ASSESSMENT OF QUALITY AND QUANTITY OF LEACHATE FROM THE MUNICIPAL SOLID WASTE LANDFILL OF BURSA

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ABSTRACT

ASSESSMENT OF QUALITY AND QUANTITY OF LEACHATE FROM THE MUNICIPAL SOLID WASTE LANDFILL OF BURSA

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In this study, regularly measured long-term leachate data from Bursa Municipal Solid Waste Landfill (MSWL) were analyzed using conventional statistical, time series and factor analyses to investigate in detail the temporal variability of leachate quality and quantity, trend, randomness, seasonality and the auto- and cross-correlations of leachate pollutants. Evaluating the results of data analyses, leachate management recommendations, including sampling strategies in monitoring programs and treatment alternatives for old and fresh leachates, were developed. Statistically analyzed leachate parameters included BOD, COD, pH, SS, electrical conductivity, total CrO_4, Cr^{6+}, Fe, Cu, Zn, Pb, Cd, CN^-, Cl, F, total P, NH_4-N, total N, SO_4, S^{2-}, total alkalinity and leachate flow rate.

Results indicated that the majority of pollutant concentrations varied in large ranges. Leachate parameters usually showed non-normal distributions and high variability in the closed T Valley compared to the open Main Valley. The majority of leachate parameters was autocorrelated and had statistically significant correlations amongst themselves. Factor analysis showed that different inter-relationships were present between leachate parameters for closed and open valleys. The sampling frequency and the number of leachate parameters need to be measured were determined to be higher for open landfills than for closed landfills.

It was recommended that leachates, having high organic strength, in open landfill be treated using biological and physical/chemical processes. However, after the closure of the landfill, physical/chemical processes were recommended for leachate treatment, as it gradually completes transition from fresh to old leachate.

Key words: Leachate, leachate characterization, leachate data analysis, statistical analysis of leachate.

ÖZ

BURSA EVSEL KATI ATIK DEPOLAMA SAHASI SIZINTI SUYU KALİTE VE MİKTAR DEĞİŞİMLERİNİN İRDELENMESİ

Akyol, Selin
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Bu çalışmada, Bursa Evsel Katı Atık Depolama Sahası'na (EKADS) ait uzun süreli ve düzenli olarak ölçülmüş sızıntı suyu verileri, konvensiyonel istatistiksel, zaman serisi ve faktör analizi yöntemleri kullanılarak analiz edilmiş ve sızıntı suyu kalitesinin zamana göre değişimi, rastsallığı, mevsimselliği ve kirleticilerin birbirleriyle olan ilişkileri ayrıntılı olarak incelenmiştir. Veri analizi sonuçlarını değerlendirerek, yeni ve eski sızıntı suyu izleme programlarına yönelik örnekleme stratejilerini ve arıtma alternatiflerini içeren sızıntı suyu yönetimi önerileri geliştirilmiştir. İstatistiksel analizi yapılan sızıntı suyu parametre verileri BOİ, KOİ, pH, AKM, elektriksel iletkenlik, toplam CrO_4, Cr^{6+}, Fe, Cu, Zn, Pb, Cd, CN^-, Cl, F, toplam P , NH_4-N, toplam N, SO_4, S^{2-}, toplam alkalinite ve sızıntı suyu debisidir.

Sonuçlar, sızıntı suyu parametrelerinin büyük bir çoğunluğunun geniş aralıklarda değiştiğini göstermektedir. Açık Ana Vadi ile karşılaştırıldığında, kapalı T Vadisi'ndeki sızıntı suyu parametreleri genellikle normal olmayan dağılım ve yüksek değişkenlik göstermektedirler. T Vadisi'nde pH, toplam alkalinite, NH_4-N, Cr^{6+}, Cl ve S normal dağılım göstermektedirler. Sızıntı suyu parametrelerinin çoğunluğu otokorelasyona ve birbirleriyle aralarında önemli istatistiksel kroskorelasyonlara sahiptir. Faktör analizi yöntemi, açık ve kapalı vadiler için sızıntı suyu parametreleri arasında farklı kroskorelasyonlar belirlemiştir. Ölçülmesi

gereken sızıntı suyu parametreleri ve ölçüm sıklıklarının açık depolama sahalarında daha fazla olduğu görülmüştür.

