

# **The current situation of sanitary landfills in Brazil and the application of economic models**

**Raul Oliveira Neto, Ph.D.**  
**Mining technology course**  
**Federal University of Pampa - UNIPAMPA**  
Avenue Anunciação s/n, ZIP 96570-000.  
Caçapava do Sul, Rio Grande do Sul, Brazil.  
[raul.oneto@uol.com.br](mailto:raul.oneto@uol.com.br)  
[raulneto@unipampa.edu.br](mailto:raulneto@unipampa.edu.br)

**Carlos Otávio Petter, Ph.D.**  
**Postgraduate Program in Mining Engineering, Metallurgy and**  
**Materials (PPGEM)**  
**Federal University of Rio Grande do Sul - UFRGS**  
Avenue Bento Gonçalves 9500, ZIP 91501-970.  
Porto Alegre, Rio Grande do Sul, Brazil.  
[cpetter@ufrgs.br](mailto:cpetter@ufrgs.br)

**José Luís Cortina, Ph. D.**  
**Department of Chemical Engineering,**  
**Catalunya Polytechnic University**  
Avenue Diagonal, 647, E-08028  
Barcelona, Spain.  
[jose.luis.cortina@upc.edu](mailto:jose.luis.cortina@upc.edu)

**Abstract:** We present the development stage of the sanitary landfills in Brazil in the context of urban solid residue management, demonstrating the necessity and importance of the employment of economic models. In the article, a cost estimate model is proposed as the basis for studies to be applied by sector management, including the city council, companies, consultants and engineers, contributing to the choice of new areas, public bids, municipal consortia and private public partnerships.

**Keywords:** Sanitary landfill, municipal solid waste, economic models, Brazil

## **Introduction**

The management of municipal residues is a subject that is becoming increasingly important in the context of global governmental concerns, and has undergone considerable development over the last decade. Although efforts have been made to reduce the quantity of residues destined to the so-called sanitary landfills, increasing

recycling and valuation, there is unanimous agreement that this system of disposal will be relied upon for a long time, mainly in the case of developing countries including Brazil. The main objective of the present article is to discuss the real situation of this scenario and to propose a model to be used as a working tool applied to economic engineering studies known as 'quick evaluations', applied during the pre-viability phase of a project.

### **Evolution of sanitary landfills in Brazil and perspectives**

The question of an adequate destination for solid residues of domestic origin has been discussed in Brazil for over 24 years. The first technical standards published by the Brazilian Association of Technical Standards (ABNT) date back to 1984 (NBR8419). However, the real application of these standards is relatively recent and only began in the last decade with the publication of the NBR (Brazilian Standards) ABNT standard 13896 (NBR13896 1997), which deals with technical specifications for the project and implantation of sanitary landfills. Following the last official enquiry published by the Brazilian Institute of Geographical Economy (IBGE 2000), of the 5507 Brazilian counties, 63.6% used open dumps (*lixões*) as their form of final destination, this being an inadequate form of residue storage with no form of environmental control procedure. Following the same publication, only 13.8% of Brazilian counties participated in sanitary landfills. This situation has evolved little, and current projections indicate that sanitary landfills have not yet reached 20% of participating counties. In association with this, there are alarming indications that show a 1% annual growth of the Brazilian population and a 3% annual growth in domestic residues (Calderoni 2003). Over recent years there has been strong movement in the promotion and encouragement of the implantation of new areas within the mould demanded by legislation. Strong action has resulted in the inspection of environmental bodies, closing down clandestine and inadequate areas such as *lixões*. As a result of this, the municipal bodies (city councils) have been forced to take measures in the regulation or rectification as, according to current legislation, it is these public bodies that are responsible for the management of these residues. The federal government has in turn been implementing financial sources and support and backing for the sector's development, encouraging new sanitary landfill projects to be integrated into the carbon credits market. A very specific scenario is consequently being outlined i.e. the tendency of mobilization and organization of small and medium-sized city councils (municipalities with less than 100 000 inhabitants) in the formation of the so-called 'municipal consortia' (Lima 2003). These consortia provide administrative and financial advantages. There is a proportional division of implantation costs and operation of sanitary landfills, beyond shared responsibility, facilitating the administration of this enterprise. The public private partnerships (PPPs) also fit into this context and offer the advantages of economic and practical order to the municipal city councils, transferring part of the responsibility to private companies. Faced with this perspective, we may conclude that there is a great necessity for the development of models for economic studies that may be used as management tools by agents involved in the sector to speed up decision making. Existing models are more concerned with the global management of solid residues and what are called 'product life cycle inventories', not centred upon the question of costs. Very little is revealed about the real implantation and operational costs of sanitary landfills within the context of Brazil's conditions, a subject that the technical literature omits (Reichert & Reis 1998).

