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Overseas Geology Series

DFID Project No. R6532

A CATALOGUE OF LEACHATE QUALITY FOR SELECTED LANDFILLS FROM NEWLY INDUSTRIALISED COUNTRIES

M E Stuart & B A Klinck

Natural Environment Research Council

BGS International®
British Geological Survey
Keyworth
Nottingham NG12 5GG
United Kingdom

A Catalogue of Leachate Quality for Selected Landfills from Newly Industrialised Countries

WEBSITE QUESTION 6

Solid waste disposal sites site are common in country areas around towns and industrial zones. How does one set about assessing potential hazard to the groundwater resource from solid waste disposal activities?

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Keyworth, Nottingham NG12 5GG
☎ 0115-936 3100 Fax 0115-936 3200
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk

Murchison House, West Mains Road, Edinburgh, EH9 3LA
☎ 0131-667 1000 Fax 0131-668 2683

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB
☎ 01491-838800 Fax 01491-692345

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, EX2 7HU
☎01392-278312 Fax 01392-437505

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE
☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7938 9056/57

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS
☎ 028-9066 6595 Fax 028-9066 2835

Parent Body
Natural Environment Research Council
Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU
☎01793-411500 Fax 01793-411501

Collaborating Institutions

British Geological Survey

Dr B A Klinck
Mrs M E Stuart

Faculty of Engineering, Autonomous University of Yucatan

Ing Roger González Herrera
Ing Victor Coronado Peraza
Ing Javier Frias Tuyin

Water Quality Department, Water Authority of Jordan

Dr Raja Gedeon
Mr Mohamed Lafi
Mrs Randa Tuffaha

Department of Mineral Resources, Thailand

Dr Vachi Ramnarong
Miss Somkid Buapeng
Mr Suchai Sinpool-Anant

EXECUTIVE SUMMARY

This report catalogues the result of work carried out as part of the Department for International Development (DFID) and British Geological Survey (BGS) Knowledge and Research (KAR) programme (Project R6532) on leachate quality. The study was undertaken in collaboration with the Department of Mineral Resources, Thailand; the Water Authority of Jordan and the Faculty of Engineering, Autonomous University of Yucatan, Mexico.

The document contains the complete dataset for leachate samples collected as part of the project. It represents a source book of leachate quality for engineers and environmental scientists, which it is hoped will provide a valuable tool in assessing the risk of proposed and existing waste sites in newly industrialised countries. Background data such as rainfall, site history and waste composition are summarised together with detailed chemical analyses of leachate quality for the project sites which include a variety of climate types, sources and disposal methods.

This catalogue should enable hydrogeologists to carry out productive modelling of contaminant migration in groundwater with well-constrained source terms. It goes some way to providing information on the temporal variability in the leachate source term for several sites and should be of use in assessing the impact of dilute and disperse sites.

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1 INTRODUCTION

The published literature on developing-world leachate quality remains sparse. Even in the UK, landfill leachate quality has only recently been systematically reviewed, and a catalogue of typical leachate chemistries produced for various classes of landfill (Robinson, 1996).

This report catalogues the result of work carried out as part of the Department for International Development (DFID) and British Geological Survey (BGS) Knowledge and Research (KAR) programme (Project R6532) on leachate quality. The study was undertaken in collaboration with the Department of Mineral Resources, Thailand, the Water Authority of Jordan, and the Faculty of Engineering, Autonomous University of Yucatan, Mexico.

The document contains the complete dataset for leachate samples collected as part of the project. It is intended to be a source book for leachate quality for engineers and environmental scientists which it is hoped will provide a valuable tool in assessing the risk of proposed and existing waste sites. This catalogue should assist in enabling hydrogeologists to carry out productive modelling of contaminant migration in groundwater with well-constrained source terms. It goes some way to providing information on the temporal variability in the leachate source term for several sites and should be of use in assessing the impact of dilute and disperse sites.

In many newly industrialised countries urbanisation is proceeding at an unprecedented rate. Holmes (1993) has drawn attention to the fact that such development is often unbalanced with much of the disposable municipal expenditure devoted to high profile, visible, infrastructure projects such as airports, ring roads and city centre developments. Waste disposal and waste management generally come well down the list of priorities in terms of allocation of funding. In the developing world the prevailing method for the disposal of municipal and domestic refuse is usually open dumping, often coupled with waste burning with minimal effort directed towards sanitary land filling practice, e.g. the use of daily cover. Site selection is generally based on geographic rather than geological and hydrogeological considerations, i.e. the closer the site to the source of the waste the better in terms of transport cost reduction. It is not uncommon therefore to find waste disposal sites within municipal boundaries and surrounded by residential areas. Clearly such sites pose a serious health risk just in terms of the problems associated with litter, stray dogs, scavenging birds, rats and airborne contamination arising from mobilisation of fine particulate matter.

Massone *et al.*, (1998), for example, describes the situation in Mar del Plata, Argentina, where three landfill sites have had to be abandoned because of odour and litter problems, and in two of the cases due to explosion of uncontrolled landfill gas. The sites also pose a threat to surface and groundwater due to some components of the leachate exceeding the maximum allowable discharge levels established by the General Administration of Sanitary Labours of Buenos Aires Province.

Cointreau (1982) lists four main health problems associated with wastes typical of newly industrialised countries:

1) Most municipal refuse contains human faecal matter. Its presence is mainly attributable to the use of disposable nappies, but also to the widespread practice of discharging untreated household septage to landfill. In Mérida, Mexico, for example, household waste had to be removed from the recycling stream because of the serious health risk to sorters due to the high content of disposable nappies.

2) Most municipal waste is likely to contain industrial waste. At the Mérida site there is an official prohibition on the acceptance of hazardous wastes. However, poor control at the waste reception area, lack of knowledge of what constitutes a dangerous waste, and a lack of understanding of the environmental impact of the disposal of such wastes means that hazardous wastes frequently enter the site and are disposed of. According to Gonzáles Herrera (1996) a large number of companies

were disposing chemical and industrial wastes in the dump without revision, and dangerous wastes derived from petroleum had been detected by the Procuradia Federal de Protección al Ambiente.

3) The decomposition products from the waste are susceptible to dissolution by infiltrating water percolating through the waste. This leads to the production of leachate that can enter both surface water and groundwater. Leachate generally contains a variety of pollutants that can contaminate groundwater. Christensen *et al.* (1994) have identified the following principal groups:

   a) inorganic macro components: calcium, magnesium, sodium, potassium, ammonium, iron, manganese, chloride, sulphate and bicarbonate.

   b) heavy metals: cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) in trace amounts.

   c) dissolved organic matter expressed as chemical oxygen demand (COD) or total organic carbon (TOC), including methane and volatile fatty acids.

   d) anthropogenic organic compounds associated with household and industrial use and generally present in very low concentrations. These compounds include, among others, aromatic hydrocarbons, chlorinated solvents and phenols.

4) Smoke from continuous burning of the waste creates extensive pollution in many cities, and burning landfills are not an uncommon site in newly industrialised countries. Generation of gas with a high content of methane can precipitate spontaneous combustion of sun dried waste which can spread internally and continue for many years.

Christensen *et al*. (1994) are of the opinion that pathogens are not important in leachates. This conclusion appears to be based on the published results of the very few investigations that have focussed on the occurrence and survival of pathogenic bacteria in leachates and associated contaminant plumes. Andreottola and Cannas (1992) noted that the presence of faecal indicator bacteria generally decreases with increasing landfill age and that growth is inhibited at temperatures greater than 60 ^{o}C. The study by Robinson (1996) indicated that the existence of pathogens in 'properly – operated' (sanitary) landfill sites is unlikely to constitute a major environmental or public health hazard. The results of the present study tend to indicate that thermotolerant bacteria, an indicator of faecal contamination, are generally present in very low concentrations in the leachates investigated. However, there is compelling evidence that coliform bacteria rapidly multiply where leachate is entering a shallow, oxygenated groundwater system, e.g. in Mérida. This strongly suggests that the leachate may be a source of pathogenic contamination given suitable aquifer conditions, such as the karstic system of the Yucatan, where zero filter efficiency (Mathess *et al.*, 1988) is to be expected coupled with fast travel times and high dilutions.

2 LEACHATE PRODUCTION

2.1 Influence of source

In the developing world municipal solid wastes tend to have a very high content of putrescible materials compared to a typical developed city in the western world (Klinck *et al.*, 1995). Waste compositions presented in the catalogue can be compared to a typical waste composition for the UK (Figure 2.1). Ultimately it is the waste composition that influences the chemistry of the leachate generated. Waste density is between two and five times higher than industrialised countries and moisture content is well in excess of 30%, i.e. the waste is generally at field capacity and any infiltration produces leachate. Indeed, Blight *et al.* (1989) and Blight *et al*. (1992) have shown that even in water deficient areas there is a potential to generate leachate because of the high organic matter contents. The widespread practice of informal recycling may explain to some extent this very high organic matter content too. This recycling process often begins even before the waste leaves its point of origin. For example, in Bangkok many homeowners and commercial establishments separate used materials for sale to secondary buyers throughout the city. Starobin and Kornberg (1991) list the following materials recovered directly from solid waste in Bangkok:

- glass bottles, both whole and broken,
- paper and paper products including newspapers, magazines, books, writing paper, cardboard boxes and corrugated boxes,
- plastic products, including clear containers, soft containers and plastic bags,
- metals, including aluminium, copper, iron and steel,
- used household items, clothing and shoes.

A second level of recycling occurs after the waste is put out for collection. In Bangkok, the municipal collection crews sort through the waste at the kerbside and separate recovered items in the trucks. These items are sold to small collection shops close to the waste disposal sites. At the landfill sites a third sorting occurs by extended family groups of scavengers living adjacent to the site.

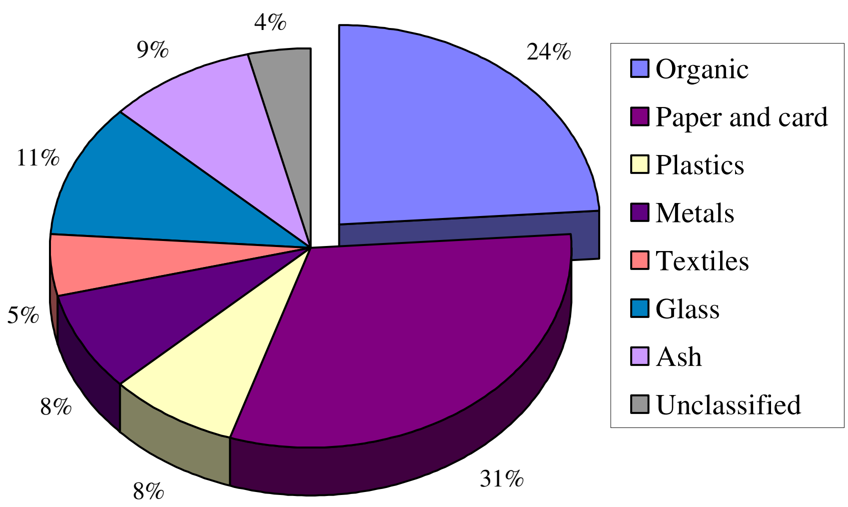


Figure 2.1 Typical waste composition for the United Kingdom

2.2 Processes

Leachate quality varies throughout the operational life of a landfill and long after its closure. There are three broad and overlapping phases of waste decomposition, in which chemical and biological processes give rise to both landfill gas and leachate during and beyond the active life of the site (Robinson, 1996):

Phase 1: Oxygen present in the wastes is rapidly consumed by aerobic decomposition. This phase typically lasts less than one month and is normally relatively unimportant in terms of leachate quality. This phase is exothermic and high temperatures may be produced. This speeds up the later phases if some of this heat is retained.

Phase 2: Anaerobic and facultative microorganisms hydrolyse cellulose and other putrescible materials such as complex carbohydrates, fats and proteins to soluble organic compounds. These hydrolysis products are then fermented during acidogenesis to various intermediates such as volatile fatty acids and alcohols. Finally, these intermediates are converted during acetogenesis to acetic acid, carbon dioxide and hydrogen. The high content of putrescible material in the waste may sustain acidogenic conditions for quite some time and provide a rich feed stock for methanogens subsequently.

Leachate from this acidic phase typically contains a high concentration of free fatty acids. It therefore has low pH of 5 or 6, and will dissolve other components of the wastes, such as the alkaline earths and heavy metals, which can be mobilised in the leachate, possibly as fatty acid complexes (see for example Christensen *et al.* (1994) and Gintautas and Huyck (1993)). The leachate also contains high concentrations of ammoniacal nitrogen and has both a high organic carbon concentration and a biochemical oxygen demand (BOD).

Phase 3: Conditions become more anaerobic as waste degradation proceeds and methanogenic bacteria gradually become established. These start to consume the simple organic compounds, producing a mixture of carbon dioxide and methane that is released as landfill gas. The carbon dioxide tends to dissolve producing the very high bicarbonate concentrations typical of Phase 3 leachates. The rate at which this phase becomes established is controlled by a number of factors, including the content of readily putrescible waste.

Since the majority of the organic compounds are high molecular weight humic and fulvic acids, the leachates are characterised by relatively low BOD values. Ammoniacal nitrogen continues to be released by areas of the waste where phase 2 is continuing and generally remains at high concentrations in the leachate. Falling redox potential immobilises many metals as sulphides in the waste (Pohland *et al*. 1993; Belevi and Baccini, 1992).

2.3 Timing of landfill stabilisation

Data collected from a large number of sites in Wisconsin (Krug and Ham, 1997) suggested that they tended to remain in the acidogenic phase during active operation of the site, but that leachate concentrations tended to be very variable. After site closure a clearer pattern was followed indicating the onset of the methanogenic phase. The conductivity (SEC) continued to rise during the lifetime of the landfill and then remained more or less constant, probably for at least 10 years. Chloride concentration, which is a major contributor to the SEC, responded in a similar manner. BOD, and to a lesser extent COD, tends to fall rapidly within the first few years after closure. The pH tends to be very variable but generally reaches 7 or more within 4 years of closure. Heavy metals concentrations, e.g. Cd, tend to decrease after about three years. Overall individual sites appeared to move from acidogenic to anaerobic conditions in an average of 4 years after closure or 10 years after waste was first placed, with small sites taking only 4 to 7 years. The speed at which waste degradation proceeds is a function of: moisture content, (thought to be the most important); temperature; waste density; age; composition; waste particle size; substrate availability; pH; microbial population; and microbial nutrient availability.

Sub-tropical and tropical arid regions are found in many developing countries and the presence of large soil moisture deficits means that the potential for leachate generation may be quite low. The lack of moisture may also permit the ingress of oxygen, delaying the onset of anaerobic conditions, and inhibit bacterial movement; movement of nutrients; buffering reactions; substrate dissolution and cellulose swelling. All of these factors may delay the onset of methanogenic conditions and production of less toxic leachate, while at the same time increasing time to stabilisation.

3. METHODOLOGY

3.1 Sample collection

Leachate was collected using a stainless steel or glass beaker or a stainless steel pressure vessel for subsequent filtration. It is important that plastic collection equipment is not used where samples are intended for analysis of organic components since there may be leaching, particularly of plasticisers.

Samples for inorganic analyses were filtered into two new 30 ml HDPE bottles under nitrogen pressure or using a plastic syringe through 0.45µm disposable filters. One of each sample pair was acidified to pH 2 with nitric acid for cation determination. The other was left unpreserved for anion determination.

All sample containers for organic components were specially pre-cleaned in the laboratory in the UK before shipping to the collection site. Dissolved organic carbon (DOC) samples were preserved by filtration through 0.45 µm silver filters using a dedicated glass syringe into 10 ml glass vials, pre-cleaned with chromic acid, and sealed with a PTFE septum.

Chemical oxygen demand (COD) samples were collected directly into glass vials and acidified to 2% with sulphuric acid. Samples for volatile fatty acids (VFA) and light hydrocarbons (BTEX) were collected directly into new 40 ml glass vials with PTFE lined screw caps (pre-cleaned by the manufacturer to US-EPA specification). Bulk samples for other organic parameters were collected using a stainless steel vessel and transferred into pre-cleaned one litre or 500 ml brown-glass Winchester bottles with PTFE lined screw caps. These were cleaned using detergent followed by distilled water and analytical grade methanol.

All samples were transferred to an icebox as quickly as possible after collection and stored in the dark at 4°C until analysis.

3.2 Field chemistry

Measurements of unstable parameters were made on-site at the point of collection in Thailand and Mexico, and in a mobile laboratory in Jordan. Jordan Water Authority staff using their own equipment made some field measurements.

Temperature, redox potential, pH and dissolved oxygen were determined using portable meters. Electrodes for pH, oxygen and conductivity were recalibrated at each new site. Redox electrode function was checked against Zobell's solution. Alkalinity was determined on-site on a filtered sample with a Hach digital titrator using standard dilute sulphuric acid and bromocresol green indicator. Duplicate determinations were generally carried out and further replicates made if poor agreement was obtained.

3.3 Laboratory analysis

3.3.1 *Inorganic determinands*

The data presented in this report was mainly obtained at the BGS laboratories. The Water Authority of Jordan provided some additional data. Quantisation was achieved for all analyses by calibration against standards of known concentration analysed in the same manner as the samples.

Cations: Major and trace cations, phosphorus and sulphate were determined using a Fisons ARL 3580 simultaneous inductively coupled plasma-optical emission spectrometer (ICP-OES). The sample is swept by an argon carrier stream into a plasma flame where it undergoes desolvation, evaporation and atomisation/ionisation. The atoms or ions decay from the excited state through radiative energy transmissions emitting light of specific energies (or wavelengths). The light emission from the plasma is separated into its component wavelengths by a monochromator and an array of photomultiplier tubes then quantifies the light intensity at specific wavelengths. Each element emits light at characteristic wavelengths and the intensity of the light is proportional to the amount of that element in the plasma.

Ammonium was determined using a Tecator FIAstar 5010 flow injection analyser. A known volume of sample is injected into a carrier stream that mixes with reagents on-line to produce a coloured complex, the intensity of the colour being proportional to the concentration of ammonium in the sample. Detection is by a spectrophotometer, with a built in flow through cell.

Anions: Major and trace anions were determined using a Dionex 2000i ion chromatography system with an autosampler, an integral conductivity detection module, and an additional on-line UV/VIS detector. The sample is injected into a mobile phase that passes through a column of anion exchange resin where the progress of the anions through the column is retarded with respect to the solvent. Different anions are retained to different degrees according to their size and charge causing the anions in solution to be separated. The conductivities and/or UV absorption of the separated anions eluted from the column are detected as transient peaks. Data is processed using Dionex data capture and processing software.

Dissolved organic carbon: Dissolved organic (together with total inorganic) carbon were determined using a Shimadzu TOC-5000 analyser. Total carbon is determined by injecting sample into the total carbon combustion tube, which is packed with platinum-coated alumina catalyst maintained at 680 C by an electrically heated furnace. All of the carbon in the sample is oxidised to carbon dioxide gas that is swept by carbon dioxide free, air carrier gas into a non-dispersive infrared detector, which measures the carbon dioxide concentration by energy absorption. Total inorganic carbon is determined by injecting sample into a phosphoric acid reservoir which liberates all inorganic, but not organic, carbon as carbon dioxide gas. This is swept into the detector as before. The output signal of the detector is displayed as a transient peak, the area of which is proportional to the carbon dioxide concentration. Organic carbon is calculated as the difference between total carbon and total inorganic carbon.

3.3.2 *Organic determinands*

Organic analyses were carried out under contract by SAC Scientific, Biggleswade, Beds SG18 8RH. Calibration for the specific methods was carried out using standards of known concentration for all analytes and analysed in the same manner as the samples. Where the same compound was detected by both a specific method and by the 'Broadscan' technique the higher concentration is quoted.

Organochlorine pesticides: The submitted sample was extracted with an aliquot of isohexane, dried using anhydrous sodium sulphate and concentrated using a combination of Kuderna-Danish and nitrogen evaporative blow-down techniques. The extract was analysed by capillary gas chromatography with electron capture detection (CapGCECD). Confirmation analysis was carried out using an alternative column.

Haloforms and chloro-solvents: A 15 ml aliquot of sample was extracted with 10 ml of pentane and the resulting extract analysed without concentration by CapGCECD.

BTEX: A one litre sample was extracted with 10 ml pentane and the resulting extract analysed without concentration using by capillary gas chromatography with flame ionisation detection (CapGCFID)

Volatile fatty acids: *An* aliquot of the submitted aqueous sample, or a dilution thereof, was analysed directly by CapGCFID.

Polyaromatic hydrocarbons (WHO 6): A one litre sample was extracted with an aliquot of cyclohexane, dried using anhydrous sodium sulphate, and concentrated using a combination of Kuderna-Danish and nitrogen evaporative blow-down techniques. The extract was analysed by high-pressure liquid chromatography with fluorescence detection.

Phthalates: An aliquot of the sample was extracted using dichloromethane, dried using anhydrous sodium sulphate, concentrated using a combination of Kuderna-Danish and nitrogen evaporative blow-down techniques and analysed by capillary gas chromatography mass spectrometry in selected ion monitoring mode.

Broadscan GCMS: The samples were extracted at neutral pH (6-8) using a 75 ml aliquot of dichloromethane. The solvent was removed and the pH of the sample then adjusted to pH 2, and a second 75 ml aliquot of dichloromethane used to extract the sample. After removal of the solvent layer, the sample pH was adjusted to >11 and a third 75 ml aliquot of dichloromethane used for the extraction. The combined dichloromethane portions from the three extraction steps above were dried over anhydrous sodium sulphate, and reduced in volume, together with further dichloromethane washing of the sodium sulphate, to approximately 5 ml using Kuderna-Danish concentration equipment. The extract was reduced to its final volume of 1 ml under a stream of dry nitrogen.

Analysis was carried out using a Hewlett Packard series II 5890 gas chromatograph coupled to a Hewlett Packard 5972 mass selective detector. The instrument was tuned and calibrated prior to analysis; data acquisition was carried out over the mass range m/z 40 to 550. Quantisation was carried out by comparison of the peak area response of a sample compound with that of deuterated compounds. This gave only an approximate estimate of the quantities present, the degree of qualitative variance being proportional to the disparity in volatility and structure between the deuterated compound and the compound under consideration. Initial compound identification was carried out using the NIST/EPA/NIH Mass Spectral Database Revision C.00.00 (1992) using a Probability Based Matching (PBM) algorithm. These results were then manually assessed, and if necessary, reference made to a hard copy version of the EPA/NIH mass spectral data base, and/or the Eight Peak Index of Mass spectra for further clarification. None of the compound identities have been confirmed by analysis of standard compounds for retention time and mass spectral confirmation. A suggested group or class of compound has been given where confident identification was not made.