Yüksek organik kirliliğe sahip olan yeni sızıntı sularını arıtmak için biyolojik ve fiziksel/kimyasal arıtma prosesleri önerilmektedir. Fakat, atık depolama sahasının kapatılmasından sonra yeni sızıntı suyunun zaman içerisinde eski sızıntı suyuna dönüşümünü tamamlaması nedeniyle, fiziksel/kimyasal prosesler daha uygun görülmektedir.

Anahtar Kelimeler: Sızıntı suyu, sızıntı suyu karakterizasyonu, sızıntı suyu veri analizi, sızıntı suyu istatistiksel analizi.

To my parents

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Al: Aluminum

Ar: Argon

As: Arsenic

C: Carbon

Ca: Calcium

Cd: Cadmium

Cl: Chloride

Co: Cobalt

Cr: Chromium

Cu: Copper

F: Fluoride

Fe: Iron

H: Hydrogen

Hg: Mercury

K: Potassium

Mg: Magnesium

Mn: Manganese

N: Nitrogen

Na: Sodium

Ni: Nickel

O: Oxygen

P: Phosphorus

Pb: Lead

S: Sulphur

Sb: Antimony

Se: Selenium

Zn: Zinc

AOH: 2-naphthol

AOX: Adsorbable organic halogen

BOD: Biochemical oxygen demand

$CaCO_3$: Calcium carbonate

CH_4: Methane

CN^-: Cyanide

COD: Chemical oxygen demand

CO_2: Carbon dioxide

CrO_4: Chromate

DO: Dissolved oxygen

DS: Dissolved solids

HC: Hydrocarbon

HCO_3: Bicarbonate

NH_3: Ammonia

NH_4^+: Ammonium

NO_3: Nitrate

NO_2: Nitrite

N_{org}: Organic nitrogen

N_{tot}: Total N

PO_4: Phosphate

P_{tot}: Total Phosphorus

SO_2: Sulphide

SO_4: Sulphate

SS: Suspended solids

TKN: Total Kjeldahl Nitrogen

TOC: Total organic carbon

TS: Total solids

TSS: Total suspended solids

TVA: Total volatile acids

VFA: Volatile fatty acids

VOA: Volatile organic acid

VS: Volatile solids

VSS: Volatile suspended solids

AET: Actual evapotranspiration

Adj Fac: Adjustment factor

Adj PET: Adjusted evapotranspiration

ANOVA: Analysis of variance

C: Runoff coefficient

CV: Coefficient of variation

dST: Change in soil storage

EC: Electrical conductivity

FC: Field capacity

I: Infiltration

It: Monthly value of heat index

IR: Input from water irrigation

L: Leachate generation

MC: Moisture content

MVDA: Multivariate data analysis

MSWL: Municipal solid waste landfill

ORP: Oxidation reduction potential

P: Input water from precipitation falling on the landfill

PERC: Percolation

$PERC_R$: Percolation in refuse

$PERC_S$: Percolation in soil

PET: Evapotranspiration

Ro: Runoff

S_k: Skewness

SR: Input from water surrounding surface Runoff

ST: Soil Moisture storage

t: Temperature (^oC)

WBM: Water balance method

W_D: Water contributed by solid waste decomposition

W_{GW}: Input water from underflow

r_k: Autocorrelation coefficient

r_{xy}: Croscorrelation coefficient

s^2: variance

$\bar{x}$: Arithmetic mean

x_m: Mode

x_M: Median

ΔS_S: Change in moisture storage in soil cover

ΔS_R: Change in moisture storage in refuse

$\rho(k)$: Autocorrelation function

$\rho_{XY}(k)$: Crosscorrelation function

CHAPTER 1

INTRODUCTION

1.1. General

Municipal solid waste management problem is presently receiving more attention worldwide, because growing population, increasing industrial developments and living standards of people have been increasing significantly the amount and diversity of solid wastes generated. Although the hazards of the municipal solid wastes do not have an immediate risk to human life and the environment, they have potential to cause detrimental effects on the human life and the environment in the long term.

Landfilling is the most widely used disposal method in the waste management policies. There are many advantages of the sanitary landfilling method. It is the most economical option and is also suitable for a wide range of wastes. Solid waste landfill is also a final destination for the disposal of the wastes produced through recovery (recycling and composting) and combustion in a waste to energy facility. A variety of physical, chemical and biological processes taking place in the landfill lead to the degradation of wastes in the presence of moisture and microorganisms. Leachate, gas and odor are produced by these processes. Leachate handling is one of the most important issues for the design and operation of landfill sites.

