (Farmer et al., 1980; Johnson and Ettinger, 1991).

**3.1 Source characterization**

Site specific data (landfill geometry, characteristics of the barriers, leachate composition, and meteorological data) were used in the present application. Chemical and physical properties of the contaminants were derived from Italian Health Institute database (ISS, 2009). The study focused on the species present in the leachate and discovered in groundwater with concentration values exceeding the Italian regulation thresholds (Aluminium, Arsenic, Iron, Lead, Manganese and Benzene).

The source for non-volatile substances was considered with a time-declining concentration through the following expression:

$$C(t) = C(0)e^{-(K*LS)} \tag{1}$$

Where: C(t) is the concentration of the species at the time t (mg $L^{-1}$); C(0) is the initial concentration of the species (mg $L^{-1}$); LS is the liquid/solid ratio at time t (L $kg^{-1}$); K is a waste specific constant accounting for the release of the species from the solid waste to the aqueous phase (Van der Slot, 2001), that depends on C(0) according to the following expression:

$$K = m \ln C(0) + c \tag{2}$$

Where m and c are empirically derived specific costants for each specie (kg L-1) (Drury et al., 2003). Initial concentration values (C(0)) was obtained from the analysis on leachate produced by the nearest and operating landfill basin.

**3.2 Exposure and migration pathway**

The following leachate pathways were considered: a) fate and transport through the unsaturated and saturated zones and; b) vapor diffusion from groundwater (only for volatile compounds). A Laplace transform technique is used in LandSim to solve the advection-diffusion equation (ADE) of contaminant transport:

$$\frac{\partial C}{\partial t} = D_L \frac{\partial^2 C}{\partial z^2} - v \frac{\partial C_{EDTA}}{\partial z} - R\gamma c \tag{3}$$

Where: x is the distance along the pathway in the direction of flow (m); t is the time (s); c (x,t) is the concentration at a distance x and a time t (m,s); v is the mean effective velocity of groundwater; R is the retardation factor (-); $\gamma$ is the rate of decay of the contaminant; $D_L$ is the longitudinal coefficient of hydrodynamic dispersion ($m^2$ $s^{-1}$). The retardation factor is evaluated as:

$$R = 1 + \left(\frac{\rho}{n}\right) k_d \tag{4}$$

Where: $\rho$ is the bulk density of material (g $cm^{-1}$); n is the effective porosity of material (-) and $K_d$ is the distribution coefficient for each specific contaminant (mL $g^{-1}$). For organic species Kd was evaluated as $K_d = K_{oc} \cdot f_{oc}$, where $K_{oc}$ (mL $g^{-1}$) is the soil organic carbon/water partition coefficient and $f_{oc}$ ( g $g^{-1}$) is the fractional soil organic carbon content. Kd values were obtained (ISS, 2009) from the database of Health Italian Institute (ISS). A general analytical solution to the 'transformed' advection-diffusion equation can be derived for each pathway, including mechanisms like advection and dispersion and for any time-varying concentration entering the pathway. The (time-dependent) concentration at the source provides the 'input' for the unsaturated vertical pathway. The transformed concentration at the end of the pathway can thus be easily calculated being the 'input' to the saturated vertical pathway. Similarly, the concentration at the end of the saturated vertical pathway provides the 'input' to the aquifer pathway. The groundwater outdoor volatilization factor ($VF_{wamb}$) was evaluated using Eq. 5a (Farmer, 1980), whereas the groundwater indoor volatilization factor ($VF_{wesp}$) was evaluated using Eq. 5b (Johnson and Ettinger ,1991):

a) $VF_{wamb} = \dfrac{H}{1 + \dfrac{U_{air}\delta_{air}L_{GW}}{D_{ws}^{eff}W}} \cdot 10^3$ b) $VF_{wesp} = \dfrac{H \cdot D_w^{eff} / L_{GW}L_B ER}{1 + \dfrac{D_{ws}^{eff}}{L_{GW}L_B ER} + \dfrac{D_{ws}^{eff}L_{crack}}{D_{crack}^{eff}L_{GW}\eta}} \cdot 10^3$ (5)

Where: H is Henry's constant (adim), $U_{air}$ is the windspeed above ground surface in ambient mixing zone (cm $s^{-1}$); $\delta_{air}$ (cm) is the ambient air mixing zone height; $L_{GW}$ (cm) is the depth to groundwater; W (cm) is the soil source dimension parallel to wind direction; $D_{WS}^{eff}$ ($cm^2$ $s^{-1}$) is the effective diffusivity above the water table; $L_B$ (cm) is the ratio of enclosed space volume to infiltration area; $L_{crack}$ (cm) is the

enclosed space foundation or wall thickness; ER (L $s^{-1}$) is the enclosed space air-exchange rate; η (adim) is the areal fraction of cracks in foundations/walls.
The inhalation concentration for the receptor $Ci_{REC}$(t) was then evaluated as:

$$Ci_{REC}(t) = GVF \cdot Ci_{POE}(t) \quad (6)$$

Where $Ci_{POE}$ (t) is the concentration of species (i), at the compliance point, evaluated through the fate and transport model (Eq. 3).