3.3.3 *Microbiology*

Samples for the determination of thermotolerant and total coliforms were prepared on-site in Thailand and Mexico. The samples were processed using an Oxfam Delagua portable incubator. A known volume of water was filtered through a sterile, gridded membrane that was then incubated in a lauryl sulphate culture medium. Coliform colonies were counted manually. In Jordan, coliform samples were collected in sterile containers and processed at the Water Authority laboratories.

4. CATALOGUE DESIGN

4.1 Structure

The catalogue is presented as a series of pages for each landfill site or group of sites. The first page contains such relevant background data as was available, e.g. climate details, landfill status (open/closed) and waste treatment (cover/waste burning etc). Information on age of waste was not generally available. The second contains available information on waste composition. The waste classifications have not been standardised since the information is very variable in quality and detail. Subsequent pages contain detailed chemical data. A summary of the data presented is shown in Table 4.1.

4.2 Site selection

The main project sites, Chiang Mai and Tha Muang, Thailand, the sites in Jordan and Mérida, Mexico were visited a number of times to cover the different seasons primarily to collect groundwater samples as well as leachate. Owing to landfill development systematic collection of leachate from the same point was not usually possible. Other leachates were collected during the same visits where possible. Other relevant leachate data already held by BGS has also been included.

Table 4.1 Summary of data in catalogue

Country	Climate type	Major Cities	Sites	Rural area	Sites
Mexico	Semi-arid	Mexico City	El Bordo		
	Tropical-humid	Mérida	Mérida		
		León	León		
Jordan	Semi-arid	Amman	Ruseifa		
		Irbid & Jerash	Al Akaider		
Thailand	Tropical-humid	Bangkok	On-Nooch Nong Khaem Lat Krabang Kamphang Sein	Kanchanaburi province	Kanchanaburi Tha Muang
	Semi-tropical-humid	Chiang Mai	Mae Hia San Sai Lamphun		
Indonesia	Tropical-humid	Bandung	Leuwigadja Sukamiskin		
Malaysia	Tropical-humid	Kuala Lumpur	Penang		

4.3 Parameter selection

All samples collected during the present project were analysed for a standard suite of inorganic elements by BGS and this data is presented in full. All field analytical data is also shown. However this is incomplete for various practical reasons, such as equipment malfunction.

For organic components the data is more complex. A wide range of sometimes-disparate analyses was available, due to the changing focus of the analytical programme as the project progressed. From these a standard suite was selected, consisting of various fatty acids, steroidal compounds, diethylhexylphthalate, tetrachloroethene, alkanes and the polycyclic aromatic hydrocarbons (PAHs). Other compounds were added to this list during compilation of the catalogue either on the basis of frequent detection or of a significant single detection.

Detection limits were always available for compounds from the specific analytical suites. Where such compounds were not detected, they are reported as being below the limit of detection (for example <1.00 mg/l). For compounds from ‘Broadscan’ analyses precise detection limits were not available and these compounds are reported as not detected (nd) where appropriate. For completeness, missing data is given as not sampled (ns).

5 REVIEW OF DATA

A summary of waste composition, rainfall and significant indicator parameters in the leachate is shown in Table 5.1 for all sites in the catalogue.

5.1 Waste composition

It is clear that there are differences between the waste streams, particularly for organics, paper and plastic (Table 5.2). For example, Mexico and Thailand have much lower percentages of organics in the waste stream whereas percentage paper in Mexico and Jordan is much higher. These differences will be reflected in the quality of leachate produced, although as shown in Table 5.3 there is no direct relationship since climate and disposal practices will also have a major impact. The main consequence of the high organic content is that leachates are high in TOC the bulk of which is probably made up of high molecular weight polar compounds.

Table 5.2 Summary of main data presented for household solid waste composition at landfill sites included in the study

Waste source	Waste components (%)				
	Organic	Paper/card	Plastic	Metal	Glass
Mexico					
Mexico City	27.6	39.5	7.4	3.5	7.1
Mérida	48.0	28.0	3.0	-	2.0
Mean	**37.8**	**33.8**	**5.2**	**3.5**	**4.6**
Jordan					
Ruseifa	61.8	23.9	3.6	3.5	3.7
Al Akaider	70.0	17.0	5.0	2.0	2.4
Mean	**65.9**	**20.5**	**4.3**	**2.8**	**3.1**
Thailand					
Nom Khaem	28.0	13.8	16.8	4.8	8.1
On Nooch	22.0	17.8	19	6.3	10.1
Kanchanaburi	48.0	19.4	18.2	2.3	3.4
Chiang Mai	70.1	6.8	0.4	1.1	0.1
Mean	**42.0**	**14.5**	**13.6**	**3.6**	**5.4**
Indonesia – Bandung	**73.4**	**9.7**	**8.6**	**0.5**	**0.4**
Malaysia – Kuala Lumpur	**63.7**	**11.7**	**7.0**	**5.4**	**2.5**

5.2 Major ions and the impact of climate

Differences in the chloride concentration of leachates from the same site probably reflect the seasonal variation in the volume of leachate being generated, since chloride is a conservative anion that is not affected by biodegradation or decay. Changes in other major ion concentrations may result from pH or redox changes in the leachate and interactions with the waste matrix. In order to demonstrate these changes, time series data were collected from four sites and are displayed using Stiff diagrams (Tonjes *et al.*, 1995) in Figures 5.1 to 5.4.

The leachate from Mérida, Mexico shows a very similar pattern over the four periods studied (Figure 5.1). The highest concentrations are seen in April, at the end of the drier season, with lower concentrations at the end of the wet season. The higher alkalinity found during the wet season probably reflects more rapid decomposition of organic material due to a higher water content in the waste, increased biodegradation and

Table 5.1 Summary of leachate quality data held in catalogue as mean per site

Parameter	Akaider	El Bordo	Kamphang Sein	Kanchan-aburi	Lamphun	Lat Krabang	León	Leuwig-adja	Mae Hia	Mérida	Penang	Ruseifa	San Sai	Suka-miskin	Tha Muang	Mean
Total VFA (µg/l)	133		125	90	19	1060			0	0		18800	225		0	2871
Diethyl hexabutyl Phthalate (µg/l)	10		158	25	6	48			23	28		8	4		10	42
Chloride (mg/l)	721	4045	3547	1467	1354	3437	1720	1990	1697	4520		13168	3359	153	2064	3194
Ammoniacal-N (mg/l)	152	1118	2255	83	68	2207	597	1250	103	539		2776	817	27	21	878
Alkalinity (as HCO_3) (mg/l)	2083	9915		4007	996	13695	3250	7270	2562	5544		38480	5785	428	752	7626
Total organic carbon (mg/l)	562	1039	1610	551	128	6582		1679	290	1367		10633	1694	18	58	2016
Cadmium (mg/l)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05	<0.05	<0.05	<0.05
Manganese (mg/l)	0.23	0.36	0.48	7.88	0.55	5.93	1.1	4.57	0.53	0.28		31.3	6.38	2.4	0.43	4.7
Organic content of waste (%)	70.0	27.6	22.0	48.0	70.1	28.0		73.4	70.1	48.0	63.7	61.8	70.1	73.4	48.0	56
Total degradable content of waste(%)	87.0	67.1	39.8	67.4	76.9	41.8		83.1	76.9	76.0	82.4	85.7	76.9	83.1	67.4	72
Plastic content of waste (%)	5	7.4	19	18.2	0.4	16.8		8.6	0.4	3	7	3.6	0.4	8.6	18.2	8
Site now closed (Y/N)	N	N	N	N	Y	N		N	Y	N		N	N	Y	N	
Waste burning occurs (Y/N)	N	N	N	Y	N	N		Y*	N	N		Y*	N	N	Y	
Average annual rainfall (mm/a)	185	450	1530	1090	1430	1530	600	2370	1430	985		185	1430	2370	1090	

*Spontaneous combustion occurs

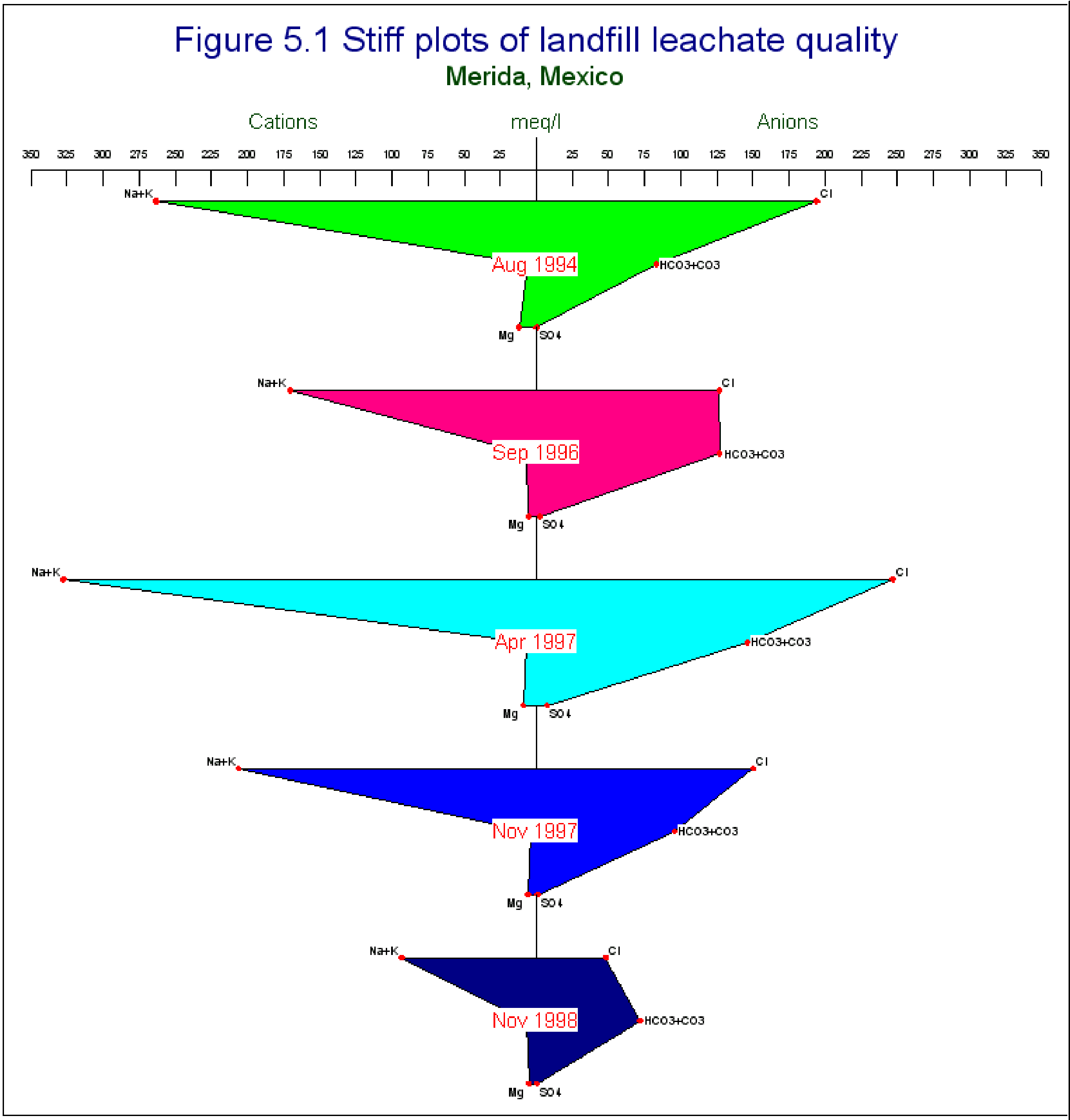


Figure 5.1 Stiff plots of landfill leachate quality
Merida, Mexico
Cations
meq/l
Anions
350 325 300 275 250 225 200 175 150 125 100 75 50 25
25 50 75 100 125 150 175 200 225 250 275 300 325 350
Na+K
Cl
HCO3+CO3
Mg
SO4
Aug 1994
Sep 1996
Apr 1997
Nov 1997
Nov 1998

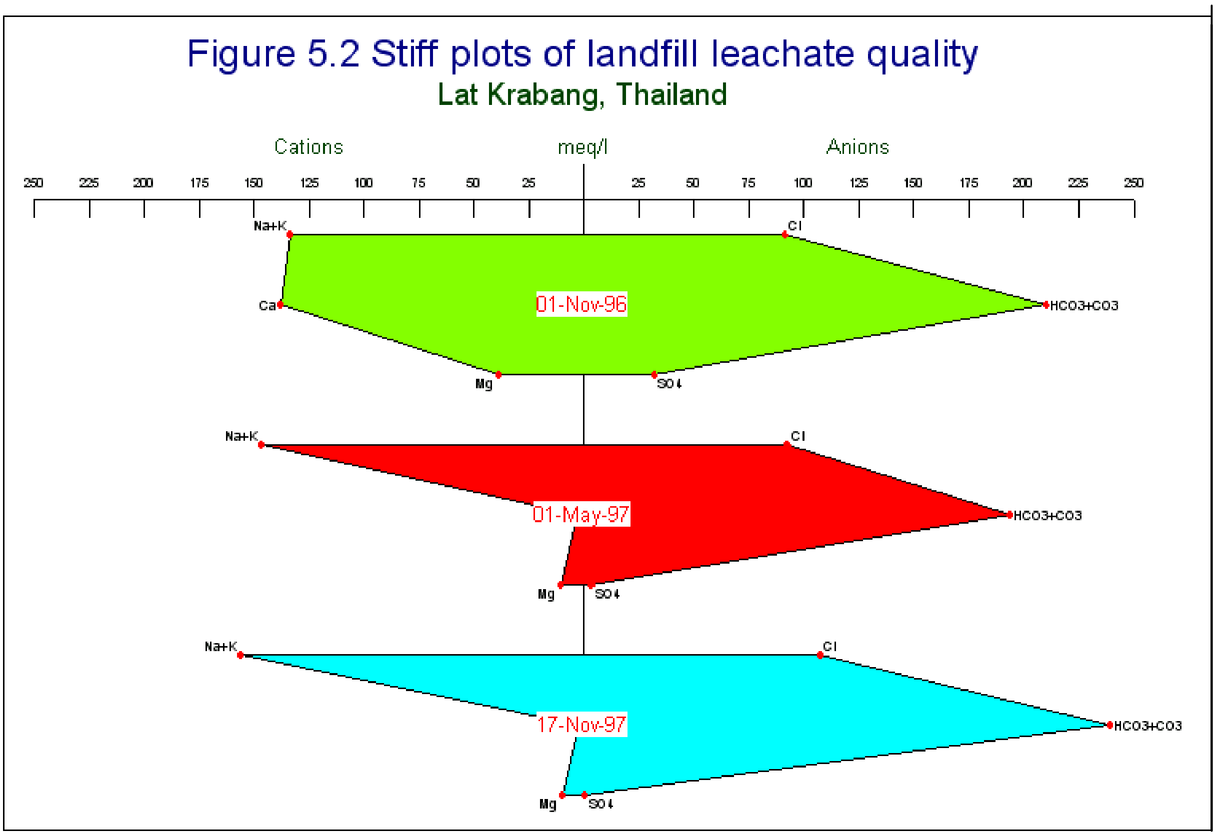
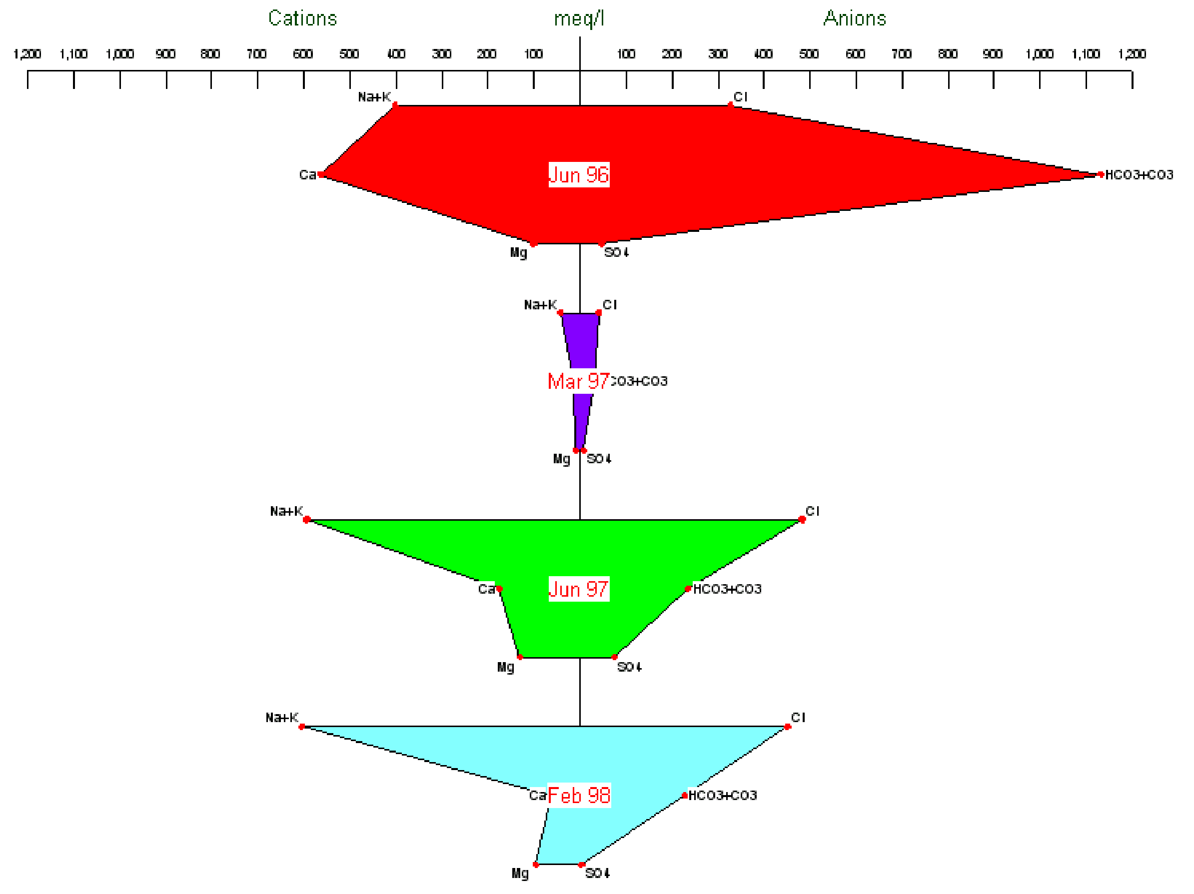


Figure 5.2 Stiff plots of landfill leachate quality
Lat Krabang, Thailand
Cations
meq/l
Anions
250
225
200
175
150
125
100
75
50
25
25
50
75
100
125
150
175
200
225
250
Na+K
Cl
Ca
HCO3+CO3
01-Nov-96
Mg
SO4
Na+K
Cl
01-May-97
HCO3+CO3
Mg
SO4
Na+K
Cl
17-Nov-97
HCO3+CO3
Mg
SO4

Figure 5.3 Stiff plots of landfill leachate quality

Ruseifa, Jordan



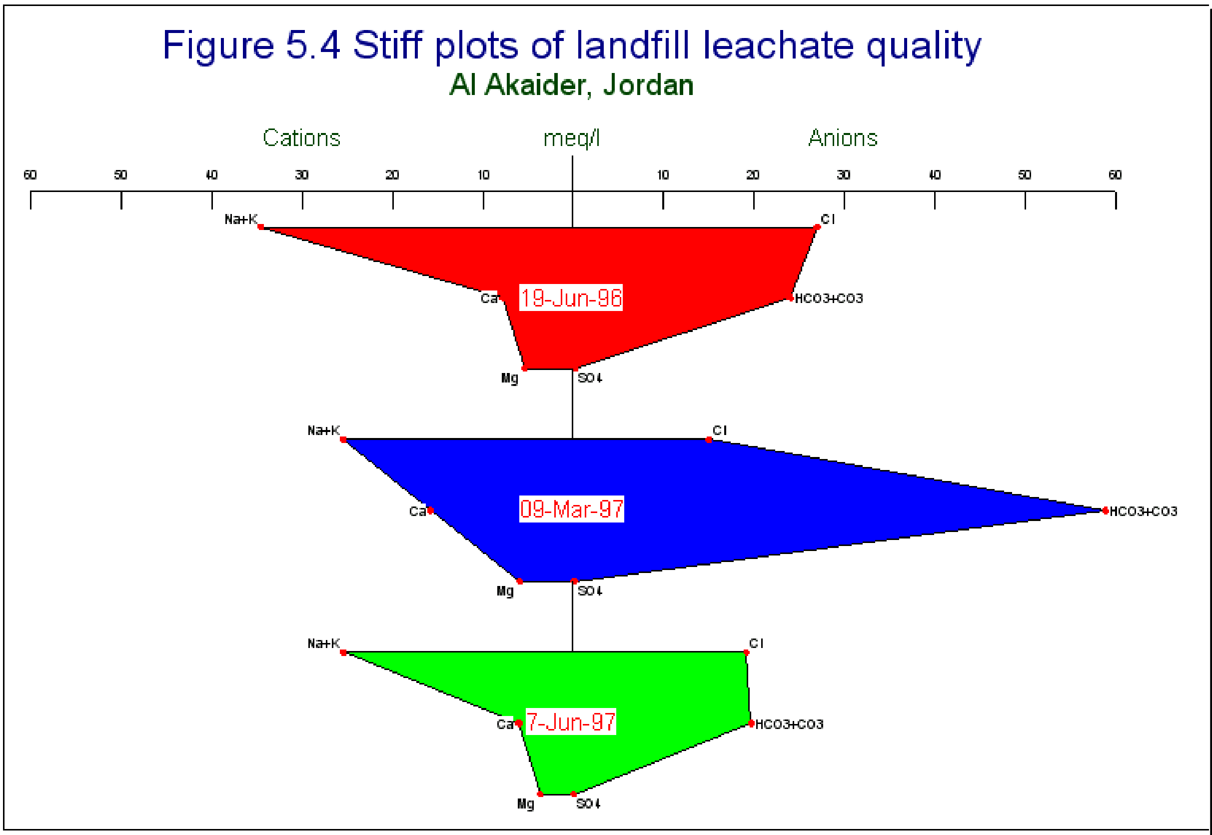


Figure 5.4 Stiff plots of landfill leachate quality
Al Akaider, Jordan
Cations
meq/l
Anions
60
50
40
30
20
10
10
20
30
40
50
60
Na+K
Ca
Mg
Cl
HCO3+CO3
SO4
19-Jun-96
09-Mar-97
7-Jun-97

production of carbon dioxide. Klinck *et al.* (1995) interpreted areal variability in sulphate concentration to be a function of the redox condition within the waste and concluded that infiltrating rainwater was responsible for maintaining acetogenic conditions. In situations such as this, where a daily cover is not used and where the waste may be of different ages, due to the disposal method employed, cycling between acetogenic and methanogenic states is likely.