Leachate is the highly polluted liquid composed of water passing through the waste and the water generated within the landfill site. It contains suspended solids, soluble components of the waste and products from the degradation of the waste by various microorganisms. Leachate characteristics are highly variable and dependent upon many factors; composition of solid waste, precipitation rate, site hydrology, waste compaction, cover design, waste age, interaction of leachate with environment, landfill design and operation.

Municipal waste leachate contains many pollutants at much higher strengths than domestic sewage. Leachate generated in municipal solid waste landfills is as toxic as leachates produced in the landfills, where hazardous waste and residential waste are co-disposed. Moreover, the effects of the leachate on the environment may continue for several years after the closure of the landfill and monitoring after the closure of the landfill is required. Thus, leachate may change the ecology of the watercourse depending upon the types of waste in the landfill. Groundwater and surface water contaminations with leachate are considered to be the most significant environmental problems related with leachate. Aquatic ecosystems may also be adversely affected by the toxic pollutants if these water courses are contaminated with leachate. Moreover, the accumulation of leachate may be a critical factor with respect to geotechnical stability of the landfill. Therefore, leachate should be collected and treated with proper methods before being discharged into the environment.

Leachate treatment is more difficult than wastewater treatment due to its high pollution load and high fluctuations in leachate production and composition. Leachate quality, quantity and the time length for leachate generation are considerably important in the assessment of landfill design and leachate treatment alternatives. The landfill age is also greatly important in the leachate treatment alternatives due to the differences in leachate quality and quantity with the age of the landfill. Because of the variations in leachate quality with time, leachate management systems should adapt to these changes during treatment. The understanding and prediction of long term trends of leachate quality and quantity is also of great importance in order to determine the type and capacity of leachate treatment method, to evaluate the potential for groundwater contamination, and to identify the degree of stabilization. Since leachate impacts on the environment may continue for several years after the closure of the landfill, leachate management methods should take these impacts into account. Leachate quality and quantity analyses are also valuable in terms of identifying the suitable, sustainable and cost effective treatment alternatives. While these identifications are necessary for the proper landfill design, characterization of leachate composition and quantity is a complicated and uncertain process.

Assessment of leachate quality and quantity data is a quite difficult task due to the wide fluctuations in leachate parameters. It would be easy if a leachate treatment method feasible for a landfill site is also feasible for the other landfill site having different characteristics. However, leachate composition changes significantly for different landfill sites and also with the age of the landfill. Collection of a wide range of site specific leachate data is needed in order to make a reliable assessment for leachate management. Recently a number of research studies on data analysis showing general assessments and ranges of leachate quality and quantity parameters have been reported in the literature (Farquhar, 1988; Rowe, 1995; Reinhart and Grosh, 1998; Urbini et al., 1999; Armstrong and Rowe, 1999; Kruempelbeck and Ehrig, 1999; Kjeldsen and Christopersen, 2001; Tatsi and Zouboulis, 2002; Khattabi et al., 2002; Frascari et al., 2003; Aluko et al., 2003; Al. Yaqout and Hamoda, 2003; Abduli and Safari, 2003; Kylefors, 2003; Slack et al., 2004; Çallı et al., 2004; Fjallborg et al., 2005), but it is still difficult to define the composition of a typical landfill leachate.

The conventional statistical evaluation, time series analysis and factor analysis of leachate data, which are measured regularly and representing different landfill stages, can help to quantify the uncertainties and interrelations in leachate characteristics. Therefore, leachate data analysis contributes to understanding the course of waste stabilization process in the landfill, and the selection of landfill design and leachate treatment methods. This study provides useful information about leachate characteristics and composition of similar landfills in Turkey, including leachate quality and quantity assessment as a basis for leachate management.

1.2. Scope and Objectives

The data analysis in this study covers the data of the closed T Valley and the active 2nd Stage of the Main Valley in Bursa MSWL. Both of them have the same sources of the municipal solid waste and landfill operation as well as site characteristics including climate and hydrogeology. Data from the X Valley was not sufficient, thus not considered in this study. The data analysis was performed initially on leachate quantity and quality parameters for each valley. Then, leachate parameters for different valleys were compared to examine the degree of stabilization took place under the closed (covered) and open (uncovered) conditions. In addition, leachate parameters for pre- and post-closure of the T Valley were compared in order to assess the degradation processes before and after the closure of the landfill.