Finally, it's important to present in this introduction that one of the alternatives to the issue of Mine Closure is in the use of remaining pits for the implementation of solid waste landfills. The main advantage of this view is in fact to achieve two objectives simultaneously, that is, the environmental recovery of areas degraded by mining activities deploying an enterprise profitable and environmentally safe.

### **Model for sanitary landfill cost estimates**

The model proposal comprises estimates of investments and operational costs for sanitary landfill studies and projects, and is based on the landfill costs versus daily residue receiving capacity curves. The data were obtained through research that comprised bibliography, questionnaires and technical visits, developed during doctorate thesis of the Raul Oliveira Neto (Neto 2008), one of the authors of this article. Within this context, the model ties in with the estimation type by size order (conceptual and preliminary study stage of project), and in the estimation technique by exponential adjustment which considers the scale effect i.e. the variation of costs according to the variation of landfill capacity. In this way, the proposal accommodates the concept of quick evaluations for analytical studies and decision making. The level or degree of precision accepted within economic engineering theory for results of this type of model lies within the margin of error between -30% and +50% (Nagle 1998). To develop this type of landfill cost estimation model, we have used the O'Hara model as a basis. Very well known in mining, this model was introduced in 1980 when O'Hara (Hustrulid & Kuchta 1995) published 'Quick guides to the evaluation of ore bodies', which has now become a classic paper. The O'Hara model covers the costs associated with both open pit and underground mining. The formulae given for equipment sizing, preproduction stripping and maintenance facilities presume that the shape and type of open pits are similar. The aspects that mining and landfills have in common allow us to use the idea of the O'Hara model within the landfill cost estimation model proposed in this study. These correlation curves are obtained using the following type of mathematical equation:

$y = A x^B$ , where  $y$  (variable answer) corresponds to the variable costs of sanitary landfills (US) and  $x$  (independent variable) to the variable capacities of sanitary landfills (tonnes of residue/day).  $A$  and  $B$  are constant parameters resulting from the conditioning or dispersal of the respective correlating databases. Figures 1 and 2 depict the exponential adjustment curves obtained through the model development for each of the cost types analyzed, demonstrating the scale effect (Neto 2008). Table 1 lists the obtained results in terms of correlation coefficients and equations obtained for the cost type identified, analyzed in the compositions of the activity structure of a sanitary landfill (Figures 1 and 2). The correlation results are directly related to the information sources that were used to form the databases from which the model originated. The best results (best correlation indices  $R$ ) of this correlation were obtained for operational costs (Cop) and for environmental and security control (Camb). This can be explained by simple counting and are consequently more trustworthy, offering greater coherence and less dispersion of the points shown in their respective graphs. The poorer results (lowest correlation index  $R$ ) were those related to the preparation costs of sanitary landfills (earth-moving and impermeabilization of the base). This can be explained by the influence of factors related to landfill capacities as well as factors related to the technical characteristics of different types of terrain (geology and topography). The  $R^2$  index obtained in this case (0.756, see Figure 1) is not considered bad for the sanitary

landfill sector, and studies of this type consider indices below this as viable (Weng & Chang 2001).

Table 1: Results obtained for sanitary landfill cost estimate models synthesized in the correlation coefficients and regression adjustment equations obtained.