For Lat Krabang, Thailand the consistent chloride concentrations suggest similar leachate dilution for all three visits (Figure 5.2). The two later samplings are very similar in composition. Leachate from the first visit shows much higher calcium, magnesium and sulphate concentrations and also very low pH and very high TOC and VFA concentrations. This suggests that the leachate at this time was derived from an area of the waste remaining in the acetogenic phase.

Fresh leachate was not being generated from the Ruseifa site, Jordan, during the first visit (June 1996) and a sample taken instead from a residual leachate pool has very high ionic strength dominated by calcium and carbonate species (Figure 5.3). This may result from dissolution of calcium from calcareous soil, used as cover material, and by bicarbonate produced from organic degradation. The next sample (March 1997) was collected during the winter wet season and is relatively dilute. Sodium and chloride are now the dominant ions. Leachates from the following summer and winter (June 1997 and May 1998) are of similar composition, but with sodium and chloride concentrations much like those of the first visit. The main problem with sampling the Ruseifa site and obtaining representative samples was the difficulty in collecting from seepages at the waste face. It is anticipated that the chemistry does not represent the true leachate composition but rather a liquid reflecting volatilisation of organics, fractional crystallisation, and evaporation of water.

Samples from Al-Akaider (Figure 5.4) were taken from a surface lagoon used for the disposal of liquid wastes. This also receives a limited leachate input from the adjacent landfill due to the aridity of the site. The dominance of carbonate species in the wet season (March 1997) may reflect increased decomposition and bacterial activity.

Despite the observed seasonal differences in chloride and carbonate, correlation coefficients between the major parameters demonstrate that chloride is well correlated with VFAs, alkalinity, TOC and manganese (Table 5.3). In contrast, average annual rainfall is moderately negatively correlated with VFA, chloride and alkalinity, and TOC/manganese less well. A potential problem with using annual rainfall is the likelihood that the effective precipitation into the waste, and hence volume of leachate produced, is not a linear function of total rainfall.

Table 5.3 Correlation matrix for major parameters

	VFA	Phthalate	Chloride	Ammonia	Alkalinity	TOC	Manganese
VFA	1						
Phthalate	-0.17	1					
Chloride	0.95	-0.03	1				
Ammonia	0.64	0.49	0.74	1			
Alkalinity	0.96	0.00	0.96	0.90	1		
TOC	0.86	-0.02	0.87	0.83	0.95	1	
Manganese	0.96	-0.22	0.86	0.60	0.93	0.87	1
%organic	0.13	-0.78	-0.17	-0.47	-0.18	-0.17	0.12
% degradable	0.31	-0.79	0.05	-0.44	0.02	-0.10	0.22
%plastic	-0.19	0.55	-0.16	0.21	-0.08	0.00	-0.10
Rainfall	-0.62	0.35	-0.52	-0.18	-0.46	-0.35	-0.35

5.3 Total organic carbon

Total organic carbon data can be difficult to interpret since it is a bulk parameter representing a wide range of different compounds. In general but not always it follows the major ions. It can be hugely variable from one year to the next as in the upper level in Mérida or in Lat Krabang. A high concentration suggests leachate from the acetogenic phase of waste decomposition and indeed TOC is correlated with VFA production.

5.4 Phthalates

Phthalate esters and other plasticisers, such as adipates, are leached from plastic products, mainly PVC, under landfill conditions (Mersiowsky and Stegmann, 1997). They are ubiquitous in the environment and are commonly reported in fresh waters and industrial discharges. Over 40% of phthalate compounds are said to have oestrogenic properties and they have long been recognised as reproductive toxicants in animals, (Fairman *et al.*, 1998). Although the effect on humans is less well understood, media attention has highlighted the possible seriousness of the situation in the UK where there is speculation that oestrogen-like substances may be linked to a reduction in male fertility (Montagnani *et al.*, 1996). These compounds are microbially degraded either aerobically or under methanogenic conditions to carbon dioxide. However, in the acetogenic phase degradation has been shown to be slow (Ejlertsson and Svensson, 1997). Of concern in landfill leachate is the presence of bis(2-ethylhexyl) phthalate which has been shown to be carcinogenic in laboratory animal experiments.

5.5 Volatile fatty acids (VFAs)

These compounds are produced during the acetogenic stage of waste decomposition, indeed it is the acetic acid that imparts the characteristic vinegar smell to these types of leachate. The absence of these compounds indicates that methanogenic conditions have been established with heavy metal stabilisation (heavy metal concentrations are generally below detection limit). In leachates with a high VFA content the pH is generally less than 7 and heavy metal concentrations can be high. To some extent this is a function of the waste stream composition. For example in Bandung, Indonesia; Bangkok, Thailand; and León, Mexico, acetogenic leachates have high concentrations of chromium derived from wastes produced during the manufacture of shoes. Manganese and zinc are also generally high in these types of leachates.

5.6 Other organic compounds detected

Interpretation of the broad scan GCMS analysis was limited to the ten highest peaks. The compounds identified are to a large extent a reflection of the composition of the original waste, but intermediate breakdown products of other compounds were routinely identified (Table 5.4). These consist mainly of oxygenated compounds, carboxylic acids and their esters and phenols.

There is often local concern that pesticides are likely to be present in leachates, particularly the heavily chlorinated cyclic compounds such as DDT. This study has shown little evidence of significant pesticide concentrations at any of the sites, apart from one instance of detection of ametryn at Tha Muang, Thailand and one of γ-HCH at Lat Krabang, Thailand.

5.7 Impact of waste burning

Waste burning fundamentally changes the waste composition. Paper is removed together with plastics and a proportion of the degradable material. Hence, a reduction in the amount of carbon dioxide produced due to biodegradation, coupled with lower concentrations of bicarbonate in the leachate, is to be expected. This is illustrated if one compares the leachate quality from the Tha Muang and Kanchanaburi sites. The original waste composition is assumed to be broadly similar based on a similar population density and level of development.

Table 5.4 Derivation of organic compounds identified in leachates

Compound	Derivation	Reference
Nicotine	Pesticide formulations as well as the use of tobacco	Hutchins *et al.*, 1983
Ametryn	Triazine herbicide used to control weeds in bananas, citrus, cocoa, coffee, maize, oil palms, pineapples, sugar cane and tea.	Worthing, 1987
γ-HCH (lindane)	Chlorinated pesticide used against wide range of soil-dwelling and phytophageous insects	Worthing, 1987
Long chain carboxylic acids (e.g. palmitic acid)	Decomposition of larger molecules in the waste and from soap formulations.	
Phenols (e.g. phenol, cresol)	Decomposition of larger molecules in the waste	
Chlorinated solvents (e.g. tetrachloroethene)	Widely used as degreasers in the engineering and leather industries as well as in dry cleaning. Persistent in aerobic environment. Volatile and majority likely to be lost to the gas phase.	Öman *et al.*, 1997
Steroidal compounds (e.g. cholesterol)	Recent sewage contamination	
Hetero-compounds (e.g. indole, benzothiazoles)	Decomposition of proteinaceous material. 2-(methylthio)benzothiazole used in fungicide formulations	
Alkanes (e.g. dodecane, squalene)	Petroleum, oil and greases. Squalene present in human skin grease.	

The main differences are seen in alkalinity and TOC, both of which are low at Tha Muang, where waste burning is practised. The relatively high redox potential, sulphate and nitrate concentrations and low manganese concentration and absence of VFAs indicating aerobic conditions. The leachate sump at Kanchanaburi has low pH and redox, high alkalinity and TOC, moderate concentrations of ammonia, VFAs and manganese, and low concentrations of sulphate and nitrate. It is considered to be transitional between the acetogenic and methanogenic phases. Waste burning has the effect of inhibiting the acetogenic stage by removing some of the putrescible feedstock and reducing the moisture content of the waste and hence the overall leachate loading and heavy metal mobility.

Concentrations of polycyclic aromatic hydrocarbons (PAHs) together with polychlorinated hydrocarbons are known to increase as a result of waste burning. Ruokojärvi *et al.* (1995) found that the principal isomers produced in burnt waste were phenanthrene, fluoranthene and pyrene. In practice all of these compounds have very limited water solubility and are likely to be immobilised to a large extent due to sorption onto the waste and superficial soils. Only very low concentrations of fluoranthene have been detected in leachates during the present study. Other potential advantages of waste burning, such as reduction in vermin and bacteria are not considered here as the remit of the project is to assess the risks from leachate through groundwater consumption. However, as a waste management strategy open waste burning should not be considered since the production of smoke and fumes is likely to mobilise these toxic compounds through volatilisation to the detriment of nearby inhabitants.

6 DISCUSSION AND SUMMARY

Data was collected from a selection of sites in the newly industrialised countries of Thailand, Mexico, Jordan and Indonesia covering a variety of climatic types. At sites investigated the waste composition was overwhelmingly dominated by the organic component. This feature of newly industrialised country wastes is also well documented by Cointreau (1982). There is a correspondingly lower content of metals and glass both of which are removed either at the landfill sites by informal scavengers or by the waste collectors prior to delivery to the landfill.

The main consequence of the high organic content is that leachates are high in TOC although GCMS analysis has been unable to identify very many specific compounds. The bulk of the TOC is probably made up of high molecular weight polar compounds. Specific analysis was carried out for VFAs, phthalates, PAHs and chlorinated solvents. The presence or absence of VFAs may indicate the degradation state of the landfill. In the methanogenic phase these compounds are not detected. PAHs arise from the burning of waste. At the sites where waste burning was practised, with the exception of minor amounts of fluoranthene, these compounds were not detected in the leachates. They are readily sorbed to the soil substrate, but constitute a hazard in the smoke generated by waste burning. Phthalates are used as a plasticiser and were detected in all of the leachates analysed. These compounds have been shown to be carcinogenic in laboratory animal experiments and to be endocrine disruptors.

As well as field determined SEC, pH, temperature, DO and redox potential a standard list of major anions, cations and trace metals are presented. The chemical data can be used as input to probabilistic landfill performance models such as LandSim (Golders Associates, 1996). Using a stochastic approach such models can be used to assess the pollution loading on an aquifer or at a receptor. The output from such models can then be used in human health risk assessments. The data presented in the catalogue can be summarised to provide statistical distributions of component concentrations for use in such models. Generally when data is sparse it is common to define a triangular distribution as a best estimate of the expected normal distribution. Only three points are required to construct the triangular distribution, they are a minimum value, a maximum value and an estimate of the mean. As an example a potassium distribution is presented for Mexico and Thailand in Figure 6.1.

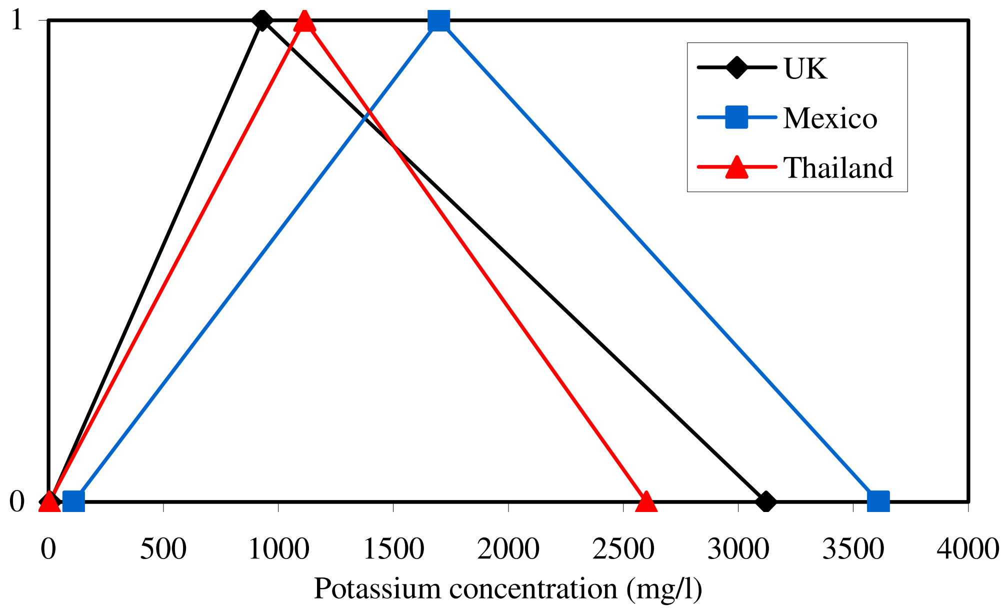


Figure 6.1 Triangular plots of minimum, mean and maximum values of potassium concentration in leachate from the UK, Mexico and Thailand

For comparison the UK default leachate distribution is also shown demonstrating the need to use appropriate data when considering risk assessments. For instance were the UK default distribution to be used in a Monte Carlo simulation of contaminant transport then the resulting output would underestimate the impact of potassium because of the way the UK distribution is skewed away from the Mexican case. Similarly in the Thai case the model would tend to sample values beyond the Thai maximum. For this reason site specific distributions should be estimated on an individual basis. Figure 6.1 also shows the effect of climate on leachate quality. The Thai data reflect the monsoonal influence on maximum concentrations. The data as a whole are quite variable and it may be more appropriate to look at seasonal data sets when developing distributions. For instance at the Merida landfill site towards the end of the wet season, when dilution effects are more noticeable, potassium concentration was 1674 mg/l. At the end of the dry season when moisture evaporation from the waste is at a maximum and leachates would be expected to be the most concentrated, potassium concentration was 3610 mg/l. This demonstrates the need to acquire an adequate time series of data prior to any landfill performance assessment.

The Stiff Plot has been found to be a useful visual method of demonstrating the temporal variability of leachates. They provide a useful method of comparing ionic strength and major ion chemistry and clearly distinguish between dilution and biodegradation. Where dilution is occurring the plot remains similar in shape, whereas increased degradation of organic material in hot and/or wet weather increases the rate of carbon dioxide production leading to higher relative alkalinity in the leachate. Where sufficient data was collected plots have been provided.

Unfortunately it has not been possible to derive correlations between waste composition and leachate quality. Perhaps the principal factors contributing to this are a lack of any detailed data on:

- The temporal development of leachate quality. At most of the sites visited leachate data was non-existent prior to the project and long term trends could not be defined.

- Variability introduced due to seasonal effects on leachate production and chemistry within the waste which is superimposed on a general background of temporally changing leachate quality in response to waste degradation and stabilisation.

- The history of site development and the age of the waste. Site development is generally uncontrolled and haphazard with no record keeping. Very few municipalities have a clear idea of what the nature their waste arisings is.

In terms of a waste minimisation strategy waste burning is an attractive option, with reduction of waste volume and a reduced carbon loading in the leachate, such as seen at Tha Muang. However the low temperatures associated with open waste burning in themselves pose a hazard, since toxic compounds such as PAHs and dioxins may be formed in the smoke.

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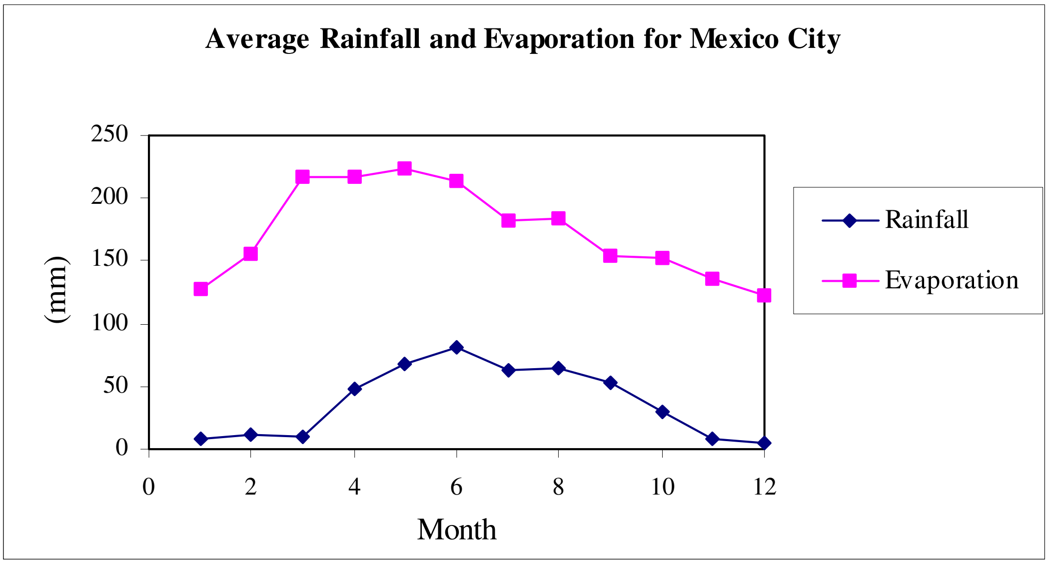
CATALOGUE

CONTENTS

MEXICO

MEXICO CITY

Climate

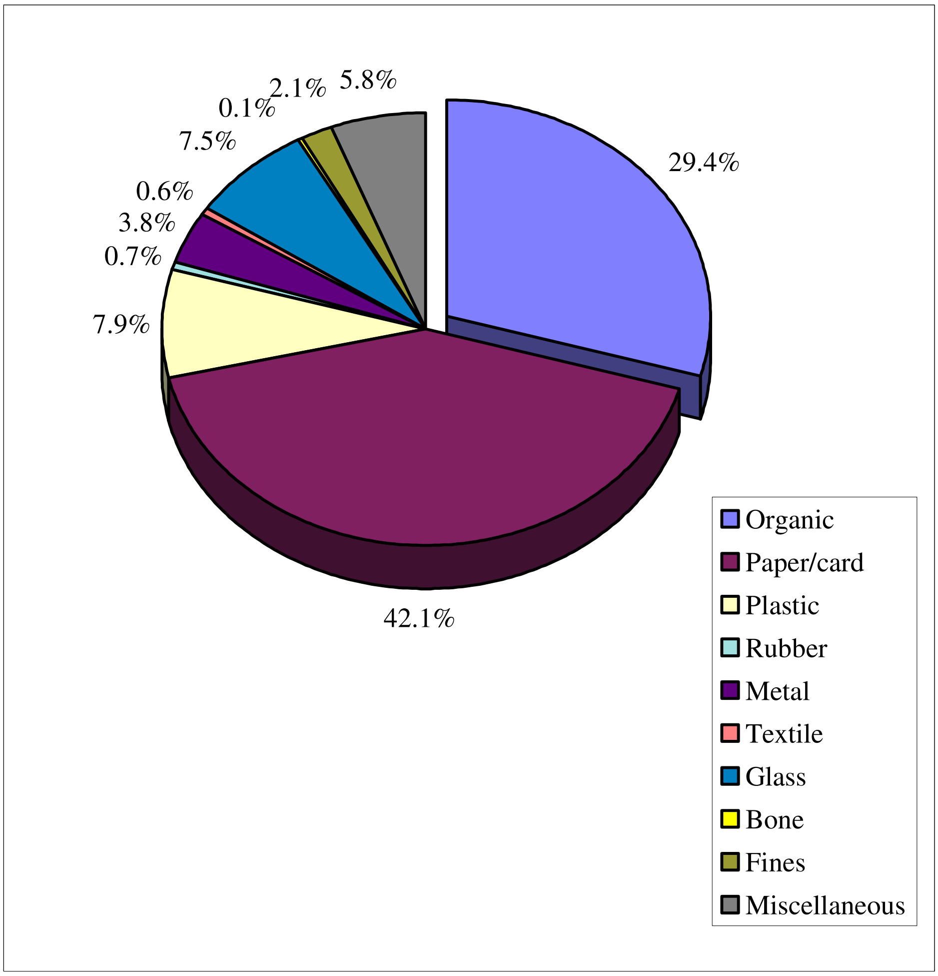


Landfill details

El Bordo

The principal site for Mexico City accepting about 50% of the waste generated. The site had been open for about 8 years at the time of sampling. Waste placement is on three raises each with a cover of silt Domestic and medical wastes are accepted, the latter being emplaced in a HDPE lined cell. Leachate is removed to HDPE lined ponds where it is allowed to evaporate.