There are not very many sanitary landfills operating in Turkey and only limited regularly measured leachate data are available to analyze leachate characteristics. The solid wastes generated in the country are usually disposed of in the open waste dump sites. Only 13 of 3215 municipalities in Turkey have a sanitary waste disposal landfill with a total capacity of 261 million tons. In the country, currently 33% of the wastes is disposed of in the sanitary landfills, 1% is being composted and 66% is being disposed of using non-conventional methods, including burying, incineration, disposal into the creeks and streams. (State Statistics Institute, 2001). There is a lack of regularly collected leachate data in Turkey. Bursa MSWL is the only landfill in Turkey having leachate quality and quantity parameters that has been measured over 9 years regularly since the beginning of the landfill operation (Bursa Municipality, 2004). Therefore, leachate data from Bursa MSWL is useful for a quantitative assessment of leachate quality and quantity in Turkey. In this study, chemical composition, quality and quantity variations in the leachate of Bursa MSWL were investigated using landfill data, collected weekly and in some instances monthly, during the last 7 years from January 1998 to August 2004.

A simple water balance method (WBM) was applied for the closed T and open Main Valleys in 2003 in order to compare the amount of measured leachate flow rate with the leachate amount determined using WBM. A conventional statistical analysis of leachate quality and quantity data was carried out to characterize pollution parameters of “fresh” and “old” leachates. The effects of climate, waste age and waste composition were also investigated. Then, a time series analysis was carried out and data characteristics such as randomness, seasonality and trend were examined. The autocorrelations and crosscorrelations within and between leachate parameters were also analyzed using time series analysis. A factor analysis, which is a multivariate data analysis method (MVDA), was performed for the T and Main Valleys in order to determine the correlations between several leachate parameters simultaneously.

Optimum landfill leachate monitoring programs should include a minimum number of measured parameters in order to reduce the labor and cost of monitoring. Time series analysis and factor analysis can be useful in the sense that some leachate parameter can be predicted using auto- and cross-correlation structures of easily measured leachate parameters, since it may not always be feasible to measure a large number of leachate parameters for a landfill. The number of monitored leachate quality parameters for leachate characterization may decrease using auto- and cross- correlation coefficients through a time series analysis along with factor analysis. Moreover, the correlations make the relationships quantitative and decrease the uncertainties in leachate characterization.

Leachate management systems are mainly dependent on the leachate quality and quantity. Due to the extensive fluctuations in leachate quality and quantity with time and seasonally, it is a difficult task to characterize leachate. Leachate treatment plants should be designed taking the maximum leachate concentrations into account. Average leachate concentrations would be overloaded during the pollutant peaks during several time periods (Tatsi and Zouboulis, 2002). Therefore, the extensive characterization and identification of leachate parameters using systematically measured data are useful in the selection and design of the leachate management systems.

The major objectives of this study were:

- the extensive identification of major pollutant parameters for both “fresh” and “old” leachates of Bursa MSWL, and their comparison with literature data;

- the systematic investigation of the trend, randomness and seasonal variability of leachate quality and quantity, and identification of the auto- and cross-correlation within and between leachate parameters; and

- the generation of useable preliminary suggestions from the analyses of available leachate data in order to design a suitable leachate management system for other similar landfills, more specifically developing sampling strategies for leachate monitoring programs and treatment alternatives for young and old leachates.

In this thesis, Chapter 2 presents the literature review about solid waste management concepts and related research on leachate characterization. Chapter 3 gives characteristics of Bursa MSWL, available leachate quality and quantity data, and the methods used in the data analysis. Chapter 4 discusses the results of leachate data analysis. Finally, Chapter 5 gives summary and conclusion of the study.

CHAPTER 2

LITERATURE SURVEY

In this chapter, basic concepts about solid wastes and leachate were reviewed. Solid waste characteristics, solid waste management, landfilling, and leachate generation and management concepts were presented in order to provide a technical background for the present study. In addition, current studies on leachate characterization for different landfills were also examined to make a comparison among different landfills having different waste composition, operational conditions and site characteristics.

2.1. Solid Waste

Solid waste is any solid and semi-solid object arising from human and animal activities that are discarded as useless or unwanted. Solid wastes are classified according to their source. The major types of solid wastes are residential, commercial, industrial, sludge and medical. Municipal solid waste mainly composed of residential and commercial wastes.

2.1.1. Solid Waste Composition and Generation

The information about the composition and quantity of solid wastes is necessary in selecting the type of pre-treatment and treatment of wastes, and disposal method. Solid waste composition and generation are also major factors affecting leachate quality and quantity. Solid waste composition and generation are highly related to the type of society, level of development and living standards of the country. The types of wastes differ greatly between communities. Therefore, it is difficult to generalize the composition and quantity of solid waste from country to country.