Sanitary landfill cost type	Correlation coefficient (R)	Regression adjustment
Cest: studies and projects	0.9528	$C_{est} = 3312.4 \text{ Cap}^{0.517}$
Cinf: infrastructure	0.9372	$C_{inf} = 12\,652 \text{ Cap}^{0.5502}$
Cpr: preparation of deposit area	0.8709	$C_{pr} = 26\,127 \text{ Cap}^{0.644}$
Camb: environmental control	0.9559	$C_{amb} = 2694.9 \text{ Cap}^{0.5553}$
Cop: operational	0.9894	$C_{op} = 9241.4 \text{ Cap}^{0.7971}$
Cmo: labor	0.9546	$C_{mo} = 14\,002 \text{ Cap}^{0.4963}$

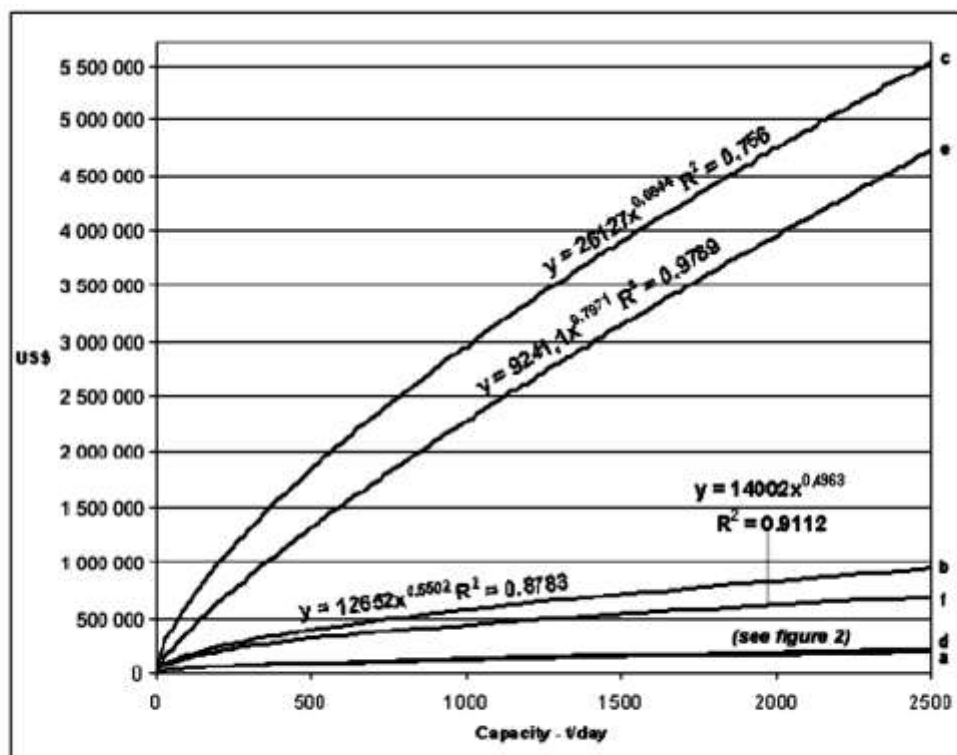


Fig. 1: Resulting graph for exponential adjustment curve of (a) cost data with studies and projects Cest: (b) infrastructure costs Cinf: (c) cost for the preparation of the deposit area Cpr: (d) costs for environmental control Camb: (e) operational costs Cop: and (f) labour costs Cmo, against daily input rate (Cap) of the studied landfills.