Waste composition for Mexico City, Mexico

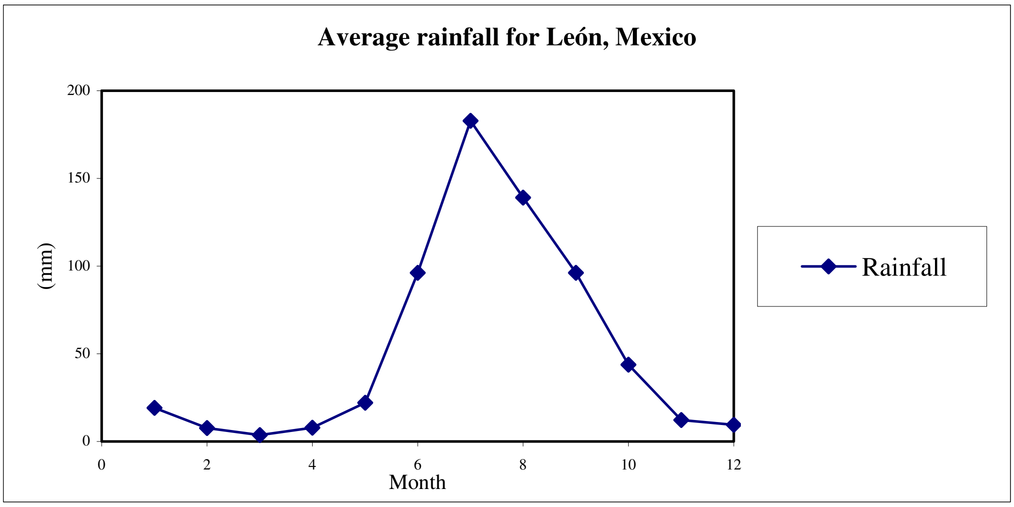


Organic	29.4
Paper/card	42.1
Plastic	7.9
Rubber	0.7
Metal	3.8
Textile	0.6
Glass	7.5
Bone	0.1
Fines	2.1
Miscellaneous	5.8

El Bordo Landfill, Mexico		Seepage new cells		Seepage 1987 cell	Lagoon
BGS code **Field code** **Sampling date**	**Units**	**M1**	**M2**	**M3**	**M4**
Inorganic determinands					
pH		8.24	8.53	8.91	8.34
Conductivity	μS/cm	ns	ns	ns	ns
Temperature	°C	ns	ns	ns	ns
Dissolved oxygen	mg/l	ns	ns	ns	ns
Redox potential	mV	ns	ns	ns	ns
Sodium	mg/l	1,720	3,210	4,040	3,030
Potassium	mg/l	1,270	1,140	2,200	2,700
Calcium	mg/l	90.5	41.0	22.6	39.3
Magnesium	mg/l	227	123	146	87.7
Alkalinity (as HCO_3)	mg/l	8,110	8,730	7,420	15,400
Chloride	mg/l	2,240	3,630	5,590	4,720
Sulphate	mg/l	11.8	131	538	124
Ammoniacal-N	mg/l	644	901	65.7	2,860
Nitrite-N	mg/l	<3.0	<3.0	<3.0	<3.0
Nitrate-N	mg/l	<0.5	<0.5	<0.5	<0.5
Total organic carbon	mg/l	1,030	697	1,070	1,360
COD	mg/l	ns	ns	ns	ns
Bromide	mg/l	ns	ns	ns	ns
Total phosphorus	mg/l	ns	ns	ns	ns
Total sulphur	mg/l	ns	ns	ns	ns
Silica	mg/l	23.7	19.5	17.1	16.8
Barium	mg/l	ns	ns	ns	ns
Strontium	mg/l	23.70	1.01	0.84	1.070
Lithium	mg/l	0.100	0.060	0.180	0.160
Boron	mg/l	22.60	13.2	14.9	7.47
Manganese	mg/l	0.83	0.43	0.04	0.12
Total iron	mg/l	3.0	1.4	1.4	3.6
Aluminium	mg/l	0.43	0.38	0.23	0.45
Cobalt	mg/l	0.06	<0.06	<0.06	<0.06
Nickel	mg/l	<0.03	<0.03	0.41	<0.05
Copper	mg/l	0.02	<0.015	0.02	0.05
Zinc	mg/l	0.15	0.10	0.09	0.30
Chromium	mg/l	0.43	0.23	0.52	0.61
Molybdenum	mg/l	<0.06	<0.06	<0.06	<0.06
Cadmium	mg/l	<0.015	<0.015	<0.015	<0.015
Lead	mg/l	<0.03	<0.03	<0.03	<0.03
Vanadium	mg/l	0.23	0.14	0.18	0.17

LEÓN, GUANAJUATO

Climate



Landfill details

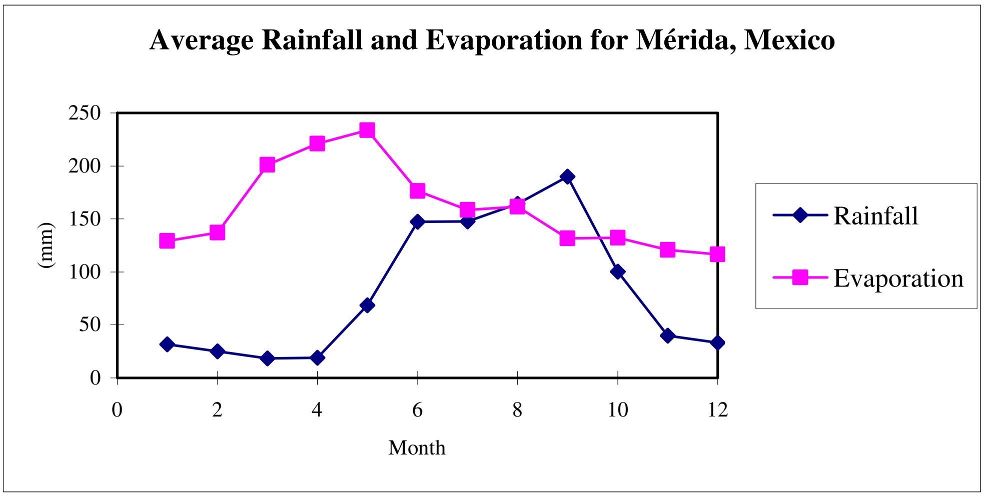
The León municipal site has been open since 1986, accepting domestic, medical and commercial wastes as well as industrial wastes from the large tanning industry in the city. The site is situated in a small tributary of the main Leon valley. Three layers of waste have been deposited in benches to a thickness of eight metres. Each layer is covered with silty sand, with venting to allow the escape of gas. Leachate is discharged without treatment into the main valley and periodically floods the main highway and a small nearby farm..

Tannery waste contains a high concentration of residual sodium chloride from hide preservation and chromium from chrome leather manufacture.

León, Guanajuato		Old waste seepage	Stream to lagoon	Drainage ditch
BGS code **Field code** **Sampling date**	**Units**	**M6**	**M7**	**M8**
Inorganic determinands				
pH		8.26	7.65	7.77
Conductivity	µS/cm	ns	ns	ns
Temperature	°C	ns	ns	ns
Dissolved oxygen	mg/l	ns	ns	ns
Redox potential	mV	ns	ns	ns
Sodium	mg/l	1,800	508	476
Potassium	mg/l	809	131	111
Calcium	mg/l	127	143	142
Magnesium	mg/l	121	35.2	32.3
Alkalinity (as HCO_3)	mg/l	5,300	2,490	1,950
Chloride	mg/l	3,680	752	729
Sulphate	mg/l	52.6	22.9	17.9
Ammonium	mg/l	1020	349	421
Nitrite	mg/l	<5.00	4.13	4.60
Nitrate	mg/l	<1.00	<0.50	<0.50
Total organic carbon	mg/l	1,620	564	476
COD	mg/l	ns	ns	ns
Bromide	mg/l	ns	ns	ns
Total phosphorus	mg/l	ns	ns	ns
Total sulphur	mg/l	ns	ns	ns
Silica	mg/l			
Barium	mg/l	ns	ns	ns
Strontium	mg/l	2.17	0.81	0.89
Lithium	mg/l	0.100	0.040	0.040
Boron	mg/l	3.07	0.68	0.57
Manganese	mg/l	0.46	1.48	1.36
Total iron	mg/l	5.0	4.0	4.2
Aluminium	mg/l	0.44	0.35	4.40
Cobalt	mg/l	0.08	<0.02	<0.02
Nickel	mg/l	0.31	<0.01	<0.01
Copper	mg/l	0.043	0.008	0.010
Zinc	mg/l	0.652	0.085	0.101
Chromium	mg/l	5.43	1.78	1.28
Molybdenum	mg/l	0.06	<0.02	<0.02
Cadmium	mg/l	<0.015	<0.005	<0.005
Lead	mg/l	<0.30	<0.10	<0.10
Vanadium	mg/l	0.17	0.02	0.03

MÉRIDA

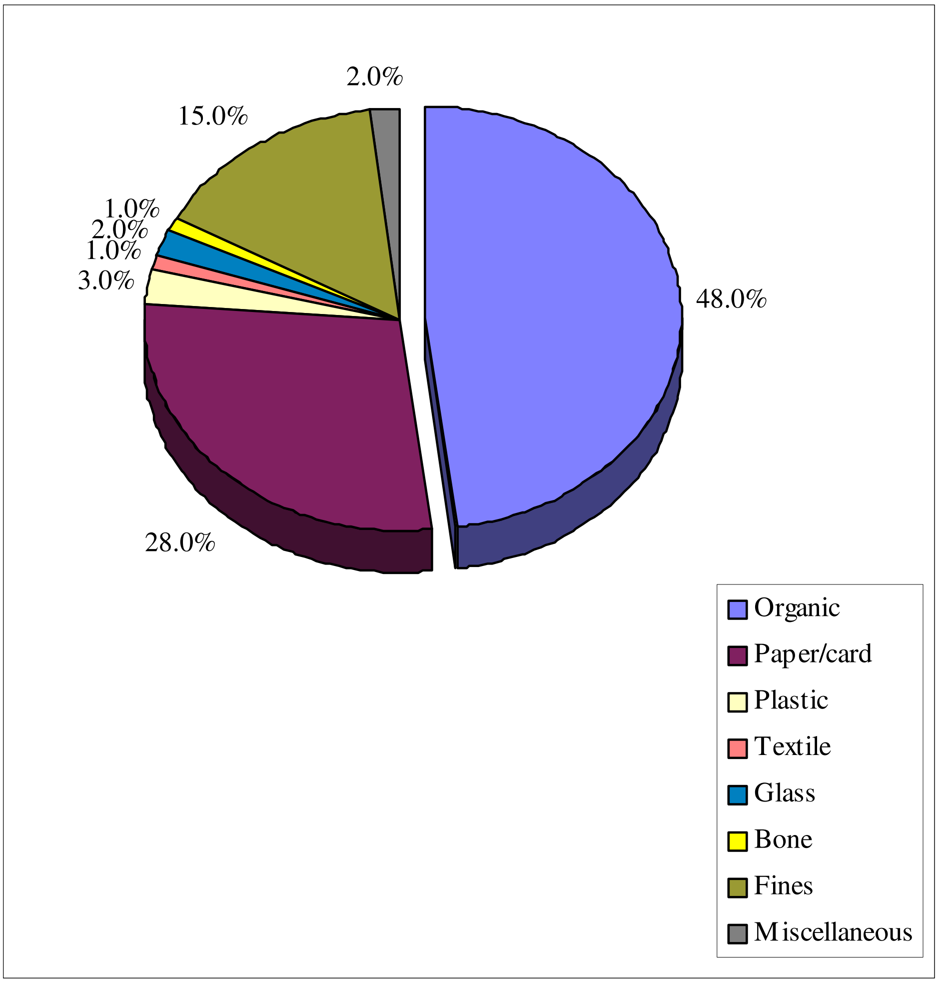
Climate



Landfill details

Large site serving Mérida, the state capital of Yucatan, accepting municipal, medical and industrial wastes, both solid and liquid. The site has a complex history of waste disposal and was originally segregated into areas for domestic solid waste, liquid waste lagoons etc. Today the site consists of a series of waste layers covered with fine material derived from the waste. Large amounts of leachate are generated and ponding occurs in each of the layers. Leachate was sampled from seepage from the two upper layers.

Waste composition for Merida, Mexico



Organic	27.6
Paper/card	39.5
Plastic	7.4
Rubber	0.7
Metal	3.5
Textile	0.6
Glass	7.1
Bone	0.1
Fines	2.0
Miscellaneous	5.4

Mérida Landfill, Mexico Upper level					
BGS code		**7192**	**8432**		
Field code		**M11**	**L1**	**L1**	**L1**
Sampling date	**Units**	**Aug-94**	**Sep-96**	**Apr-97**	**Oct-97**
Inorganic determinands					
pH		8.24	7.78	7.83	8.04
Conductivity	µS/cm	ns	29,100	33,750	22,900
Temperature	°C	ns	ns	36.3	33.9
Dissolved oxygen	mg/l	ns	ns	ns	ns
Redox potential	mV	ns	ns	134	(116)
Sodium	mg/l	4,440	2,941	5,670	3,514
Potassium	mg/l	2,740	1,674	3,610	2,090
Calcium	mg/l	118	135	138	84.6
Magnesium	mg/l	146	66.7	110	72.3
Alkalinity (as HCO_3)	mg/l	5,070	7,747	8,960	5,320
Chloride	mg/l	6,880	4,489	8,752	5,830
Sulphate	mg/l	7.44	121	357	38.8
Ammoniacal-N	mg/l	610	57.8	1,008	701
Nitrite-N	mg/l	<0.50	<2.00	<4.00	<2.00
Nitrate-N	mg/l	<1.00	<10.0	<20.0	<10.0
Total organic carbon	mg/l	1,340	1,478	3,298	191
COD	mg/l	ns	ns	8,150	ns
Bromide	mg/l	14.6	6.95	17.6	14.9
Total phosphorus	mg/l	ns	<10.0	7.68	8.85
Total sulphur	mg/l	ns	ns	ns	ns
Silica	mg/l	14.5	18.7	11.1	14.0
Barium	mg/l	ns	0.1	0.253	0.237
Strontium	mg/l	1.29	1.12	1.24	0.90
Lithium	mg/l	0.25	0.270	0.254	0.187
Boron	mg/l	7.07	7.24	9.51	9.15
Manganese	mg/l	0.12	0.12	0.30	0.26
Total iron	mg/l	9.53	15.0	26.5	26.1
Aluminium	mg/l	1.17	0.66	2.20	1.23
Cobalt	mg/l	<0.06	<0.20	<0.20	<0.20
Nickel	mg/l	0.42	<1.00	0.84	<1.00
Copper	mg/l	0.14	<0.05	4.34	0.92
Zinc	mg/l	0.76	<0.05	2.52	0.60
Chromium	mg/l	0.20	<0.10	0.62	0.42
Molybdenum	mg/l	<0.06	<0.20	<0.20	<0.20
Cadmium	mg/l	<0.02	<0.05	0.03	<0.50
Lead	mg/l	<0.30	<1.00	<1.00	<1.00
Vanadium	mg/l	0.59	0.24	0.90	0.90

Mérida Landfill, Mexico Upper level				
BGS code		**8432**		
Field code		**L1**	**L1**	**L1**
Sampling date	**Units**	**Sep-96**	**Apr-97**	**Oct-97**
Organic determinands				
Acetic acid (C2)	mg/l	<5.0	<1.0	<1.0
Propionic acid (C3)	mg/l	<5.0	<1.0	<1.0
Iso-butyric acid (C4)	mg/l	<5.0	<1.0	<1.0
N-butyric acid (C4)	mg/l	<5.0	<1.0	<1.0
Iso-valeric acid (C5)	mg/l	<5.0	<1.0	<1.0
N-valeric acid (C5)	mg/l	<5.0	<1.0	<1.0
Iso-caproic acid (C6)	mg/l	<5.0	<1.0	<1.0
N-caproic acid (C6)	mg/l	<5.0	<1.0	<1.0
Enanthic acid (C7)	mg/l	nd	ns	ns
Branched caprylic acid (C8)	mg/l	nd	ns	ns
Caprylic acid (C8)	mg/l	nd	ns	ns
Pelagonic acid (C9)	mg/l	nd	ns	ns
Phenyl acetic acid	mg/l	nd	ns	ns
Phenyl propionic acid	mg/l	nd	ns	ns
Cyclohexane carboxylic acid	mg/l	nd	ns	ns
Cyclohexane propionic acid	mg/l	nd	ns	ns
Myristic acid (C14)	µg/l	nd	ns	ns
Myristic acid alkyl esters	µg/l	nd	ns	ns
Palmitic acid (C16)	µg/l	nd	ns	ns
Oleic acid (unsat.C18)	µg/l	nd	ns	ns
Stearic acid (C18)	µg/l	nd	ns	ns
Caffeine	µg/l	nd	ns	ns
Nicotine	µg/l	nd	ns	ns
Butoxyethanol	µg/l	nd	ns	ns
Linalyl alkyl esters	µg/l	nd	ns	ns
Nonanal	µg/l	nd	ns	ns
Phenol	µg/l	nd	ns	ns
Cresol	µg/l	6.70	ns	ns
Ethyl phenol	µg/l	nd	ns	ns
Cholesterol	µg/l	nd	ns	ns
Cholestanol	µg/l	21.0	ns	ns
Coprostanone	µg/l	nd	ns	ns
Indole	µg/l	nd	ns	ns
Benzothiazoles	µg/l	nd	ns	ns
Tetrachloroethene	µg/l	<0.20	ns	ns
Diethyl hexyl phthalate	µg/l	51.0	41.6	ns
γ–HCH	µg/l	ns	ns	ns
Ametryne	µg/l	nd	ns	ns
Total alkanes	µg/l	nd	ns	ns
Squalene	µg/l	nd	ns	ns
Benzo(b)fluoranthene	ng/l	26	ns	ns
Benzo(k)fluoranthene	ng/l	6.5	ns	ns
Benzo(a)pyrene	ng/l	21	ns	ns
Benzo(ghi)perylene	ng/l	30	ns	ns
Fluoranthene	ng/l	99	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	6.7	ns	ns

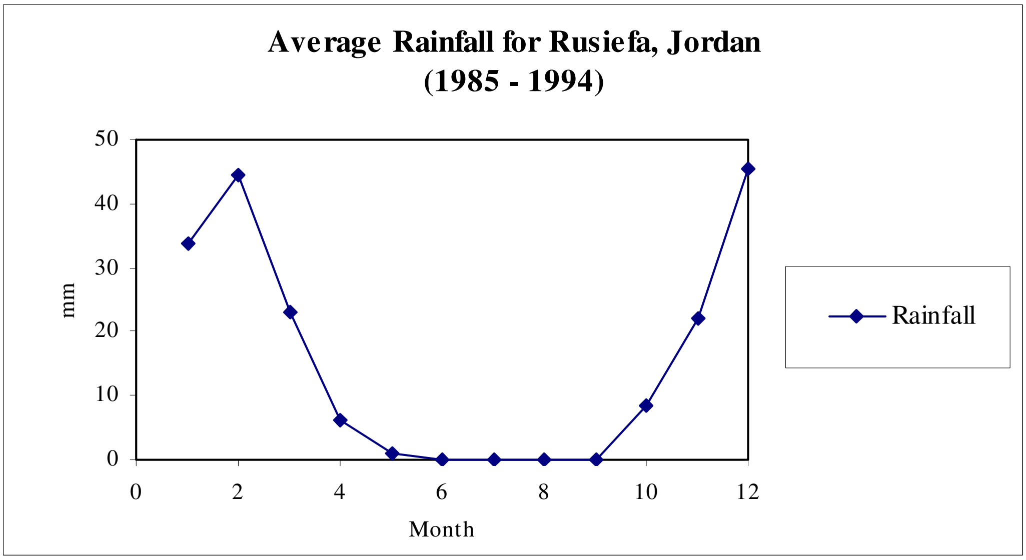
Mérida Landfill, Mexico Lower level				
BGS code		**8433**		
Field code		**L2**	**L2**	**L2**
Sampling date	**Units**	**Sep-96**	**Apr-97**	**Nov-97**
Inorganic determinands				
pH		8.23	7.96	7.94
Conductivity	µS/cm	17,650	12,400	14,710
Temperature	°C	ns	37.1	33.8
Dissolved oxygen	mg/l	ns	ns	ns
Redox potential	mV	ns	185	47.0
Sodium	mg/l	2,273	1,900	1,453
Potassium	mg/l	2,016	1,480	1,493
Calcium	mg/l	114	90.1	124
Magnesium	mg/l	65.0	35.1	62.7
Alkalinity (as HCO_3)	mg/l	4,075	817	6,344
Chloride	mg/l	3,065	2,807	2,176
Sulphate	mg/l	335	610	<5.00
Ammoniacal-N	mg/l	527	15.1	923
Nitrite-N	mg/l	<2.00	60.7	<1.00
Nitrate-N	mg/l	<10.0	471.0	5.31
Total organic carbon	mg/l	2,495	535	206
COD	mg/l	ns	1,120	ns
Bromide	mg/l	7.87	7.58	7.81
Total phosphorus	mg/l	<10.0	1.69	9.20
Total sulphur	mg/l	ns	ns	ns
Silica	mg/l	9.60	2.34	15.3
Barium	mg/l	0.196	0.091	0.185
Strontium	mg/l	0.750	0.692	0.768
Lithium	mg/l	0.150	0.026	0.106
Boron	mg/l	8.30	4.67	5.77
Manganese	mg/l	0.49	0.13	0.38
Total iron	mg/l	33.3	1.68	36.0
Aluminium	mg/l	3.05	0.66	1.67
Cobalt	mg/l	<0.20	<0.20	<0.20
Nickel	mg/l	<1.00	0.38	<1.00
Copper	mg/l	1.35	3.84	0.44
Zinc	mg/l	1.53	0.39	0.53
Chromium	mg/l	0.85	<0.10	0.77
Molybdenum	mg/l	<0.20	<0.20	<0.20
Cadmium	mg/l	<0.05	<0.05	<0.50
Lead	mg/l	<1.00	<1.00	<1.00
Vanadium	mg/l	1.01	0.23	0.59

Mérida Landfill, Mexico Lower level				
BGS code **Field code** **Sampling date**	**Units**	**8433** **L2** **Sep-96**	 **L2** **Apr-97**	 **L2** **Nov-97**
Organic determinands				
Acetic acid (C2)	mg/l	<5.0	<1.0	<1.0
Propionic acid (C3)	mg/l	<5.0	<1.0	<1.0
Iso-butyric acid (C4)	mg/l	<5.0	<1.0	<1.0
N-butyric acid (C4)	mg/l	<5.0	<1.0	<1.0
Iso-valeric acid (C5)	mg/l	<5.0	<1.0	<1.0
N-valeric acid (C5)	mg/l	<5.0	<1.0	<1.0
Iso-caproic acid (C6)	mg/l	<5.0	<1.0	<1.0
N-caproic acid (C6)	mg/l	<5.0	<1.0	<1.0
Enanthic acid (C7)	mg/l	nd	ns	ns
Branched caprylic acid (C8)	mg/l	10.0	ns	ns
Caprylic acid (C8)	mg/l	1.80	ns	ns
Pelagonic acid (C9)	mg/l	3.20	ns	ns
Phenyl acetic acid	mg/l	nd	ns	ns
Phenyl propionic acid	mg/l	nd	ns	ns
Cyclohexane carboxylic acid	mg/l	nd	ns	ns
Cyclohexane propionic acid	mg/l	nd	ns	ns
Myristic acid (C14)	µg/l	nd	ns	ns
Myristic acid alkyl esters	µg/l	nd	ns	ns
Palmitic acid (C16)	µg/l	3.00	ns	ns
Oleic acid (unsat.C18)	µg/l	37.0	ns	ns
Stearic acid (C18)	µg/l	nd	ns	ns
Caffeine	µg/l	nd	ns	ns
Nicotine	µg/l	nd	ns	ns
Butoxyethanol	µg/l	nd	ns	ns
Linalyl alkyl esters	µg/l	nd	ns	ns
Nonanal	µg/l	2.50	ns	ns
Phenol	µg/l	nd	ns	ns
Cresol	µg/l	nd	ns	ns
Ethyl phenol	µg/l	nd	ns	ns
Cholesterol	µg/l	nd	ns	ns
Cholestanol	µg/l	nd	ns	ns
Coprostanone	µg/l	nd	ns	ns
Indole	µg/l	nd	ns	ns
Benzothiazoles	µg/l	nd	ns	ns
Tetrachloroethene	µg/l	<0.2	ns	ns
Diethyl hexyl phthalate	µg/l	4.10	14.8	ns
γ–HCH	µg/l	ns	ns	ns
Ametryne	µg/l	nd	ns	ns
Total alkanes	µg/l	630	ns	ns
Squalene	µg/l	nd	ns	ns
Benzo(b)fluoranthene	ng/l	15.0	ns	ns
Benzo(k)fluoranthene	ng/l	4.1	ns	ns
Benzo(a)pyrene	ng/l	8.9	ns	ns
Benzo(ghi)perylene	ng/l	23.0	ns	ns
Fluoranthene	ng/l	41.0	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	4.7	ns	ns