Solid waste composition and generation show seasonal variations. Even day to day variations can be detected in the waste composition and generation.

Table 2.1 lists some sources of solid wastes in a community. The sources and contents of the solid wastes are explained in detail by Poulsen (2003). Municipal solid wastes are generally a mixture of several different materials if source separation is not applied. The biodegradable fraction includes food waste, garden waste, paper, diapers and cardboard. Biodegradable wastes generally have higher water content than the inorganic fractions. Inert wastes include ash and certain types of construction and demolition wastes. Industrial wastes and sludge are often more homogeneous than the municipal solid wastes. Sludge from wastewater treatment plants may be a problem, because it may contain toxic compounds and heavy metals. It also increases the amount of leachate generated (Tatsi and Zouboulis, 2002). Table 2.2 shows the average components of residential solid wastes for different levels of income and development.

Table 2.1. Sources of solid wastes (Tchobanoglous and Kreith, 2002)

Source	Facilities or locations where waste is generated	Types of wastes
Residential	Single-family and multifamily dwellings; low-medium-, and high -density apartments;etc.	Food wastes, paper, cardboard, plastics,textiles,leather,yard wastes,wood,glass,tin cans, aluminum,other metal, ashes, street leaves,special wastes,and household hazardous wastes
Commercial	Stores,restaurants,markets, office buildings, hotels, motels,print shops, service stations, auto repair shops,etc.	Paper,cardboard,plastics,wood, food wastes,glass,metal wastes, ashes,special wastes, hazardous wastes,etc.
Institutional	Schools,hospitals,prisons, governmental centers,etc.	Same as commercial
Industrial (nonprocess wastes)	Construction,fabrication, light and heavy manufacturing,refineries, chemical plants, power plants,demolition,etc.	Paper,cardboard,plastics,wood, food wastes,glass,metal wastes, ashes,special wastes, hazardous wastes,etc
Municipal solid waste*	All of the preceding	All of the preceding
Construction and demolition	New construction sites, road repair,renovation sites,razing of buildings, broken pavement,etc.	Wood,steel,concrete,dirt,etc.
Municipal services (excluding treatment facilities)	Street cleaning, landscaping,catch-basin cleaning,parks and beaches,other recreational areas,etc.	Special wastes,rubbish,street sweepings,landscape and tree trimmings,cath-basin debris; general wastes from parks,beaches,and recreational areas,etc.
Treatment facilities	Water,wastewater, industrial treatment processes,etc.	Treatment plant wastes, principally composed of residual sludges and other residual materials
Industrial	Construction,fabrication, light and heavy manufacturing,refineries, chemical plants, power plants,demolition,etc.	Industrial process wastes,scrap materiasl,etc.;nonindustrial waste including food wastes, rubbish,ashes,demolition and construction wastes,special wastes,and hazardous waste
Agricultural	Field and row crops, orchards,vineyards,dairies, feedlots,farms,etc.	Spoiled food wastes, agricultural wastes,rubbish,and hazardous wastes

* The term municipal solid waste (MSW) is normally assumed to include all of the wastes generated in a community, with the exception of waste generated by municipal services, treatment plants, and industrial and agricultural processes.

Table 2.2. Composition (% wet weight basis) of municipal residential solid waste as related to regional income (Poulsen 2003)

Component	**Low-income Countries (%)**	**Middle-income Countries (%)**	**High-income Countries (%)**
Food waste	40-85	20-65	6-30
Paper/cardboard	1-10	8-30	25-60
Plastics	1-5	2-6	2-8
Yard wastes	1-5	1-10	10-20
Other organic	2-10	2-15	4-15
Inorganic	1-55	1-45	7-35
Sum biodegradable	45-95	30-95	45-90

2.1.2. Physical Chemical and Biological Properties of Solid Waste

The chemical composition of solid waste consists of different elements including carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), chlorine (Cl) and heavy metals. Table 2.3 shows typical chemical composition of wastes.