### 3.3 Risk assessment

In order to apply the risk assessment procedure the maximum daily intake considering the exposure for an average lifetime of 70 years ($MDI_{70}$ (mg $kg^{-1}$ $day^{-1}$)) was considered:

$$MDI_{70} = C \cdot EM \quad (7)$$

Where C is the concentration of chemical in air (mg/$m^3$), and EM (mg $kg^{-1}$ $day^{-1}$) is expressed as:

$$EM = Qc \cdot EF \cdot ED / (BW \cdot AT) \quad (8)$$

Where $Q_C$ is the inhalation ($m^3$ $day^{-1}$) or ingestion rate (mg $day^{-1}$), EF is the exposure frequency (days or years), ED is the exposure duration (years), AT is the averaging time (years) and BW represents the body weight (Kg). Risk assessment for carcinogenic effect was calculated using the following equation:

$$R = MDI_{70} \cdot Sf \quad (9)$$

Where R is the cancer hazard risk, Sf (kg·d·$mg^{-1}$) representing the chemical's carcinogenic potency after administration. Toxicological values were taken from ISS database (2009).

## 4. Results and discussion

### 4.1 Leachate plume modeling and risk evaluation for groundwater

The calculated trends of chemicals, initially present in the leachate (source) are reported in Figure 1. For all the contaminants, concentrations levels, within the waste body, significantly declined over the years. Inorganic substances declined less rapidly, with heavy metal content in the landfill being negligible after about 50 years for Aluminum, after 400 years for Lead and after 700-1000 years for Manganese, Iron and Arsenic. Benzene was not evident in the landfill beyond 35 years. Concentrations of contaminants at monitoring well, assumed as the compliance point, are reported in Figure 2, together with the regulatory limits (CSC) and the observed value during groundwater monitoring campaign in 2006 (31 years after landfilling started). The inorganic substances are the main causes of concern for leachate plume leakage, attaining peak concentrations after a long period (130 y for Manganese, 280 y for Iron, 340 y for Lead, 560 y for Arsenic and 1500 y for Aluminum). All these substances show high retardation factors.

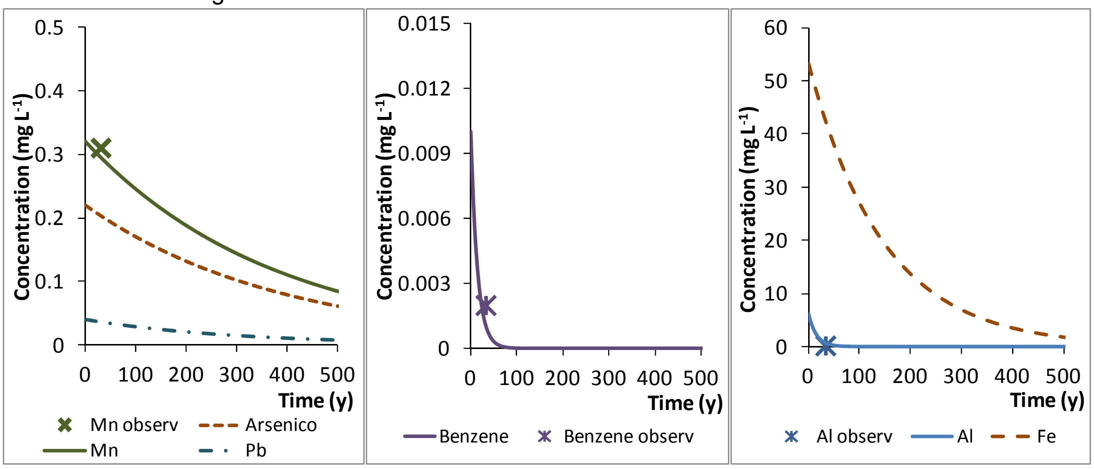


*Figure 1: Simulated trend of chemicals in the leachate and measured concentration (31 years after landfilling started).*