JORDAN

AMMAN

Climate



Landfill details

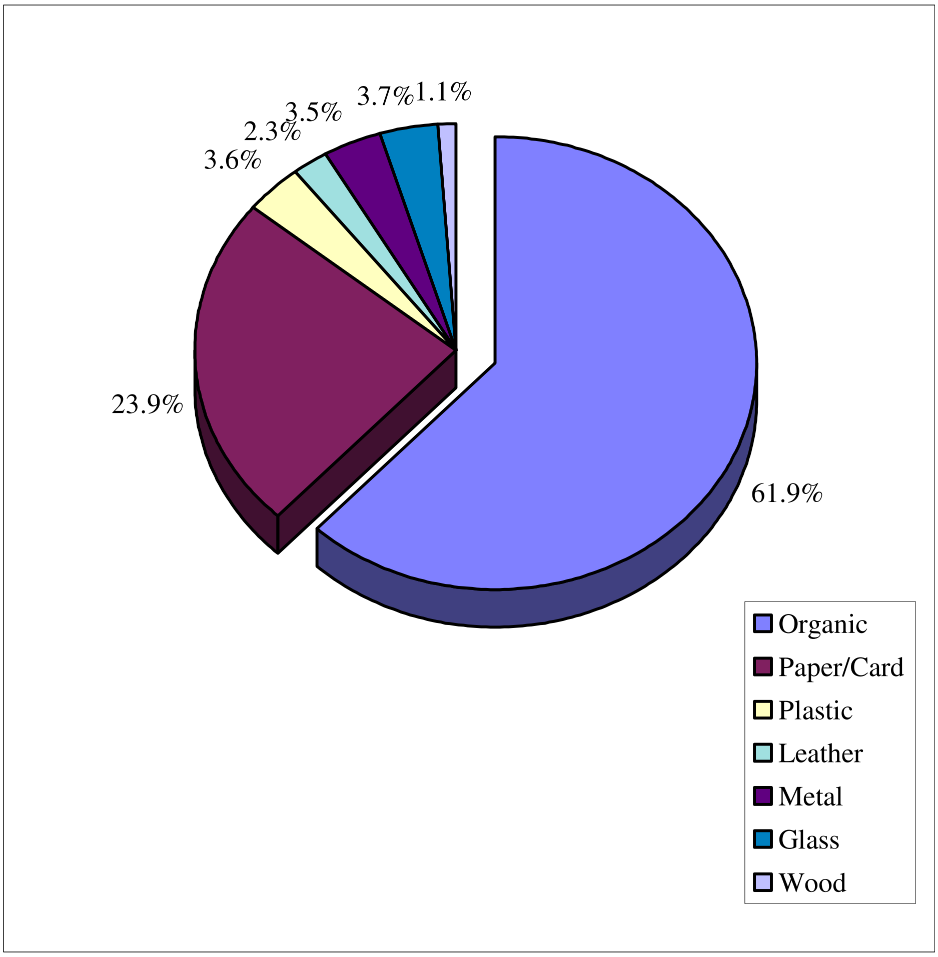
Ruseifa

Large site in abandoned phosphate quarries serving Amman and the surrounding area and accepting solid waste only, mainly municipal but with some industrial and commercial. The first phase operated from 1989-1992 and is now closed and capped off. The second phase is operated as a sanitary landfill with daily soil cover being used. Leachate is directed to a lagoon downslope from the waste face.

Al-Akaider

The principal landfill for the cities of Irbid and Jerash and other areas of northern Jordan. Both solid and liquid wastes are accepted from municipal sources and septic tanks, as well as industrial effluents and sludges. Solid waste is sorted at the site and recyclable materials collected. The remaining waste is compacted and covered with soil. Liquid wastes are collected in a series of lagoons. Excess liquid is used to irrigate a plantation of trees and then ponds in a dry river bed.

Waste composition for Ruseifa, Amman, Jordan

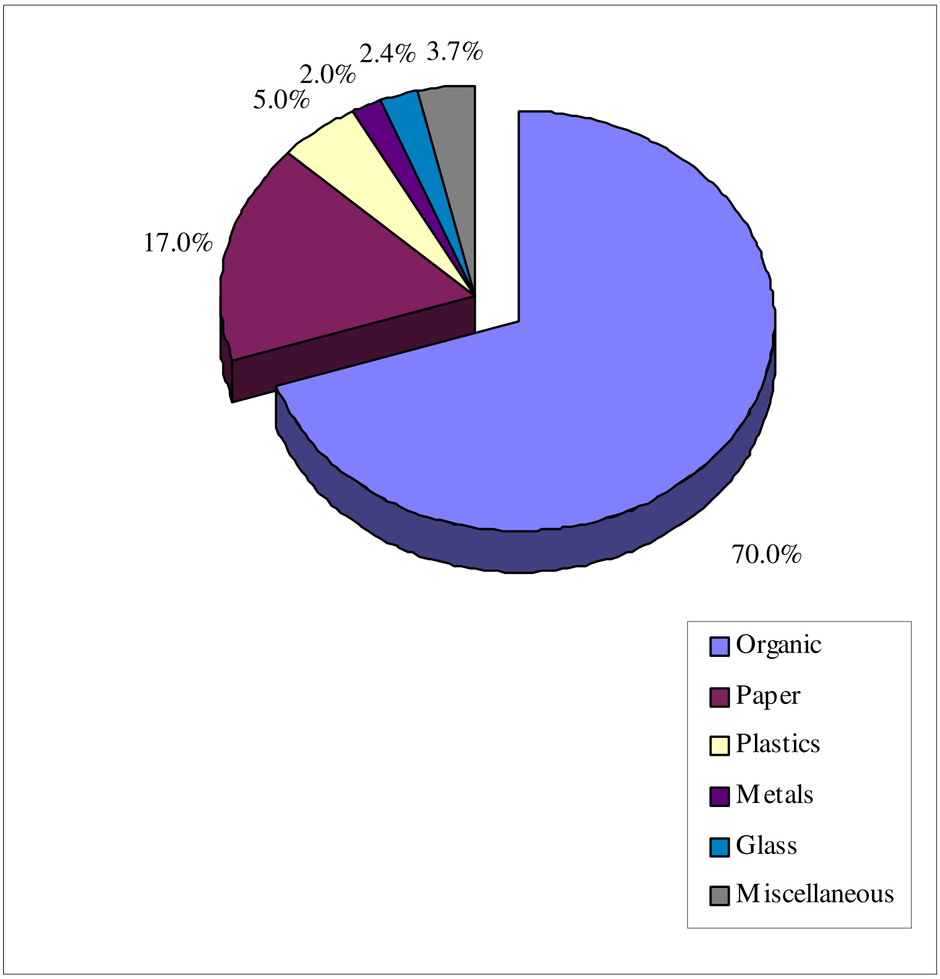


Organic	61.9
Paper/Card	23.9
Plastic	3.6
Leather	2.3
Metal	3.5
Glass	3.7
Wood	1.1

Ruseifa Landfill, Amman, Jordan **Leachate pool**						
BGS code **Field code** **Sampling date**	**Units**	**8264** **JA-1** **17-Jun-96**	**8269** **JA-6** **23-Jun-96**	**8934** **JA-8** **6-Mar-97**	**JA-20** **1-Jun-97**	**JA-26** **1-Feb-98**
Inorganic determinands						
pH		ns	6.89	7.00	5.61	4.5
Conductivity	µS/cm	200,000	150,000	7,500	100,000	100,000
Temperature	°C	24	ns	14	ns	ns
Dissolved oxygen	mg/l	ns	ns	0.70	0.50	0.70
Redox potential	mV	ns	ns	148	(156)	-110
Sodium	mg/l	6,933	13,927	795	10,092	10,227
Potassium	mg/l	3,917	7,392	336	6,042	6,246
Calcium	mg/l	11,301	21,961	257	3,532	1,255
Magnesium	mg/l	1,229	2,283	117	1,589	1,173
Alkalinity (as HCO_3)	mg/l	69,000	93,330	1,875	14,355	13,838
Chloride	mg/l	11,600	19,900	1,454	17,097	15,791
Sulphate	mg/l	2,220	3,830	390	3,529	149
Ammoniacal-N	mg/l	2,820	6,075	189	2,010	2,787
Nitrite-N	mg/l	<1.50	<3.00	<1.00	<10.0	nd
Nitrate-N	mg/l	14.2	10.1	<5.00	<50.0	<5.00
Total organic carbon	mg/l	3,592	ns	1,072	29,040	8,829
COD	mg/l	229,932	233,151	ns	ns	ns
Bromide	mg/l	20.4	36.0	<1.50	26.6	29.1
Total phosphorus	mg/l	31.0	63.1	<1.00	158	8.14
Total sulphur	mg/l	968	1,713	ns	ns	ns
Silica	mg/l	5.86	8.25	5.63	64.7	14.4
Barium	mg/l	0.37	1.05	0.10	3,705	0.44
Strontium	mg/l	20.1	37.3	1.46	26.1	6.53
Lithium	mg/l	0.64	1.43	<0.10	0.94	0.621
Boron	mg/l	9.78	18.4	0.88	14.1	10.5
Manganese	mg/l	33.6	62.0	0.58	60.1	0.31
Total iron	mg/l	122	147	2.11	1217	9.13
Aluminium	mg/l	3.68	5.13	<0.20	99.1	1.07
Cobalt	mg/l	0.41	0.96	<0.20	<0.20	<0.20
Nickel	mg/l	3.68	7.27	<1.00	5.35	1.71
Copper	mg/l	0.11	0.14	<0.50	0.01	<0.05
Zinc	mg/l	42.1	64.3	0.14	128	<0.05
Chromium	mg/l	0.87	1.34	<0.03	5.91	1.07
Molybdenum	mg/l	<0.20	0.41	<0.20	0.86	<0.20
Cadmium	mg/l	<0.05	<0.05	<0.05	0.08	<0.05
Lead	mg/l	<1.00	<1.00	<1.00	<1.00	<1.00
Vanadium	mg/l	0.20	0.34	<0.10	3.19	0.63

Ruseifa Landfill, Amman, Jordan Leachate pool						
BGS code		**8264**	**8269**	**8934**		
Field code		**JA-1**	**JA-6**	**JA-8**	**JA-20**	**JA-26**
Sampling date	**Units**	**17-Jun-96**	**23-Jun-96**	**6-Mar-97**	**1-Jun-97**	**1-Feb-98**
Organic determinands						
Acetic acid (C2)	mg/l	21,270	ns	<1.0	847	ns
Propionic acid (C3)	mg/l	20,315	ns	5.1	798	ns
Iso-butyric acid (C4)	mg/l	3,220	ns	17.0	122	ns
N-butyric acid (C4)	mg/l	53,380	ns	68.0	4,379	nd
Iso-valeric acid (C5)	mg/l	1,925	ns	29.0	202	202
N-valeric acid (C5)	mg/l	8,130	ns	17.0	582	11
Iso-caproic acid (C6)	mg/l	1,805	ns	16.0	54.0	11.0
N-caproic acid (C6)	mg/l	8,870	ns	28.0	677	25
Enanthic acid (C7)	mg/l	ns	ns	4.0	17.2	17.2
Branched caprylic acid (C8)	mg/l	ns	ns	102	nd	nd
Caprylic acid (C8)	mg/l	ns	ns	nd	nd	9.6
Pelagonic acid (C9)	mg/l	ns	ns	nd	nd	nd
Phenyl acetic acid	mg/l	ns	ns	4.2	6.6	10
Phenyl propionic acid	mg/l	ns	ns	7.6	12.6	21
Cyclohexane carboxylic acid	mg/l	ns	ns	nd	nd	6.8
Cyclohexane propionic acid	mg/l	ns	ns	nd	nd	nd
Myristic acid (C14)	µg/l	ns	ns	nd	nd	nd
Myristic acid alkyl esters	µg/l	ns	ns	nd	nd	nd
Palmitic acid (C16)	µg/l	ns	ns	2,930	1,830	nd
Oleic acid (unsat.C18)	µg/l	ns	ns	2,760	1,600	nd
Stearic acid (C18)	µg/l	ns	ns	nd	11,160	nd
Caffeine	µg/l	ns	ns	nd	nd	nd
Nicotine	µg/l	ns	ns	nd	nd	nd
Butoxyethanol	µg/l	ns	ns	nd	nd	nd
Linalyl alkyl esters	µg/l	ns	ns	nd	nd	nd
Nonanal	µg/l	ns	ns	nd	nd	nd
Phenol	µg/l	ns	ns	nd	nd	nd
Cresol	µg/l	ns	ns	nd	nd	nd
Ethyl phenol	µg/l	ns	ns	nd	nd	nd
Cholesterol	µg/l	ns	ns	270	nd	nd
Cholestanol	µg/l	ns	ns	nd	nd	nd
Coprostanone	µg/l	ns	ns	nd	nd	nd
Indole	µg/l	ns	ns	nd	nd	nd
Tetrachloroethene	µg/l	<2.0	<2.0	<0.2	nd	nd
Diethyl hexyl phthalate	µg/l	ns	ns	nd	22	1
γ–HCH	µg/l	<10.0	ns	ns	nd	nd
Ametryne	µg/l	ns	ns	nd	nd	nd
Total alkanes	µg/l	ns	ns	nd	nd	nd
Squalene	µg/l	ns	ns	nd	nd	nd
Benzo(b)fluoranthene	ng/l	201	ns	4.0	ns	ns
Benzo(k)fluoranthene	ng/l	114	ns	2.3	ns	ns
Benzo(a)pyrene	ng/l	342	ns	4.4	ns	ns
Benzo(ghi)perylene	ng/l	158	ns	7.2	ns	ns
Fluoranthene	ng/l	1,540	ns	10.4	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	249	ns	5.0	ns	ns

Waste composition for Al-Akaider, Jordan



Organic	70.0
Paper	17.0
Plastics	5.0
Metals	2.0
Glass	2.4
Miscellaneous	3.6

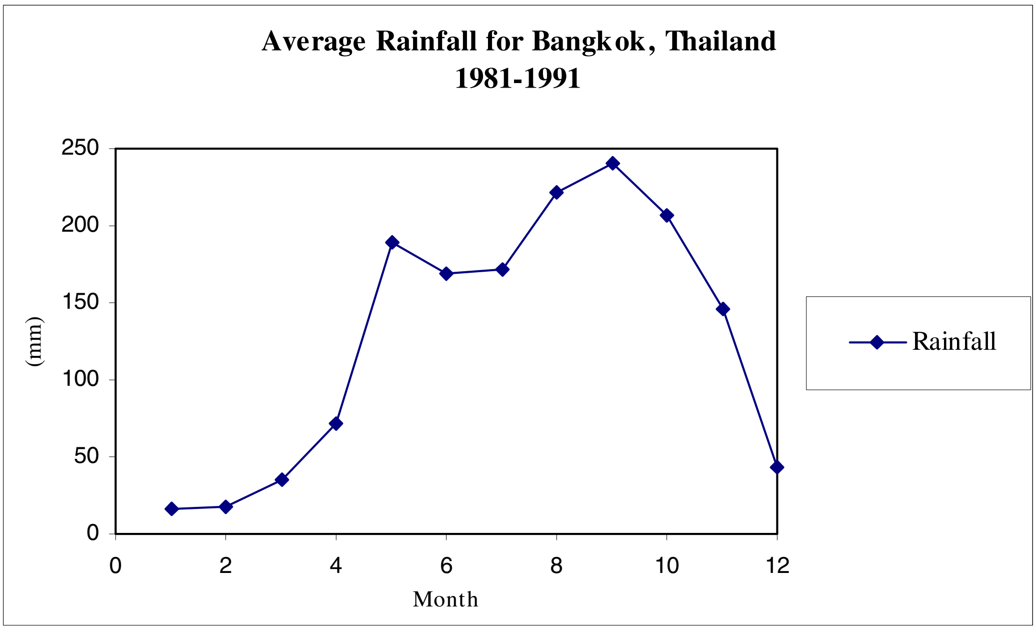
Al-Akaider Landfill, Jordan Second lagoon				
BGS code		**8271**	**8933**	
Field code		**JK-1**	**JK-4**	**JK-7**
Sampling date	**Units**	**19-Jun-96**	**9-Mar-97**	
Inorganic determinands				
pH		ns	7.40	8.45
Conductivity	µS/cm	5,300	5,000	4,100
Temperature	°C	ns	24	ns
Dissolved oxygen	mg/l	ns	2.0	1.3
Redox potential	mV	ns	301	20
Sodium	mg/l	724	363	531
Potassium	mg/l	120	378	91.5
Calcium	mg/l	156	316	121
Magnesium	mg/l	65.8	71.8	44.1
Alkalinity (as HCO_3)	mg/l	1,464	3,587	1,198
Chloride	mg/l	956	531	677
Sulphate	mg/l	8.29	<5.00	<2.00
Ammoniacal-N	mg/l	108	164	184
Nitrite-N	mg/l	<0.15	<1.00	<0.40
Nitrate-N	mg/l	<2.00	<5.00	<2.00
Total organic carbon	mg/l	168	1,491	25.5
COD	mg/l	1,237	ns	ns
Bromide	mg/l	1.2	<1.5	0.94
Total phosphorus	mg/l	6.47	28.2	3.20
Total sulphur	mg/l	6.60	ns	ns
Silica	mg/l	28.5	21.8	30.4
Barium	mg/l	0.029	0.091	0.038
Strontium	mg/l	0.57	0.82	0.49
Lithium	mg/l	<0.05	<0.10	<0.005
Boron	mg/l	0.96	1.0	0.65
Manganese	mg/l	0.06	0.56	0.08
Total iron	mg/l	0.13	4.44	0.17
Aluminium	mg/l	<0.20	<0.20	<0.05
Cobalt	mg/l	<0.20	<0.20	<0.02
Nickel	mg/l	<1.00	<1.00	<0.02
Copper	mg/l	<0.05	<0.05	<0.01
Zinc	mg/l	<0.05	0.20	0.01
Chromium	mg/l	<0.10	<0.10	<0.01
Molybdenum	mg/l	<0.20	<0.20	<0.02
Cadmium	mg/l	<0.05	<0.05	<0.01
Lead	mg/l	<1.00	<1.00	<0.10
Vanadium	mg/l	<0.10	<0.10	<0.01

Al-Akaider Landfill, Jordan Second lagoon				
BGS code		**8271**	**8933**	
Field code		**JK-1**	**JK-4**	**JK-7**
Sampling date	**Units**	**19-Jun-96**	**9-Mar-97**	
Organic determinands				
Acetic acid (C2)	mg/l	<1.0	122	45.0
Propionic acid (C3)	mg/l	<1.0	4.4	23.0
Iso-butyric acid (C4)	mg/l	<1.0	11	8.2
N-butyric acid (C4)	mg/l	<1.0	95	4.0
Iso-valeric acid (C5)	mg/l	<1.0	26	21.0
N-valeric acid (C5)	mg/l	<1.0	27	2.5
Iso-caproic acid (C6)	mg/l	<1.0	4.5	<1.0
N-caproic acid (C6)	mg/l	<1.0	<1.0	7.5
Enanthic acid (C7)	mg/l	ns	nd	nd
Branched caprylic acid (C8)	mg/l	ns	nd	nd
Caprylic acid (C8)	mg/l	ns	nd	nd
Pelagonic acid (C9)	mg/l	ns	nd	nd
Phenyl acetic acid	mg/l	ns	nd	nd
Phenyl propionic acid	mg/l	ns	nd	0.17
Cyclohexane carboxylic acid	mg/l	ns	nd	nd
Cyclohexane propionic acid	mg/l	ns	nd	nd
Myristic acid (C14)	µg/l	ns	0.26	nd
Myristic acid alkyl esters	µg/l	ns	nd	nd
Palmitic acid (C16)	µg/l	ns	0.47	170
Oleic acid (unsat.C18)	µg/l	ns	nd	70.0
Stearic acid (C18)	µg/l	ns	nd	nd
Caffeine	µg/l	ns	nd	nd
Nicotine	µg/l	ns	nd	nd
Butoxyethanol	µg/l	ns	nd	nd
Linalyl alkyl esters	µg/l	ns	nd	nd
Nonanal	µg/l	ns	nd	nd
Phenol	µg/l	ns	500	nd
Cresol	µg/l	ns	4750	nd
Ethyl phenol	µg/l	ns	725	nd
Cholesterol	µg/l	ns	nd	nd
Cholestanol	µg/l	ns	0.12	nd
Coprostanone	µg/l	ns	nd	nd
Indole	µg/l	ns	nd	115
Tetrachloroethene	µg/l	<0.2	<0.2	nd
Diethyl hexyl phthalate	µg/l	ns	nd	21.0
γ–HCH	µg/l	<0.1	ns	nd
Ametryne	µg/l	ns	nd	nd
Total alkanes	µg/l	ns	60.0	nd
Squalene	µg/l	ns	nd	nd
Benzo(b)fluoranthene	ng/l	78	9.7	ns
Benzo(k)fluoranthene	ng/l	44	5.3	ns
Benzo(a)pyrene	ng/l	135	9.3	ns
Benzo(ghi)perylene	ng/l	91	8.7	ns
Fluoranthene	ng/l	484	49	ns
Indeno(1,2,3-cd)pyrene	ng/l	169	3.3	ns

THAILAND

BANGKOK

Climate



Site details

Nong-Khaem & On-Nooch

Waste collection centres serving metropolitan Bangkok. These sites include composting plants which process part of the incoming waste. The remainder passes to landfill.