Table 2.3. Chemical composition of different waste materials (Poulsen, 2003)

Component	**C (%)[a]**	**H (%)**	**O (%)**	**N (%)**	**S (%)**	**Cl (%)**
Food waste	44.8	6.5	32.3	2.8	0.3	1.0
Garden waste	42.4	5.3	31.8	1.6	0.4	0.2
Newsprint	48.8	6.3	42.4	0.1	0.3	0.1
Magazines	39.2	5.5	39.2	0.1	0.2	0.1
Wood	49.0	6.0	41.2	0.2	0.1	0.1
Paper	42.1	5.8	38.8	0.4	0.3	0.8
Rubber	47.9	6.0	12.9	1.4	1.3	5.6
Textiles	49.6	6.7	36.1	4.1	0.4	0.4
Plastics	66.4	9.2	9.5	1.1	2.5	0.4
Cardboard	46.0	6.4	44.3	0.1	0.3	0.1
Mixed waste	35.7	4.8	26.8	0.6	1.0	0.6

[a] Percentages indicate relative quantity as related to the dry weight

The physical properties of solid waste are important in handling and treatment of the waste generated. Table 2.4 presents the important physical properties and of solid waste and the typical data (Tchobanoglous et al., 1977; Rowe, 1996; Yıldız, 2001)

Table 2.4. Important physical properties of solid wastes

Parameter	**Unit**	**Range**
Moisture content (MC)	cm^3/cm^3	15-40
Energy content[a]	Btu/lb	4000-5500
Density (Good compacted)	kg/m^3	860-940
Void ratio		2-15
Field capacity (FC) (uncompacted waste)	cm^3/cm^3	0.5-0.6
Hydraulic conductivity	m/s	10^{-4}-10^{-7}
Ash content	% weight	15-30

[a] Btu/lb * 2.326 = kJ/kg

Municipal solid waste contains numerous microbial organisms and it may be contaminated with pathogenic microorganisms. Waste stabilization processes occur by a range of bacteria including aerobic, anaerobic and facultative.

2.2. Solid Waste Management

Solid waste management system is a set of activities including waste production, collection, transfer, transport and treatment including transformation of wastes into useful products and final disposal. For the proper planning, design and operation of solid waste management systems, quantity, composition and physical, chemical and biological properties of solid wastes produced in the community should be investigated. Therefore, it is needed to collect site specific representative data characterizing the wastes.

Sustainable waste management strategy aims to minimize the production of waste discharged into environment by using newer technologies and processes and to encourage re-use and recycling of waste to minimize the proportion of waste disposed into the landfill. One method of recycling is energy production by waste incineration.

Waste reduction is the minimization of waste by any process that avoids or reduces the waste at its source. Re-use means using a material more than once or re-using it in another application. Recycling includes the collection, separation, clean-up and processing of recyclable waste materials to produce a marketable product. Landfilling is the most common and suitable waste disposal method due to its low cost and its suitability for a wide range of wastes. It is also final disposal route for the wastes produced during the recovery and combustion processes. In addition, landfill gas generated in the landfills can be used as energy sources if treated properly.

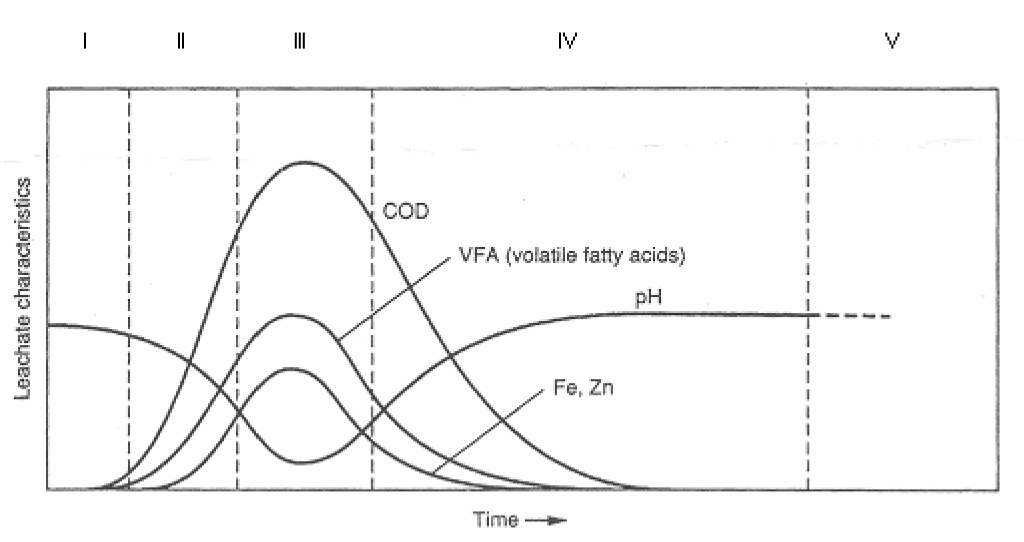
2.2.1. Landfills

Landfills have been used as the waste disposal sites for many decades for municipal, industrial, commercial and hazardous wastes. Landfill technologies have been developing with the technological advances in the last years in order to minimize the harmful effects of the landfills on the environment. Landfill technologies have developed from the open dump sites to the engineered sanitary landfill sites. The major effects of the landfill sites are leachate, landfill gas contamination into the environment and odor. Leachate and landfill gas generation continue many years after the closure of the landfill.