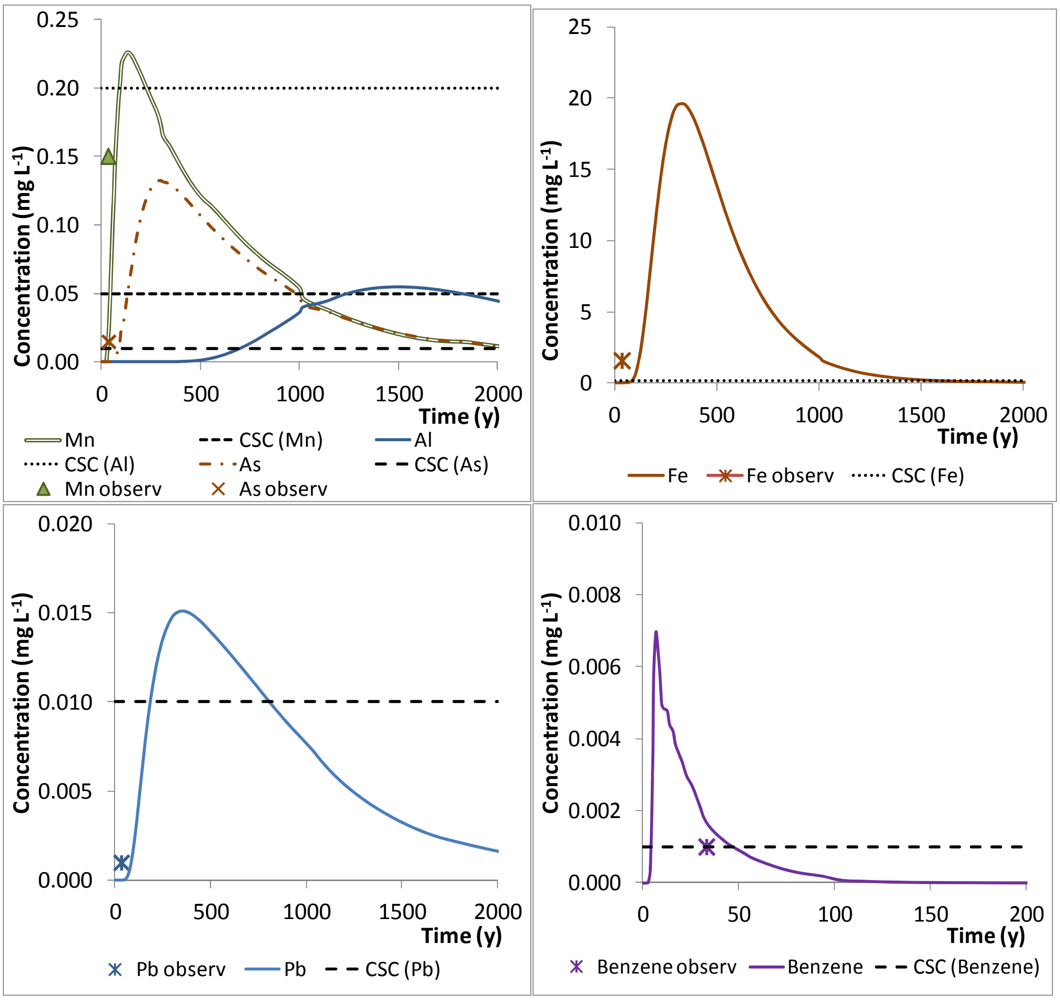


*Figure 2: Simulated leachate plume concentrations at the compliance point and measured values at the monitoring well.*

As a consequence, peak concentrations at the monitoring well and in the unsaturated zone, occurred at different times, indicating that the related pollutions were not simultaneous and the effects on groundwater quality and on human target vary with time. The time evolution of pollution from the different contaminants should carefully be considered when a risk analysis is performed, especially when various contaminants can contribute to the cumulative risk evaluation, in order not to overestimate the effects on health.

The concentrations of contaminants in the simulated leachate plume, at the compliance point, were compared with the Italian regulatory concentration limits (CSC) imposed to maintain groundwater quality for current or future drinking water abstraction (Figure 2). Arsenic, Manganese, Lead, Iron and Benzene exceed drinking water standard, as also evidenced by groundwater analysis made in 2006.

**4.2 Health risk assessment**

Carcinogenic risk was assessed for inhalation of the only volatile compound present in the leachate (benzene). Risk assessment was calculated on the basis of the Chronic Daily Intake (CDI) and its correspondent slope factor (Sf). In Table 1, exposure value (EM), groundwater volatilization factors and calculated cancer risk values are reported for inhalation exposures.