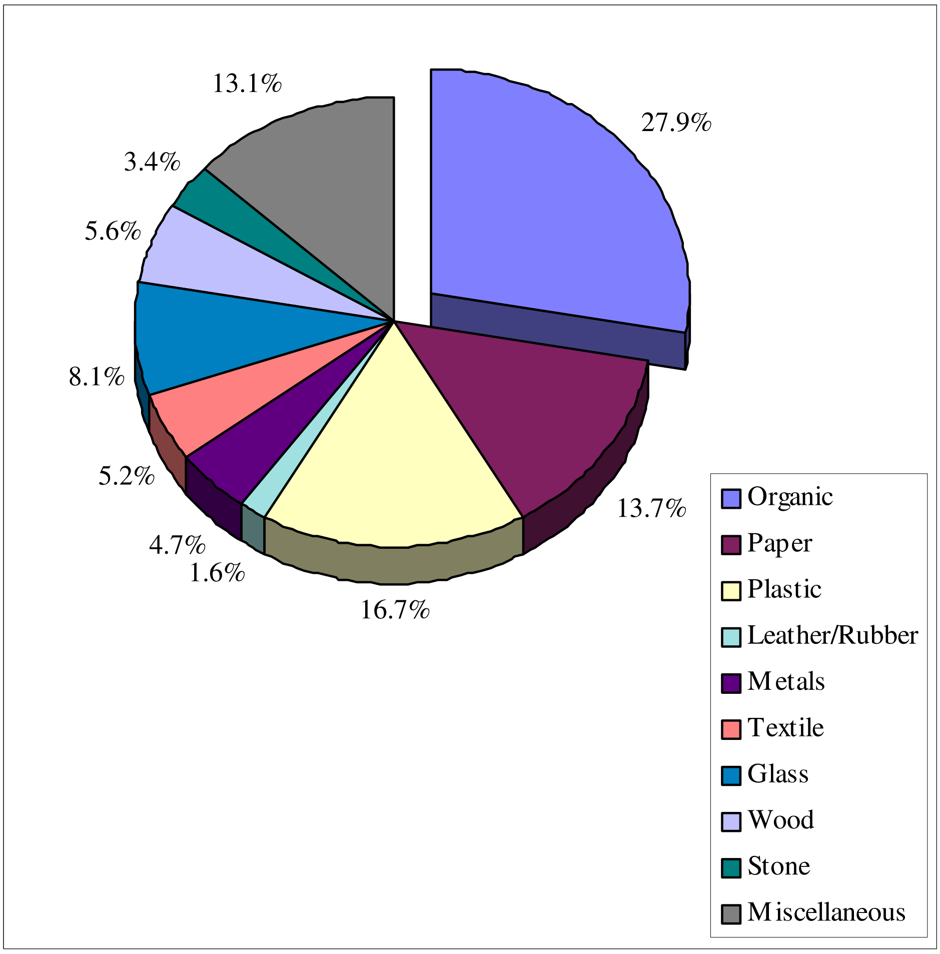
Lat Krabang

Large 35 ha landfill site situated in an old clay pit. The waste has been deposited in layers with intermediate clay cover. Considerable amounts of leachate are generated. Samples were collected from ponding on intermediate layers and from a drainage canal at the periphery of the raise.

Kamphang Saen

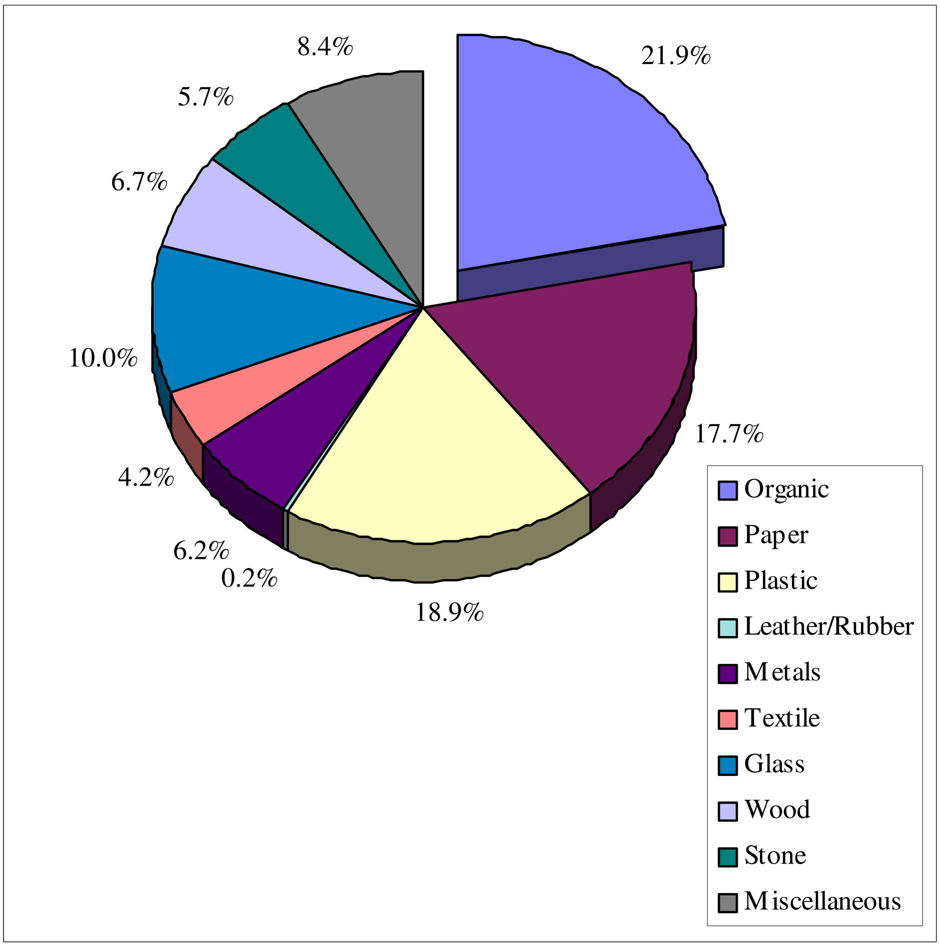
Large site similar to above.

Waste composition for Nong Khaem, Bangkok, Thailand



Organic	28.0
Paper	13.8
Plastic	16.8
Leather/Rubber	1.7
Metals	4.8
Textile	5.2
Glass	8.1
Wood	5.7
Stone	3.4
Miscellaneous	13.1

Waste composition for On-Nooch, Bangkok,Thailand



Organic	22.0
Paper	17.8
Plastic	19.0
Leather/Rubber	0.2
Metals	6.3
Textile	4.3
Glass	10.1
Wood	6.8
Stone	5.77
Miscellaneous	8.45

Lat Krabang, Bangkok, Thailand				
BGS code		**8618**		
Field code		**T1**	**TBL1**	**TBL2**
Sampling date	**Units**	**1-Nov-96**	**1-May-97**	**17-Nov-97**
Inorganic determinands				
pH		5.86	ns	7.57
Conductivity	µS/cm	36,700	ns	28,100
Temperature	°C	ns	ns	32.9
Dissolved oxygen	mg/l	0.10	ns	ns
Redox potential	mV	83	ns	70
Sodium	mg/l	2,336	2,264	2,453
Potassium	mg/l	1,253	1,891	1,932
Calcium	mg/l	2,767	60.3	54.6
Magnesium	mg/l	472	129	121
Alkalinity (as HCO_3)	mg/l	12,810	11,813	14,580
Chloride	mg/l	3,235	3,274	3,802
Sulphate	mg/l	1,526	158	14.9
Ammoniacal-N	mg/l	1,174	2,415	3,032
Nitrite-N	mg/l	<1.00	<4.00	0.74
Nitrate-N	mg/l	<5.00	<20.0	<1.00
Total organic carbon	mg/l	18,000	1,353	392
COD	mg/l	ns	2,700	2,700
Bromide	mg/l	4.46	7.03	7.45
Total phosphorus	mg/l	24.9	25.0	1,770
Total sulphur	mg/l	ns	ns	ns
Silica	mg/l	45.4	20.0	25.5
Barium	mg/l	0.21	0.11	0.20
Strontium	mg/l	5.38	0.35	0.35
Lithium	mg/l	0.44	0.24	0.22
Boron	mg/l	7.57	5.02	6.20
Manganese	mg/l	17.3	0.24	0.24
Total iron	mg/l	192	1.90	2.77
Aluminium	mg/l	1.26	0.34	0.37
Cobalt	mg/l	<0.20	<0.20	<0.20
Nickel	mg/l	1.31	<1.00	<1.00
Copper	mg/l	<0.05	<0.10	<0.05
Zinc	mg/l	0.91	0.17	0.15
Chromium	mg/l	1.43	0.69	0.78
Molybdenum	mg/l	<0.20	<2.00	<0.20
Cadmium	mg/l	<0.05	<0.05	<0.05
Lead	mg/l	<1.00	<1.00	<1.00
Vanadium	mg/l	<0.10	<0.10	<0.10

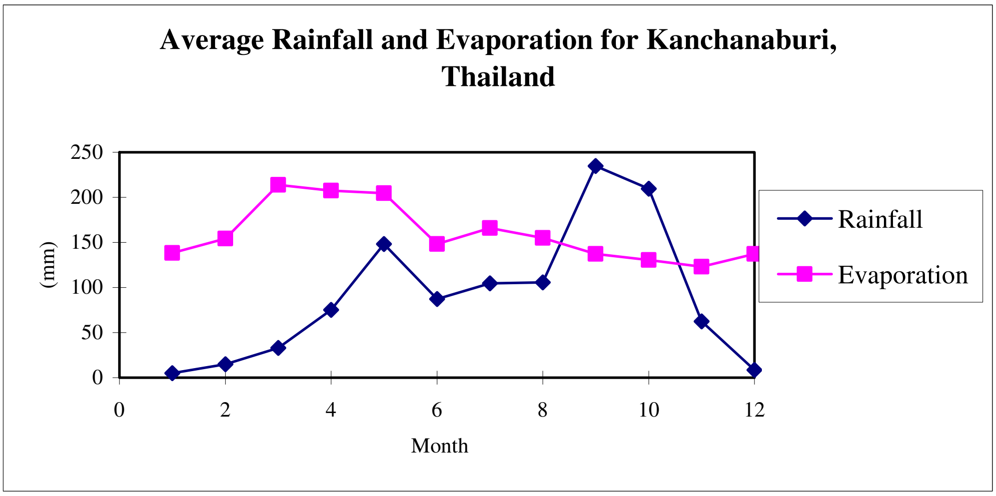
Lat Krabang, Bangkok, Thailand				
BGS code Field code Sampling date	Units	8618 T1 1-Nov-96	 TBL1 1-May-97	 TBL2 17-Nov-97
Organic determinands				
Acetic acid (C2)	mg/l	133	<1.0	<1.0
Propionic acid (C3)	mg/l	174	<1.0	<1.0
Iso-butyric acid (C4)	mg/l	86.0	<1.0	<1.0
N-butyric acid (C4)	mg/l	729	<1.0	<1.0
Iso-valeric acid (C5)	mg/l	187	<1.0	<1.0
N-valeric acid (C5)	mg/l	339	<1.0	<1.0
Iso-caproic acid (C6)	mg/l	26.0	<1.0	<1.0
N-caproic acid (C6)	mg/l	1,500	nd	nd
Enanthic acid (C7)	mg/l	111	nd	nd
Branched caprylic acid (C8)	mg/l	nd	nd	nd
Caprylic acid (C8)	mg/l	14	nd	nd
Pelagonic acid (C9)	mg/l	95	nd	nd
Phenyl acetic acid	mg/l	nd	nd	nd
Phenyl propionic acid	mg/l	nd	nd	nd
Cyclohexane carboxylic acid	mg/l	nd	nd	nd
Cyclohexane propionic acid	mg/l	nd	nd	nd
Myristic acid (C14)	µg/l	nd	nd	nd
Myristic acid alkyl esters	µg/l	nd	nd	nd
Palmitic acid (C16)	µg/l	260	nd	nd
Oleic acid (unsat.C18)	µg/l	nd	49	60
Stearic acid (C18)	µg/l	nd	nd	nd
Caffeine	µg/l	200	nd	nd
Nicotine	µg/l	14,000	nd	nd
Butoxyethanol	µg/l	7,500	nd	nd
Linalyl alkyl esters	µg/l	nd	nd	9.6
Nonanal	µg/l	nd	nd	nd
Phenol	µg/l	nd	nd	nd
Cresol	µg/l	nd	nd	nd
Ethyl phenol	µg/l	nd	nd	nd
Cholesterol	µg/l	nd	nd	nd
Cholestanol	µg/l	nd	nd	nd
Coprostanone	µg/l	nd	nd	5.7
Indole	µg/l	nd	nd	nd
Benzothiazolone	µg/l	nd	105	21.0
Tetrachloroethene	µg/l	<0.20	nd	nd
Diethyl hexyl phthalate	µg/l	175	112	16.6
γ–HCH	µg/l	1.4	nd	nd
Ametryne	µg/l	nd	nd	nd
Total alkanes	µg/l	nd	33.0	19.8
Squalene	µg/l	nd	nd	5.7
Benzo(b)fluoranthene	ng/l	6.0	ns	ns
Benzo(k)fluoranthene	ng/l	<3.0	ns	ns
Benzo(a)pyrene	ng/l	6.6	ns	ns
Benzo(ghi)perylene	ng/l	3.0	ns	ns
Fluoranthene	ng/l	40.2	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	<3.0	ns	ns

Kamphang Sein, Bangkok, Thailand				
BGS code		**8722**	**8723**	**8724**
Field code		**T10**	**T11**	**T12**
Sampling date	**Units**	**1-Dec-97**	**1-Dec-97**	**1-Dec-97**
Inorganic determinands				
pH		7.58	7.19	8.26
Conductivity	μS/cm	42,000	14,000	8,000
Temperature	°C	ns	ns	ns
Dissolved oxygen	mg/l	1.10	1.80	8.20
Redox potential	mV	ns	ns	ns
Sodium	mg/l	3,070	1,460	1,120
Potassium	mg/l	2,600	1,010	515
Calcium	mg/l	62.5	126	35.4
Magnesium	mg/l	59.9	132	146
Alkalinity (as HCO_3)	mg/l	24,339	7,625	1,403
Chloride	mg/l	6,249	2,498	1,894
Sulphate	mg/l	<5.00	6.38	117
Ammoniacal-N	mg/l	5,300	1,424	40.6
Nitrite-N	mg/l	<2.00	<0.40	97.3
Nitrate-N	mg/l	<5.00	<1.00	<5.00
Total organic carbon	mg/l	4,139	566	125
COD	mg/l	12,900	1,560	524
Bromide	mg/l	17.40	5.35	4.67
Total phosphorus	mg/l	48.1	14.6	6.41
Total sulphur	mg/l	ns	ns	ns
Silica	mg/l	21.4	14.7	7.98
Barium	mg/l	0.38	0.17	0.04
Strontium	mg/l	0.25	0.39	0.08
Lithium	mg/l	<0.05	<0.05	0.02
Boron	mg/l	5.59	2.11	1.24
Manganese	mg/l	0.35	0.60	0.48
Total iron	mg/l	18.8	1.57	0.06
Aluminium	mg/l	1.32	0.33	0.06
Cobalt	mg/l	<0.20	<0.20	<0.20
Nickel	mg/l	<1.00	<1.00	<0.10
Copper	mg/l	0.20	<0.05	<0.01
Zinc	mg/l	1.40	0.61	0.22
Chromium	mg/l	2.42	<0.50	<0.05
Molybdenum	mg/l	<0.20	<0.20	<0.20
Cadmium	mg/l	<0.05	<0.05	<0.05
Lead	mg/l	<1.00	<1.00	<1.00
Vanadium	mg/l	0.10	<0.10	0.01

Kamphang Sein, Bangkok, Thailand				
BGS code		**8722**	**8723**	**8724**
Field code		**T10**	**T11**	**T12**
Sampling date	**Units**	**1-Dec-96**	**1-Dec-96**	**1-Dec-96**
Organic determinands				
Acetic acid (C2)	mg/l	11.0	24.0	24.0
Propionic acid (C3)	mg/l	7.9	15.0	7.9
Iso-butyric acid (C4)	mg/l	15.0	8.0	<5.0
N-butyric acid (C4)	mg/l	53.0	45.0	14.0
Iso-valeric acid (C5)	mg/l	12.0	<5.0	<5.0
N-valeric acid (C5)	mg/l	23.0	12.0	<5.0
Iso-caproic acid (C6)	mg/l	<5.0	<5.0	<5.0
N-caproic acid (C6)	mg/l	49.0	49.0	7.8
Enanthic acid (C7)	mg/l	4.26	nd	nd
Branched caprylic acid (C8)	mg/l	nd	nd	nd
Caprylic acid (C8)	mg/l	2.82	nd	nd
Pelagonic acid (C9)	mg/l	nd	nd	nd
Phenyl acetic acid	mg/l	0.81	nd	nd
Phenyl propionic acid	mg/l	0.81	nd	nd
Cyclohexane carboxylic acid	mg/l	4.80	nd	nd
Cyclohexane propionic acid	mg/l	1.02	nd	nd
Myristic acid (C14)	µg/l	nd	nd	nd
Myristic acid alkyl esters	µg/l	nd	nd	1,620
Palmitic acid (C16)	µg/l	nd	nd	86.0
Oleic acid (unsat.C18)	µg/l	nd	nd	nd
Stearic acid (C18)	µg/l	nd	nd	nd
Caffeine	µg/l	nd	nd	nd
Nicotine	µg/l	nd	nd	nd
Butoxyethanol	µg/l	nd	nd	nd
Linalyl alkyl esters	µg/l	nd	nd	nd
Nonanal	µg/l	nd	nd	nd
Phenol	µg/l	nd	nd	nd
Cresol	µg/l	nd	nd	nd
Ethyl phenol	µg/l	nd	nd	nd
Cholesterol	µg/l	nd	nd	nd
Cholestanol	µg/l	nd	55.0	nd
Coprostanone	µg/l	nd	75.0	nd
Indole	µg/l	nd	nd	46.0
Benzothiazoles	µg/l	1,560	235	nd
Tetrachloroethene	µg/l	nd	nd	nd
Diethyl hexyl phthalate	µg/l	330	145	nd
γ–HCH	µg/l	<0.1	<0.1	<0.1
Ametryne	µg/l	nd	nd	nd
Total alkanes	µg/l	nd	nd	63.0
Squalene	µg/l	nd	35.0	nd
Benzo(b)fluoranthene	ng/l	ns	ns	ns
Benzo(k)fluoranthene	ng/l	ns	ns	ns
Benzo(a)pyrene	ng/l	ns	ns	ns
Benzo(ghi)perylene	ng/l	ns	ns	ns
Fluoranthene	ng/l	ns	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	ns	ns	ns

KANCHANABURI

Climate



Landfill details

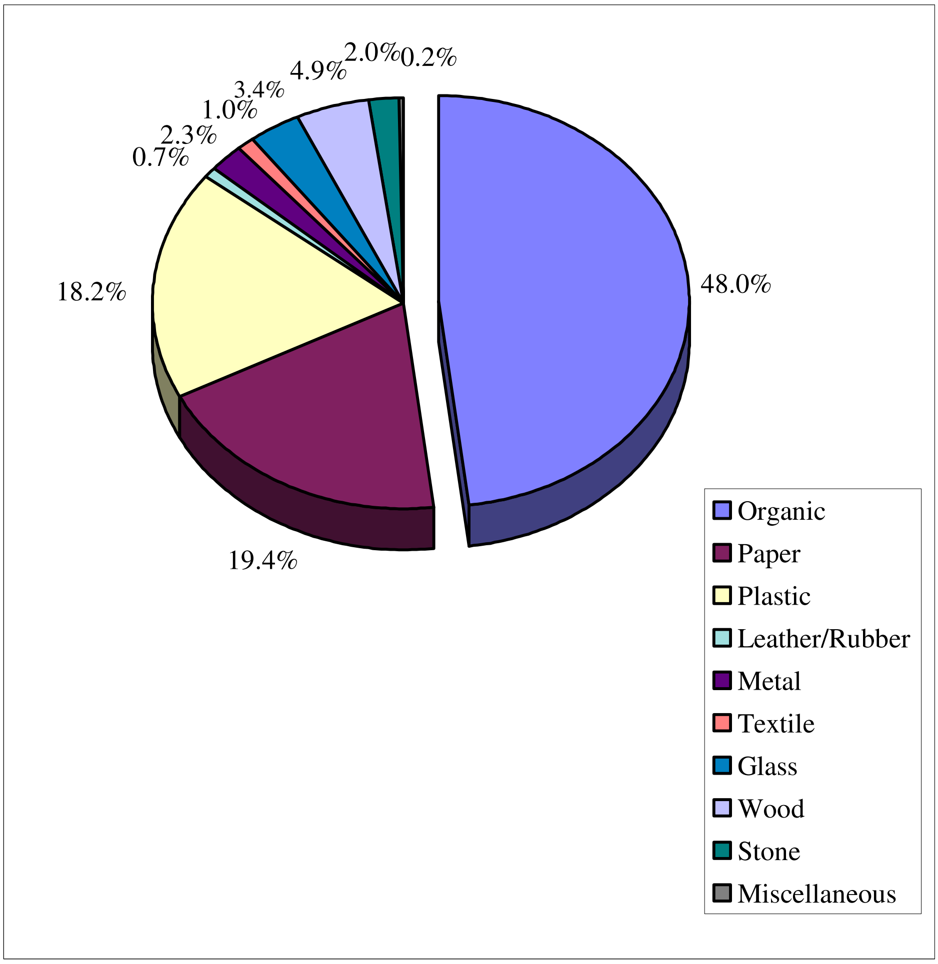
Kanchanaburi

Small open dump serving provincial capital of Kanchanaburi. No waste cover. Leachate collected from sump in centre of dump and from seepage from waste toe.

Tha Muang

Small enclosed surface dump serving village of Tha Muang. No waste cover. Waste periodically burnt. Leachate collected from two lagoons in centre of waste.