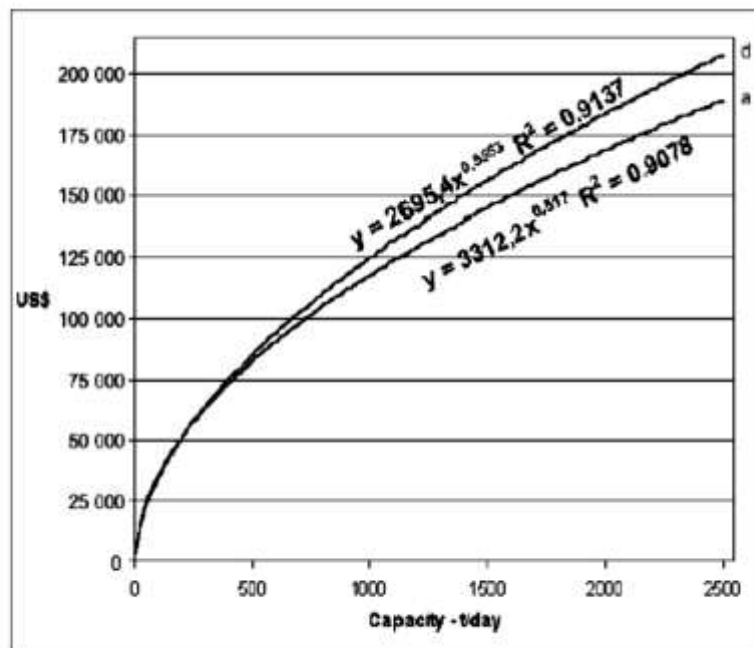


Fig. 2: Details of resulting graph for exponential adjustment curve of (a) cost data with studies and projects Cest and (d) costs for environmental control Camb against daily input rate (Capi) of the studied landfills.

Validation tests were carried out on the model, comparing the values obtained from real sanitary landfill cases published by trustworthy sources, municipal city councils within the state of Rio Grande do Sul, Brazil, and the control and research body in São Paulo, Brazil. The average error rate was between  $-13\%$  and  $+26\%$  and therefore falls within the acceptable interval previously quoted. The sanitary landfills published have a daily receiving capacity of between 20 and 1150 tonnes/day, a representative and reachable interval (Neto 2008).

To the development of this study and the understanding of its users, abbreviations have been utilized in order to identify all data types obtained and their respective adopted classifications. Table 2 lists the notation for each classification, also considered as database variables.

Note that  $CI=Cest+Cinf+Cpr+Camb$ ,  $CO=Cop+Cmo$  and  $CT=CI+CO$ . Note also that many variables are dimensionless; these are indicators of the presence or absence of the characteristics that they represent. They are referred to as binary variables as they can only take the values 0 or 1.

Table 2: Complete database resulting from sanitary landfill cost collection.

Database variable	Notation	Unit
Initial study cost	Cest	US\$
Infrastructure cost	Cinf	US\$
Preparation cost	Cpr	US\$
Security and environmental costs	Camb	US\$
Total implantation cost (investments)	CI	US\$
Annual operation cost	Cop	US\$
Annual manpower cost	Cmo	US\$
Total annual operational cost	CO	US\$
Total cost	CT	US\$
Daily landfill capacity	Cap	t/dia
Useful sanitary landfill area	Are	ha
Primary level leachate treatment	TP	–
Secondary level leachate treatment	TS	–
Tertiary level leachate treatment	TT	–
Biogas recuperation and generation of energy	BG	–
Municipal landfill management	GM	–
Private landfill management	GP	–
Topography of area – plan view	plan	–
Topography of area – section view	enc	–
Disused mining cavity	cav	–
Landfill process operation by ramp	ramp	–
Landfill process operation by unit cells	trin	–
Predominant clay lithology	arg	–
Predominant claystone lithology	sai	–
Predominant sedimentary lithology (sandstone)	aren	–
Predominant igneous lithology (granite/basalt)	ign	–

## Conclusions

The proposed economic cost estimate model presents a reasonable level of prediction, even when taking into account the uncertainties involved in the decisions made in preliminary studies for the implantation of new sanitary landfills or in the optimization of existing landfills. This way it allows us, through simple use of equations that depend on only one variable, to study various options and alternatives in both economic terms as well as in terms of the size of the enterprises (sanitary landfills). We can eliminate the worst cases and follow on with more detailed studies in order to determine the best alternative. The levels of risk are progressively reduced in this way, making the study

suitable for quick evaluations often used in economic engineering (Weng & Chang 2001).

The main advantages and applications of the model in the context of municipal solid residue management are:

- To establish price limits for the decreeing of public bids made by the city councils, avoiding waste of public money;
- To establish financing sources and subsidies issued by the municipal, state and federal-level governments;
- To aid the establishment of municipal ‘trash’ taxes, charged to the population;
- Definition of costs to be shared between municipalities in the formation of consortia;
- Definition of costs involved in the PPPs; and
- The possibility of model adaptation as a fast and easy-to-use piece of software, enabling the integration of other cost types such as those of transport and the closure of sanitary landfills.

This whole range of practical applications seeks to aid the development and optimization of sanitary landfills, to contribute towards the improved integrated management planning of solid municipal residues.

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