Sanitary landfills are the engineered facilities for the disposal of the wastes and include spreading the waste in an appropriate area, compacting it to the smallest possible volume, and then covering it by the soil daily and after the closure of landfill to reduce the possibility of uncontrolled fire, wind distribution of the refuse, and the inhabitation of the landfill by vermin. Although landfilling is the least desired method for the waste disposal in the waste management hierarchy, it is the most common method used.

2.2.2. Waste Stabilization Processes

Organic wastes in the landfills goes under physical, chemical and biological reactions during the biodegradation processes. The complete biodegradation of wastes in the landfill can take many decades to complete. Waste stabilization process consists of five sequential phases. However, it is almost impossible to identify each stage for a landfill. Thus, only two distinct stages, acidogenic and methanogenic, are used in leachate characterization. Leachate and landfill gas characteristics change significantly from one phase to another. Because of the heterogeneous nature of the waste, all different stages may be progressing simultaneously in a landfill until stabilization of the landfill has been reached (Williams, 1998). Therefore, separate cells in the same landfill will be at different decomposition stages (Armstrong and Rowe, 1999). Biodegradation processes by microorganisms are optimal at optimum temperature, adequate moisture, nutrient supply and absence of toxic sentences. Landfill stabilization stages are described in the following subsections. Waste stabilization stages in the landfill were shown on Figure 2.1.



(I-Initial Adjustment, II-Transition Phase, III-Acid Phase,
IV-Methane Fermentation and V-Maturation Phase)

Figure 2.1. Generalized phases in the landfill (Tchobanoglous and Kreith, 2002)

2.2.2.1. Stage I. Initial Adjustment Phase

Initial placement of waste into the landfill takes place in this stage. In this period, sufficient moisture develops and microbial activity is supported for the degradation of the organic wastes in the presence of oxygen. Preliminary changes in the environmental conditions occur to produce favorable conditions for the decomposition processes.

The microorganisms in this phase are aerobic type and they require oxygen. They utilize the available oxygen and easily degradable organic components of the waste to produce simpler hydrocarbons (HC), carbon dioxide (CO_2), water and heat. The heat generated from the exothermic degradation reaction can raise the temperature of the waste up to 70-90 ^{o}C (Williams, 1998). Water and carbon dioxide are released as gas or absorbed into water to form carbonic acid and results in acidity in leachate. The aerobic stage continues a few days or weeks depending on the availability of oxygen. Available oxygen is a function of the amount of air in the waste and degree of waste compaction. Leachate includes particulate matter, highly soluble salts and small amount of organics from the aerobic degradation process. In this stage no significant leachate generation occurs.

2.2.2.2. Stage II. Transition Phase

In this stage transition from aerobic conditions to anaerobic conditions occurs due to depletion of oxygen. A trend toward reducing conditions is established in accordance with shifting of electron acceptors from oxygen to nitrates and sulphates (SO_4), and the displacement of oxygen by carbon dioxide. In this phase, measurable concentrations of carbonaceous oxygen demand (COD) (480 to 18000 mg/L) and volatile organic acid (VOA) (100 to 3000 mg/L) can be detected in leachate (Reinhart and Grosh, 1998).