Waste composition for Kanchanaburi, Thailand



Organic	48.0
Paper	19.4
Plastic	18.2
Leather/Rubber	0.7
Metal	2.3
Textile	1.0
Glass	3.4
Wood	4.9
Stone	2.0
Miscellaneous	0.2

Kanchanaburi, Thailand		Leachate sump	Toe seepage
BGS code		**8619**	**8620**
Field code		**T2**	**T3**
Sampling date	**Units**	**1-Nov-96**	**1-Nov-96**
Inorganic determinands			
pH		6.31	7.09
Conductivity	mS/cm	19,200	5,540
Temperature	°C	ns	ns
Dissolved oxygen	mg/l	0.40	ns
Redox potential	mV	(46)	178
Sodium	mg/l	421	433
Potassium	mg/l	591	7.98
Calcium	mg/l	319	767
Magnesium	mg/l	96.0	21.9
Alkalinity (as HCO_3)	mg/l	7,533	481
Chloride	mg/l	1,191	1,742
Sulphate	mg/l	37.8	22.3
Ammoniacal-N	mg/l	165	0.42
Nitrite-N	mg/l	<1.00	<0.40
Nitrate-N	mg/l	<5.00	<2.00
Total organic carbon	mg/l	989	112
COD	mg/l	ns	ns
Bromide	mg/l	3.29	7.56
Total phosphorus	mg/l	5.86	<0.10
Total sulphur	mg/l	ns	ns
Silica	mg/l	29.9	4.22
Barium	mg/l	0.74	1.28
Strontium	mg/l	0.78	0.29
Lithium	mg/l	0.10	<0.01
Boron	mg/l	0.76	<0.05
Manganese	mg/l	2.37	13.4
Total iron	mg/l	2.20	0.77
Aluminium	mg/l	0.22	0.22
Cobalt	mg/l	<0.20	<0.20
Nickel	mg/l	<0.10	<0.10
Copper	mg/l	<0.05	<0.05
Zinc	mg/l	0.22	0.30
Chromium	mg/l	<0.01	<0.01
Molybdenum	mg/l	<0.20	<0.20
Cadmium	mg/l	<0.05	<0.05
Lead	mg/l	<0.10	<0.10
Vanadium	mg/l	<0.10	<0.10

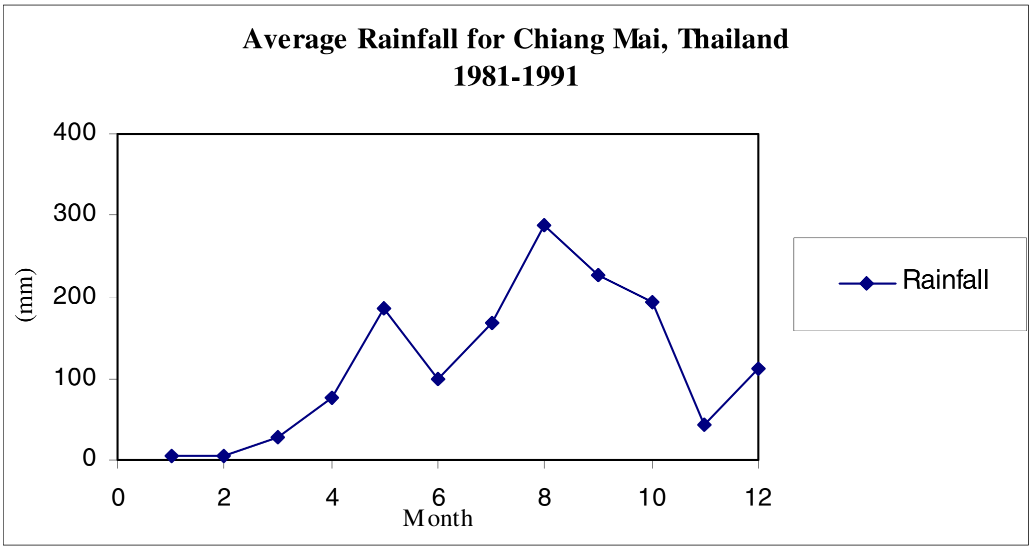
Kanchanaburi, Thailand		Leachate sump	Toe seepage
BGS code		**8619**	**8620**
Field code		**T2**	**T3**
Sampling date	**Units**	**1-Nov-96**	**1-Nov-96**
Organic determinands			
Acetic acid (C2)	mg/l	9.8	<5.0
Propionic acid (C3)	mg/l	52.0	<5.0
Iso-butyric acid (C4)	mg/l	6.8	<5.0
N-butyric acid (C4)	mg/l	44.0	<5.0
Iso-valeric acid (C5)	mg/l	26.0	<5.0
N-valeric acid (C5)	mg/l	37.0	<5.0
Iso-caproic acid (C6)	mg/l	<5.0	<5.0
N-caproic acid (C6)	mg/l	4.0	<5.0
Enanthic acid (C7)	mg/l	1.45	nd
Branched caprylic acid (C8)	mg/l	nd	nd
Caprylic acid (C8)	mg/l	1.50	nd
Pelagonic acid (C9)	mg/l	nd	nd
Phenyl acetic acid	mg/l	0.97	nd
Phenyl propionic acid	mg/l	3.68	nd
Cyclohexane carboxylic acid	mg/l	1.39	0.16
Cyclohexane propionic acid	mg/l	nd	nd
Myristic acid (C14)	mg/l	390	nd
Myristic acid alkyl esters	mg/l	nd	nd
Palmitic acid (C16)	mg/l	1,910	nd
Oleic acid (unsat.C18)	mg/l	1,790	185
Stearic acid (C18)	mg/l	820	nd
Caffeine	mg/l	nd	nd
Nicotine	mg/l	nd	nd
Butoxyethanol	mg/l	nd	nd
Linalyl alkyl esters	mg/l	nd	nd
Nonanal	mg/l	nd	nd
Phenol	mg/l	nd	nd
Cresol	mg/l	nd	nd
Ethyl phenol	mg/l	nd	nd
Cholesterol	mg/l	nd	nd
Cholestanol	mg/l	nd	nd
Coprostanone	mg/l	nd	nd
Indole	mg/l	nd	nd
Tetrachloroethene	mg/l	<0.20	<0.20
Diethyl hexyl phthalate	mg/l	nd	50.0
g-HCH	mg/l	<0.1	<0.1
Ametryne	mg/l	nd	nd
Total alkanes	mg/l	nd	nd
Squalene	mg/l	nd	178
Benzo(b)fluoranthene	ng/l	<3.0	<3.0
Benzo(k)fluoranthene	ng/l	<3.0	<3.0
Benzo(a)pyrene	ng/l	<3.0	<3.0
Benzo(ghi)perylene	ng/l	<3.0	<3.0
Fluoranthene	ng/l	<3.0	<3.0
Indeno(1,2,3-cd)pyrene	ng/l	<3.0	<3.0

Tha Muang, Kanchanaburi Thailand				
BGS code		**8621**	**8622**	
Field code		**T4**	**T5**	**TM14**
Sampling date	**Units**	**1-Nov-96**	**1-Nov-96**	**19-Nov-97**
Inorganic determinands				
pH		7.63	7.64	7.14
Conductivity	µS/cm	4,820	3,010	18,480
Temperature	°C	ns	ns	30.3
Dissolved oxygen	mg/l	1.00	0.90	ns
Redox potential	mV	67	253	315
Sodium	mg/l	438	259	1,941
Potassium	mg/l	457	3.20	1809
Calcium	mg/l	146	117	681
Magnesium	mg/l	79.4	52.2	404
Alkalinity (as HCO_3)	mg/l	1,159	891	207
Chloride	mg/l	928	527	4736
Sulphate	mg/l	117	56.5	3000
Ammoniacal-N	mg/l	40.1	22.3	0.49
Nitrite-N	mg/l	0.51	<0.40	0.63
Nitrate-N	mg/l	<2.00	<2.00	19.6
Total organic carbon	mg/l	73.0	63.5	36.2
COD	mg/l	ns	ns	171
Bromide	mg/l	1.43	0.96	6.53
Total phosphorus	mg/l	4.35	4.27	<1.00
Total sulphur	mg/l	ns	ns	ns
Silica	mg/l	12.3	13.1	<0.20
Barium	mg/l	0.13	0.11	0.10
Strontium	mg/l	0.34	0.26	1.33
Lithium	mg/l	0.06	0.05	0.14
Boron	mg/l	0.47	0.34	0.67
Manganese	mg/l	0.63	0.57	0.08
Total iron	mg/l	0.42	0.40	<0.10
Aluminium	mg/l	0.09	0.08	0.51
Cobalt	mg/l	<0.20	<0.20	<0.20
Nickel	mg/l	<0.10	<0.10	<1.00
Copper	mg/l	<0.05	<0.05	<0.05
Zinc	mg/l	0.31	0.32	0.08
Chromium	mg/l	<0.01	<0.01	<0.10
Molybdenum	mg/l	<0.20	<0.20	<0.20
Cadmium	mg/l	<0.50	<0.05	<0.05
Lead	mg/l	<1.00	<0.10	<1.00
Vanadium	mg/l	<0.10	<0.10	<0.10

Tha Muang, Kanchanaburi, Thailand				
BGS code		**8621**	**8622**	
Field code		**T4**	**T5**	**TM14**
Sampling date	**Units**	**1-Nov-96**	**1-Nov-96**	**19-Nov-97**
Organic determinands				
Acetic acid (C2)	mg/l	<5.0	<5.0	<1.0
Propionic acid (C3)	mg/l	<5.0	<5.0	<1.0
Iso-butyric acid (C4)	mg/l	<5.0	<5.0	<1.0
N-butyric acid (C4)	mg/l	<5.0	<5.0	<1.0
Iso-valeric acid (C5)	mg/l	<5.0	<5.0	<1.0
N-valeric acid (C5)	mg/l	<5.0	<5.0	<1.0
Iso-caproic acid (C6)	mg/l	<5.0	<5.0	<1.0
N-caproic acid (C6)	mg/l	<5.0	<5.0	<1.0
Enanthic acid (C7)	mg/l	nd	nd	nd
Branched caprylic acid (C8)	mg/l	nd	nd	nd
Caprylic acid (C8)	mg/l	nd	nd	nd
Pelagonic acid (C9)	mg/l	nd	nd	nd
Phenyl acetic acid	mg/l	nd	nd	nd
Phenyl propionic acid	mg/l	nd	nd	nd
Cyclohexane carboxylic acid	mg/l	nd	nd	nd
Cyclohexane propionic acid	mg/l	nd	nd	nd
Myristic acid (C14)	µg/l	nd	nd	nd
Myristic acid alkyl esters	µg/l	nd	14.0	nd
Palmitic acid (C16)	µg/l	11.0	13.0	nd
Oleic acid (unsat.C18)	µg/l	51.0	23.0	nd
Stearic acid (C18)	µg/l	nd	nd	nd
Caffeine	µg/l	nd	nd	nd
Nicotine	µg/l	nd	nd	nd
Butoxyethanol	µg/l	nd	nd	nd
Linalyl alkyl esters	µg/l	nd	nd	nd
Nonanal	µg/l	10	16	nd
Phenol	µg/l	nd	nd	nd
Cresol	µg/l	nd	nd	nd
Ethyl phenol	µg/l	nd	nd	nd
Cholesterol	µg/l	nd	11.0	nd
Cholestanol	µg/l	nd	nd	nd
Coprostanone	µg/l	nd	nd	nd
Indole	µg/l	nd	nd	nd
Benzothiazolone	µg/l	nd	nd	nd
Tetrachloroethene	µg/l	<0.20	<0.20	nd
Diethyl hexyl phthalate	µg/l	14.0	15.0	1.01
γ–HCH	µg/l	<0.1	<0.1	nd
Ametryne	µg/l	nd	52.0	nd
Total alkanes	µg/l	24.0	nd	nd
Squalene	µg/l	nd	11.0	nd
Benzo(b)fluoranthene	ng/l	<3.0	<3.0	ns
Benzo(k)fluoranthene	ng/l	<3.0	<3.0	ns
Benzo(a)pyrene	ng/l	<3.0	<3.0	ns
Benzo(ghi)perylene	ng/l	<3.0	<3.0	ns
Fluoranthene	ng/l	<3.0	5.6	ns
Indeno(1,2,3-cd)pyrene	ng/l	<3.0	<3.0	ns

CHIANG MAI

Climate



Landfill details

Mae Hia

Site serving the city of Chiangmai from 1958 to 1989. Waste was disposed by a mixture of filling with soil cover and open dumping. The site was closed after complaints from local residents about groundwater pollution. The waste is now soil covered and leachate was sampled from a small lagoon remaining within the original dump area.

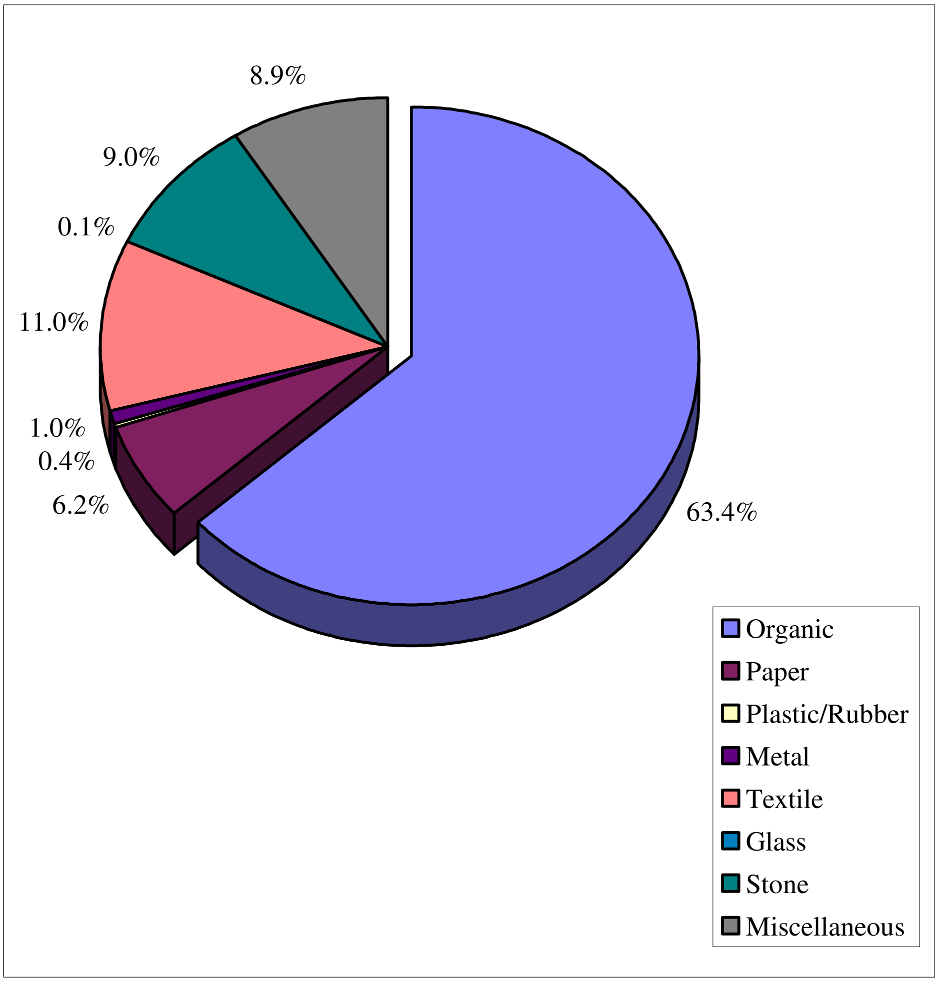
San Sai

A new site built to replace Mae Hia, where waste is dumped, without cover, into a lined excavation. Leachate collects in the centre of the site. Provision has been made to pump out and treat the leachate but this was not operational at the time of sampling.

Lamphun

A small site, now closed and covered serving the town of Lamphun. Leachate was collected from an open lagoon.

Waste composition for Chiang Mai, Thailand



Organic	70.1
Paper	6.8
Plastic/Rubber	0.4
Metal	1.1
Textile	12.2
Glass	0.1
Stone	10.0
Miscellaneous	9.8

Mae Hia, Chiang Mai, Thailand			
BGS code **Field code** **Sampling date**	**Units**	**TCL1** **1-May-97**	**TCL6** **23-Nov-97**
Inorganic determinands			
pH		9.42	7.05
Conductivity	µS/cm	11,080	7,600
Temperature	°C	26.3	32.1
Dissolved oxygen	mg/l	nd	nd
Redox potential	mV	nd	(27)
Sodium	mg/l	1,210	567
Potassium	mg/l	2,078	1,088
Calcium	mg/l	22.4	149.0
Magnesium	mg/l	119	106
Alkalinity (as HCO_3)	mg/l	2,635	2,489
Chloride	mg/l	2,315	1,079
Sulphate	mg/l	201	332
Ammoniacal-N	mg/l	6.85	200
Nitrite-N	mg/l	<2.00	28.6
Nitrate-N	mg/l	<10.00	<1.00
Total organic carbon	mg/l	392	188
COD	mg/l	855	528
Bromide	mg/l	4.59	2.39
Total phosphorus	mg/l	<1.00	1.87
Total sulphur	mg/l	ns	ns
Silica	mg/l	13.5	14.9
Barium	mg/l	0.09	0.55
Strontium	mg/l	0.12	0.58
Lithium	mg/l	<0.05	<0.05
Boron	mg/l	1.69	1.05
Manganese	mg/l	0.10	0.95
Total iron	mg/l	0.04	0.25
Aluminium	mg/l	<0.20	<0.20
Cobalt	mg/l	<0.20	<0.20
Nickel	mg/l	<1.00	<1.00
Copper	mg/l	<0.05	<0.05
Zinc	mg/l	0.02	0.05
Chromium	mg/l	<0.10	<0.10
Molybdenum	mg/l	<0.20	<0.20
Cadmium	mg/l	<0.05	<0.05
Lead	mg/l	<1.00	<1.00
Vanadium	mg/l	<0.10	<0.10

Mae Hia, Chiang Mai, Thailand			
BGS code Field code Sampling date	Units	 TCL1 1-May-97	 TCL6 23-Nov-97
Organic determinands			
Acetic acid (C2)	mg/l	<1.0	<1.0
Propionic acid (C3)	mg/l	<1.0	<1.0
Iso-butyric acid (C4)	mg/l	<1.0	<1.0
N-butyric acid (C4)	mg/l	<1.0	<1.0
Iso-valeric acid (C5)	mg/l	<1.0	<1.0
N-valeric acid (C5)	mg/l	<1.0	<1.0
Iso-caproic acid (C6)	mg/l	<1.0	<1.0
N-caproic acid (C6)	mg/l	<1.0	<1.0
Enanthic acid (C7)	mg/l	nd	nd
Branched caprylic acid (C8)	mg/l	nd	nd
Caprylic acid (C8)	mg/l	nd	nd
Pelagonic acid (C9)	mg/l	nd	0.10
Phenyl acetic acid	mg/l	nd	nd
Phenyl propionic acid	mg/l	nd	nd
Cyclohexane carboxylic acid	mg/l	nd	nd
Cyclohexane propionic acid	mg/l	nd	nd
Myristic acid (C14)	µg/l	nd	nd
Myristic acid alkyl esters	µg/l	nd	nd
Palmitic acid (C16)	µg/l	nd	4.90
Oleic acid (unsat.C18)	µg/l	nd	nd
Stearic acid (C18)	µg/l	nd	nd
Caffeine	µg/l	nd	nd
Nicotine	µg/l	nd	nd
Butoxyethanol	µg/l	nd	nd
Linalyl alkyl esters	µg/l	nd	nd
Nonanal	µg/l	16.0	6.00
Phenol	µg/l	nd	nd
Cresol	µg/l	10.0	nd
Ethyl phenol	µg/l	nd	nd
Cholesterol	µg/l	nd	nd
Cholestanol	µg/l	nd	nd
Coprostanone	µg/l	nd	nd
Indole	µg/l	nd	nd
Benzothiazoles	µg/l	nd	nd
Tetrachloroethene	µg/l	nd	nd
Diethyl hexyl phthalate	µg/l	37.5	8.54
γ–HCH	µg/l	nd	nd
Ametryne	µg/l	nd	nd
Total alkanes	µg/l	38.00	nd
Squalene	µg/l	nd	nd
Benzo(b)fluoranthene	ng/l	ns	ns
Benzo(k)fluoranthene	ng/l	ns	ns
Benzo(a)pyrene	ng/l	ns	ns
Benzo(ghi)perylene	ng/l	ns	ns
Fluoranthene	ng/l	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	ns	ns

San Sai, Chiang Mai, Thailand			
BGS code Field code Sampling date	**Units**	**TCL3 1-May-97**	**TCL4 22-Nov-97**
Inorganic determinands			
pH		6.77	6.98
Conductivity	µS/cm	12,700	28,300
Temperature	°C	36.8	36.9
Dissolved oxygen	mg/l	nd	nd
Redox potential	mV	nd	(42)
Sodium	mg/l	1,680	2,179
Potassium	mg/l	499	1,819
Calcium	mg/l	616	199
Magnesium	mg/l	237	182
Alkalinity (as HCO_3)	mg/l	1,830	9,740
Chloride	mg/l	3,068	3,650
Sulphate	mg/l	359	1.58
Ammoniacal-N	mg/l	284	1,350
Nitrite-N	mg/l	<5.00	0.32
Nitrate-N	mg/l	<10.0	<1.00
Total organic carbon	mg/l	2,398	990
COD	mg/l	6,800	1,980
Bromide	mg/l	<3.00	3.73
Total phosphorus	mg/l	1.13	14.3
Total sulphur	mg/l	ns	ns
Silica	mg/l	3.91	25.2
Barium	mg/l	0.63	0.22
Strontium	mg/l	1.02	0.58
Lithium	mg/l	<0.05	0.10
Boron	mg/l	<0.50	1.22
Manganese	mg/l	11.1	1.65
Total iron	mg/l	14.6	3.08
Aluminium	mg/l	0.25	<0.20
Cobalt	mg/l	<0.20	<0.20
Nickel	mg/l	<1.00	<1.00
Copper	mg/l	<0.05	<0.05
Zinc	mg/l	0.15	0.24
Chromium	mg/l	<0.10	0.16
Molybdenum	mg/l	<0.20	<0.20
Cadmium	mg/l	<0.05	<0.05
Lead	mg/l	<1.00	<1.00
Vanadium	mg/l	<0.10	<0.10