*Table 1: Exposure values (EM), volatilization factor and carcinogenic risk (R) for Benzene*

| Scenarios | Sf $(mg\cdot kg^{-1}\cdot d))^{-1}$ | $C_{POE}$ ($\mu g\ L^{-1}$) | $VF_{wesp}$ | $VF_{wamb}$ | EM $(m^3\cdot kg^{-1}\cdot d^{-1})$ | Risk | |
|---|---|---|---|---|---|---|---|
| | | | | | Adults | Indoor | Outdoor |
| a) | $2.73\cdot 10^{-2}$ | 1.81 | $2.48\cdot 10^{-3}$ | $2.35\cdot 10^{-5}$ | 0.101 | $1.24\cdot 10^{-8}$ | $1.17\cdot 10^{-10}$ |
| b) | $2.73\cdot 10^{-2}$ | 6.96 | $2.48\cdot 10^{-3}$ | $2.35\cdot 10^{-5}$ | 0.101 | $4.76\cdot 10^{-8}$ | $4.50\cdot 10^{-10}$ |

Two scenarios were considered: a) risk at the current time; b) risk at the time of the concentration peak occurrence. Because the site is catalogued as industrial site, only inhalation exposure (indoor and outdoor) for adults was considered.
The evaluated cancer risk (indoor) was equal to $1.24\cdot 10^{-8}$ and $4.76\cdot 10^{-8}$ for the scenario (a) and (b) respectively. Results for the different scenarios for cancer effects show risk estimates which are orders of magnitude below those accepted from the main international agencies (Word Health Organization, United States Environmental Protection Agency) and by Italian legislation (Decreto Legislativo 16 Gennaio, 2008), so adverse health effects can be considered tolerable.

## 5. Conclusions

Results of the simulation on the Cozzo Vuturo Landfill, constructed without engineering barriers, drainage system and superficial capping, show as Arsenic, Manganese, Lead, Iron and Benzene exceed drinking water standard at the compliance point. Old landfills that not fulfill current law design criteria, pose a threat to groundwater. However results for cancer risk, due to inhalation of volatile compounds (benzene), for different scenarios, are orders of magnitude below those accepted from the main international agencies and by local legislation. The proposed combined approach allows the time-dependent behaviour of contaminants associated with the disposal of MSW landfills to be modelled and the related risk to be evaluated. Results show the possibility to individuate the non simultaneous trend (peak concentrations at the monitoring well, and in the unsaturated zone, occurred in different times) of any pollutant and then to evaluate evolution of the effects on groundwater quality and on human targets. The proposed risk analysis for old landfills thus represents an useful tool to assist decision makers to evaluate the chance of remediation or to establish a priority hierarchy for different sites remediation actions.

### References

Decreto Legislativo 16 Gennaio, 2008, n.4, Ulteriori disposizioni correttive ed integrative del decreto legislativo 3 aprile 2006, n.152, recante norme in materia ambientale (In Italian), Gazzetta Uf ciale n.24, 29 gennaio 2008, Suppl. Ordinario n. 24.

Drury D., Hall D.H., Dowle J., 2003, The development of LandSim 2.5, NGCLC Report GW/03/09, Environment Agency, Bristol, UK.

Farmer, W.J., Yang M.S., Letey J., Spencer W.F., 1980, Hexachlorobenzene: Its Vapor Pressure and Vapor Phase Diffusion in Soil, Soil Sci. Soc. Am J., 44, 445-450.

Hall D.H., Drury D., Keeble, R., Morgans A., Wyles R., 2006, Establishing equilibrium and pollutant removal requirements for UK landfills, R&D Technical Report P1e465, Environment Agency, Bristol, UK.

ISS (Istituto Superiore di Sanità), 2009, Toxicological database (In Italian), <www.apat.gov.it>

Johnson P.C, Ettinger R.A.,1991, Heuristic model for predicting the intrusion rate of contaminant vapors into building, Environ. Sci. Technol, 25(8), 1445-1452.

USEPA (United States Environmental Protection Agency), 2005, Guidelines for carcinogen risk assessment, Federal Register 70(66), 17765-17817

Van Der Slot H. A., Rietra R.R.J.J., Vroom R.C., Schariff H., Woelders J. A., 2001, Similarities in the long term leaching behaviour of predominantly inorganic waste, MSWI bottom ash, degraded MSW and bioreactor residues. Proceedings Sardinia, Eighth International Waste Management and Landfill Symposium, Vol 1, 199-208.

Vianello C., Maschio G., 2011, Risk analysis of natural gas pipeline: case study of a generic pipeline, Chemical Engineering Transaction, 24, 1309-1314