San Sai, Chiang Mai, Thailand			
BGS code			
Field code		**TCL3**	**TCL4**
Sampling date	**Units**	**1-May-97**	**22-Nov-97**
Organic determinands			
Acetic acid (C2)	mg/l	14.0	<1.0
Propionic acid (C3)	mg/l	20.0	<1.0
Iso-butyric acid (C4)	mg/l	49.0	<1.0
N-butyric acid (C4)	mg/l	14.0	<1.0
Iso-valeric acid (C5)	mg/l	61.0	<1.0
N-valeric acid (C5)	mg/l	80.0	<1.0
Iso-caproic acid (C6)	mg/l	4.3	<1.0
N-caproic acid (C6)	mg/l	207	<1.0
Enanthic acid (C7)	mg/l	18.0	nd
Branched caprylic acid (C8)	mg/l	nd	nd
Caprylic acid (C8)	mg/l	5.11	nd
Pelagonic acid (C9)	mg/l	nd	nd
Phenyl acetic acid	mg/l	1.22	nd
Phenyl propionic acid	mg/l	2.29	nd
Cyclohexane carboxylic acid	mg/l	2.60	nd
Cyclohexane propionic acid	mg/l	nd	nd
Myristic acid (C14)	µg/l	nd	nd
Myristic acid alkyl esters	µg/l	nd	nd
Palmitic acid (C16)	µg/l	nd	nd
Oleic acid (unsat.C18)	µg/l	nd	24.0
Stearic acid (C18)	µg/l	nd	nd
Caffeine	µg/l	nd	nd
Nicotine	µg/l	nd	nd
Butoxyethanol	µg/l	nd	nd
Linalyl alkyl esters	µg/l	nd	7.40
Nonanal	µg/l	nd	6.40
Phenol	µg/l	nd	nd
Cresol	µg/l	nd	12.0
Ethyl phenol	µg/l	nd	nd
Cholesterol	µg/l	nd	nd
Cholestanol	µg/l	nd	nd
Coprostanone	µg/l	nd	nd
Indole	µg/l	nd	nd
Benzothiazoles	µg/l	nd	3.30
Tetrachloroethene	µg/l	nd	nd
Diethyl hexyl phthalate	µg/l	2.10	6.26
γ–HCH	µg/l	nd	nd
Ametryne	µg/l	nd	nd
Total alkanes	µg/l	nd	19.0
Squalene	µg/l	nd	nd
	ns		
Benzo(b)fluoranthene	ng/l	ns	ns
Benzo(k)fluoranthene	ng/l	ns	ns
Benzo(a)pyrene	ng/l	ns	ns
Benzo(ghi)perylene	ng/l	ns	ns
Fluoranthene	ng/l	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	ns	ns

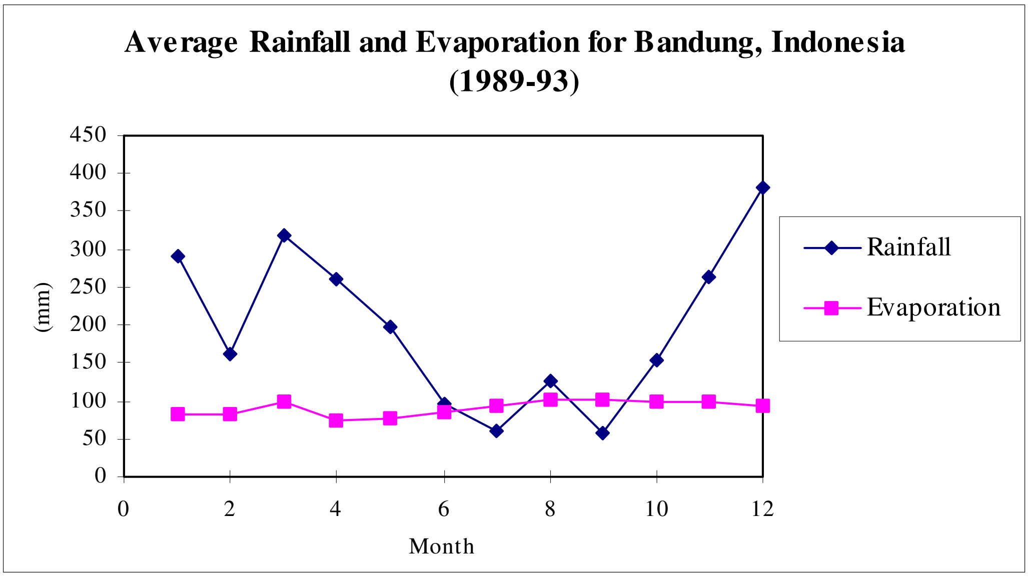
Lamphun, Chiang Mai, Thailand			
BGS code **Field code** **Sampling date**	**Units**	**TCL2** **1-May-97**	**TCL5** **22-Nov-97**
Inorganic determinands			
pH		9.68	7.96
Conductivity	µS/cm	6,740	5,160
Temperature	°C	30.0	32.2
Dissolved oxygen	mg/l	nd	nd
Redox potential	mV	nd	172
Sodium	mg/l	864	496
Potassium	mg/l	882	523
Calcium	mg/l	21.6	43.7
Magnesium	mg/l	77.8	47.0
Alkalinity (as HCO_3)	mg/l	830	1,163
Chloride	mg/l	1,729	979
Sulphate	mg/l	70.8	2.02
Ammoniacal-N	mg/l	2.94	133
Nitrite-N	mg/l	12.2	6.9
Nitrate-N	mg/l	266	0.54
Total organic carbon	mg/l	142	113
COD	mg/l	344	1,520
Bromide	mg/l	1.98	1.18
Total phosphorus	mg/l	<1.00	<1.00
Total sulphur	mg/l	ns	ns
Silica	mg/l	3.34	11.8
Barium	mg/l	0.71	0.87
Strontium	mg/l	0.33	0.28
Lithium	mg/l	<0.05	<0.05
Boron	mg/l	<0.50	<0.50
Manganese	mg/l	0.04	1.07
Total iron	mg/l	0.04	0.43
Aluminium	mg/l	<0.20	<0.20
Cobalt	mg/l	<0.20	<0.20
Nickel	mg/l	<1.00	<1.00
Copper	mg/l	<0.05	<0.05
Zinc	mg/l	0.02	0.18
Chromium	mg/l	<0.10	<0.10
Molybdenum	mg/l	<0.20	<0.20
Cadmium	mg/l	<0.05	<0.05
Lead	mg/l	<1.00	<1.00
Vanadium	mg/l	<0.10	<0.10

Lamphun, Chiang Mai, Thailand			
BGS code			
Field code		**TCL2**	**TCL5**
Sampling date	**Units**	**1-May-97**	**22-Nov-97**
Organic determinands			
Acetic acid (C2)	mg/l	<1.0	4.1
Propionic acid (C3)	mg/l	<1.0	6.4
Iso-butyric acid (C4)	mg/l	<1.0	7.4
N-butyric acid (C4)	mg/l	<1.0	3.7
Iso-valeric acid (C5)	mg/l	<1.0	7.9
N-valeric acid (C5)	mg/l	<1.0	2.2
Iso-caproic acid (C6)	mg/l	<1.0	3.7
N-caproic acid (C6)	mg/l	<1.0	1.6
Enanthic acid (C7)	mg/l	nd	nd
Branched caprylic acid (C8)	mg/l	nd	nd
Caprylic acid (C8)	mg/l	nd	nd
Pelagonic acid (C9)	mg/l	nd	nd
Phenyl acetic acid	mg/l	nd	nd
Phenyl propionic acid	mg/l	nd	nd
Cyclohexane carboxylic acid	mg/l	nd	nd
Cyclohexane propionic acid	mg/l	nd	nd
Myristic acid (C14)	µg/l	nd	nd
Myristic acid alkyl esters	µg/l	nd	nd
Palmitic acid (C16)	µg/l	nd	12.0
Oleic acid (unsat.C18)	µg/l	nd	64.0
Stearic acid (C18)	µg/l	nd	nd
Caffeine	µg/l	nd	nd
Nicotine	µg/l	nd	nd
Butoxyethanol	µg/l	nd	nd
Linalyl alkyl esters	µg/l	nd	nd
Nonanal	µg/l	nd	14.0
Phenol	µg/l	nd	22.0
Cresol	µg/l	nd	5.90
Ethyl phenol	µg/l	nd	nd
Cholesterol	µg/l	nd	nd
Cholestanol	µg/l	nd	nd
Coprostanone	µg/l	nd	nd
Indole	µg/l	nd	11.0
Benzothiazoles	µg/l	nd	nd
Tetrachloroethene	µg/l	6.30	nd
Diethyl hexyl phthalate	µg/l	2.00	10.1
γ–HCH	µg/l	nd	nd
Ametryne	µg/l	nd	nd
Total alkanes	µg/l	7.60	5.50
Squalene	µg/l	nd	nd
	ns		
Benzo(b)fluoranthene	ng/l	ns	ns
Benzo(k)fluoranthene	ng/l	ns	ns
Benzo(a)pyrene	ng/l	ns	ns
Benzo(ghi)perylene	ng/l	ns	ns
Fluoranthene	ng/l	ns	ns
Indeno(1,2,3-cd)pyrene	ng/l	ns	ns

INDONESIA

BANDUNG

Climate



Landfill details

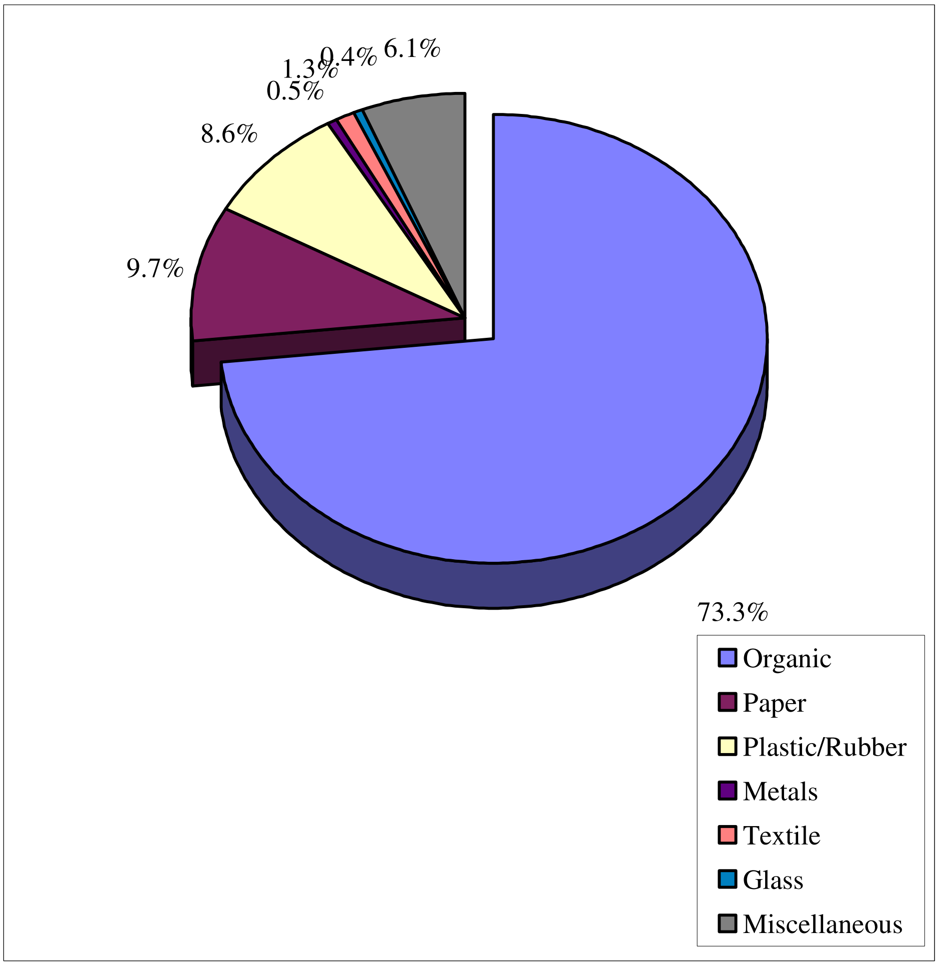
Leuwigadja

Site in a disused quarry acting since 1986 as a valley infill accepting domestic and industrial wastes from Bandung. Leachate flows from the waste as a small stream into the valley below.

Sukamiskin

An engineered containment site serving Bandung from 1987 to 1991. The base of the site is lined with a clay mineral liner and the site is covered with a silty clay layer to minimise infiltration. Leachate from perched levels in the waste and other site drainage is channelled to oxidation ponds.

Waste composition for Bandung, Indonesia



Organic	73.4
Paper	9.7
Plastic/Rubber	8.6
Metals	0.5
Textile	1.3
Glass	0.4
Miscellaneous	6.1

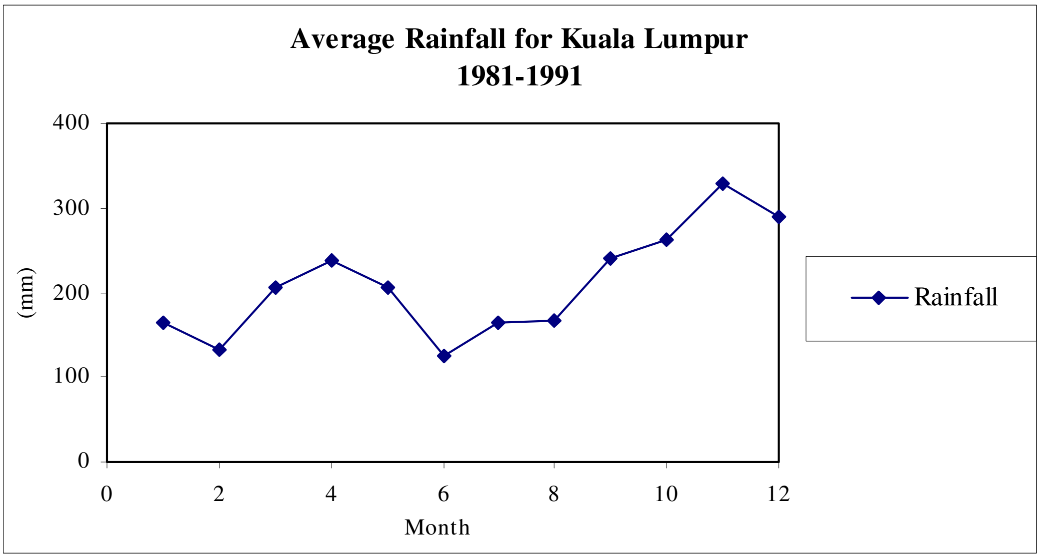
Leuwigadja, Bandung, Indonesia			
BGS code		**6628**	**6629**
Field code			
Sampling date	**Units**	**2/23/90**	**2/23/90**
Inorganic determinands			
pH		7.61	8.41
Conductivity	μS/cm	ns	ns
Temperature	°C	ns	ns
Dissolved oxygen	mg/l	ns	ns
Redox potential	mV	ns	ns
Sodium	mg/l	892	1,130
Potassium	mg/l	821	1,600
Calcium	mg/l	547	86.4
Magnesium	mg/l	149	56.2
Alkalinity (as HCO_3)	mg/l	9,760	4,780
Chloride	mg/l	1,650	2,330
Sulphate	mg/l	<20.0	159
Ammoniacal-N	mg/l	500	2,000
Nitrite-N	mg/l	<1.00	<1.00
Nitrate-N	mg/l	<1.00	<1.00
Total organic carbon	mg/l	2,390	968
COD	mg/l	ns	ns
Bromide	mg/l	3.60	8.41
Total phosphorus	mg/l	6.40	12.0
Total sulphur	mg/l	ns	ns
Silica	mg/l	15.8	11.2
Barium	mg/l	1.81	0.27
Strontium	mg/l	2.93	0.54
Lithium	mg/l	0.01	<0.03
Boron	mg/l	1.68	2.38
Manganese	mg/l	8.67	0.473
Total iron	mg/l	0.39	6.23
Aluminium	mg/l	0.24	0.41
Cobalt	mg/l	<0.02	<0.06
Nickel	mg/l	0.37	0.38
Copper	mg/l	0.014	0.386
Zinc	mg/l	0.025	0.463
Chromium	mg/l	0.09	0.25
Molybdenum	mg/l	<0.02	<0.06
Cadmium	mg/l	<0.005	<0.020
Lead	mg/l	<0.10	<0.30
Vanadium	mg/l	0.02	0.06

Sukamiskin, Bandung, Indonesia		Leachate	Surface pool	Leachate seep	Leachate lagoon
BGS code		**6623**	**6624**	**6625**	**6626**
Field code					
Sampling date	**Units**	**2/23/90**	**2/23/90**	**2/23/90**	**2/23/90**
Inorganic determinands					
pH		7.31	7.65	7.62	7.91
Conductivity	µS/cm	ns	ns	ns	ns
Temperature	°C	ns	ns	ns	ns
Dissolved oxygen	mg/l	ns	ns	ns	ns
Redox potential	mV	ns	ns	ns	ns
Sodium	mg/l	11.5	36.7	91.8	128
Potassium	mg/l	5.88	16.8	76.5	165
Calcium	mg/l	22.5	56.0	102	50.1
Magnesium	mg/l	8.35	24.6	43.3	23.7
Alkalinity (as HCO_3)	mg/l	138	231	656	686
Chloride	mg/l	5.08	115	189	301
Sulphate	mg/l	<2.00	<2.00	<2.00	7.09
Ammoniacal-N	mg/l	0.51	1.48	24.9	81.1
Nitrite-N	mg/l	<0.10	<0.10	<0.10	<0.30
Nitrate-N	mg/l	<0.10	0.15	<0.10	2.21
Total organic carbon	mg/l	2.12	8.13	28.2	32.1
COD	mg/l	ns	ns	ns	ns
Bromide	mg/l	<0.10	0.10	0.35	0.79
Total phosphorus	mg/l	<1.00	<1.00	<1.00	<1.00
Total sulphur	mg/l	ns	ns	ns	ns
Silica	mg/l	26.5	3.28	7.38	3.70
Barium	mg/l	0.048	0.112	0.377	0.566
Strontium	mg/l	0.108	0.659	1.220	0.841
Lithium	mg/l	<0.01	<0.01	<0.01	<0.01
Boron	mg/l	<0.05	<0.05	0.08	0.15
Manganese	mg/l	0.292	3.430	3.870	1.990
Total iron	mg/l	0.02	<0.01	0.01	0.01
Aluminium	mg/l	<0.02	<0.02	<0.02	<0.02
Cobalt	mg/l	<0.02	<0.02	<0.02	<0.02
Nickel	mg/l	<0.02	0.03	<0.02	<0.02
Copper	mg/l	<0.005	<0.005	<0.005	<0.005
Zinc	mg/l	<0.005	<0.005	<0.005	<0.005
Chromium	mg/l	<0.01	<0.01	<0.01	<0.01
Molybdenum	mg/l	<0.02	<0.02	<0.02	<0.02
Cadmium	mg/l	<0.005	<0.005	<0.005	<0.005
Lead	mg/l	<0.10	<0.10	<0.10	<0.10
Vanadium	mg/l	<0.01	<0.01	<0.01	<0.01

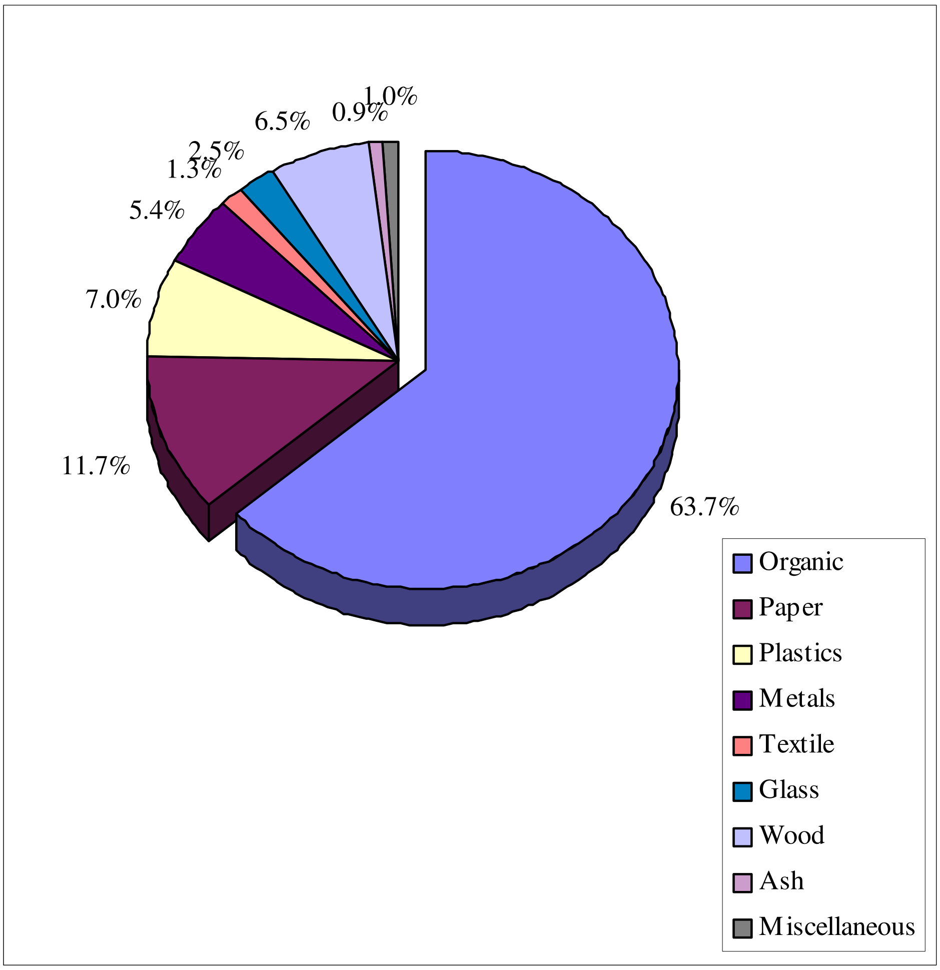
MALAYSIA

Kuala Lumpur

Climate



Waste composition for Kuala Lumpur, Malaysia



Organic	63.7
Paper	11.7
Plastics	7.0
Metals	5.4
Textile	1.3
Glass	2.5
Wood	6.5
Ash	0.9
Miscellaneous	1.0

Penang, Malaysia		
BGS code **Field code** **Sampling date**	**Units**	
Inorganic determinands		
pH		7.60
Conductivity	µS/cm	ns
Temperature	°C	ns
Dissolved oxygen	mg/l	ns
Redox potential	mV	ns
Sodium	mg/l	1,680
Potassium	mg/l	ns
Calcium	mg/l	790.0
Magnesium	mg/l	ns
Alkalinity (as HCO_3)	mg/l	ns
Chloride	mg/l	ns
Sulphate	mg/l	1200
Ammoniacal-N	mg/l	ns
Nitrite-N	mg/l	ns
Nitrate-N	mg/l	12.00
Total organic carbon	mg/l	ns
COD	mg/l	8,400
Bromide	mg/l	ns
Total phosphorus	mg/l	ns
Total sulphur	mg/l	ns
Silica	mg/l	ns
Barium	mg/l	ns
Strontium	mg/l	ns
Lithium	mg/l	ns
Boron	mg/l	ns
Manganese	mg/l	ns
Total iron	mg/l	1.10
Aluminium	mg/l	ns
Cobalt	mg/l	ns
Nickel	mg/l	1.04
Copper	mg/l	0.090
Zinc	mg/l	0.800
Chromium	mg/l	0.40
Molybdenum	mg/l	ns
Cadmium	mg/l	ns
Lead	mg/l	0.32
Vanadium	mg/l	ns