2.2.2.3. Stage III. Acid Formation Phase

Initially, hydrolysis converts organic matter on a solid form to soluble form. Hydrolysis is followed by microbial conversion of biodegradable organics. High concentrations of VOA's, ammonia (NH_3), hydrogen, and carbon dioxide are produced in this stage. pH in this stage often drops to a value of 5 or lower due to the acidic conditions (Tchobanoglous and Kreith, 2002). The organic acids produced are mainly acetic acid. They also include propionic, butyric, lactic and formic acids and acid derivative material. The acidic conditions in this stage increase the solubility of metal ions. Thus, metal concentration in leachate increases in this stage. In addition, organic acids, Cl ions, ammonium (NH_4^+) ions and phosphate (PO_4^{3-}) ions readily form complexes with metal ions and increase the solubilization of metal ions in leachate (Williams, 1998). The highest concentrations of BOD (biochemical oxygen demand), COD, and specific conductance are detected during this phase (Reinhart and Grosh, 1998). Leachate in this phase has high BOD/COD ratios (commonly > 0.7). Acid phase anaerobic biodegradation processes are carried out by a mixed anaerobic population, composed of strict and facultative anaerobes. Facultative anaerobes breakdown the materials and reduce the redox potential so that methanogenic bacteria can grow (Andreottola and Cannas, 1992). Sorptive capacity of the waste decreases in this stage. Substrates and nutrients are consumed quickly and sufficient biomass growth (acidogenic bacteria) occurs in this stage (Reinhart and Grosh, 1998).

2.2.2.4. Stage IV. Methane Formation Phase

Intermediate acids formed during the acid formation phase are converted to methane (CH_4) and carbon dioxide by methanogenic bacteria. Optimum pH values for methanogenic bacteria are 6-8 (Andreottola and Cannas, 1992). CH_4 is the major gas in this stage and dominates CO_2. BOD and COD concentrations decreases as much of these materials are converted to landfill gas. Leachate composition in this phase is reflected by low BOD/COD ratio due to the reduced biodegradability of the waste. A small portion of the original refuse organic content (e.g. lignin-type aromatic compounds) is not degraded to any extent anaerobically and remains in the landfill material. These lignin-type compounds are important factors in adsorption and complexation mechanisms (Reinhart and Grosh, 1998). The initial sulphate amount slowly reduces to sulphide (SO_2) due to decrease in redox potential (Andreottola and Cannas, 1992). The neutral pH conditions (about 7) and low redox potential in this phase provides the immobilization of metal ions by facilitating the formation of metal hydroxides, sulphides, carbonates and complexes of organic substances (Kylefors, 2002).

2.2.2.5. Stage V. Maturation Phase

In this final stage, nutrients and available substrates are limited. Leachate and landfill gas decrease and remain stable at very smaller concentrations due to the decrease in the biological activity. New aerobic microorganisms may slowly replace the anaerobic microorganisms and convert residual CH_4 to CO_2 and water.

Therefore, oxygen and oxidized species may slowly reappear in this stage. During this phase, the leachate often contains higher amounts of fulvic and humic acids, which are difficult to degrade further (Tchobanoglous and Kreith, 2002).

2.2.3. Factors Affecting Waste Stabilization

There are many factors affecting waste stabilization processes in the landfill. Leachate characteristics are also highly variable and dependent upon waste stabilization processes.

2.2.3.1. Waste Composition

Municipal solid waste has large variation in the composition depending on the living standards and economic conditions of the country. The major components of municipal solid waste are the biodegradable fraction. The leachate quality and the amount of biodegradation depend on the proportion of organic components in the waste. The fraction of bioreactive components varies with many factors, for example higher concentrations of garden waste are produced in spring and autumn, and more industrially developed countries produce more paper. Inert wastes do not undergo any significant physical, chemical or biological reactions when deposited in a landfill. The major sources of inert wastes are the construction and demolition industries. Other sources also contribute to the inert wastes, for example ash from waste incineration (Williams, 1998). The inorganic content in the leachate depends on the contact between waste and the leaching water, pH and the chemical balance at the solid-liquid interface. The presence of toxic substances may slow down or inhibit the stabilization processes in the landfill (Andreottola and Cannas, 1992).

2.2.3.2. Moisture Content

Moisture content is the major factor affecting waste biodegradation. The moisture content within the site depends on the inherent moisture content of the waste, the amount of rainfall and snowfall entering the landfill and percolation of the surface water and groundwater into the landfill site. Moisture content is also dependent on the biodegradation rate of the waste, because water is also a biodegradation product. Landfill gas production increases with the moisture content within the landfill. Moisture in the landfill serves as a reactant in the hydrolysis reactions, transports nutrients and enzymes, dissolves metabolites, provides pH buffering, dilutes inhibitory substances, provides surface area to microbial biodegradation, and limits microbial cell growth. High moisture flow rates can wash out soluble organics and microbial cells out of the landfill. Thus, microbial activity will be less important in determination of leachate quality. In addition the moisture content of the waste, the movement of the moisture in the landfill to distribute the microorganisms and nutrients and wash out the degradation products is also important (Williams, 1998).

2.2.3.3. Depth of Waste

Leachate quality and quantity are both dependent upon the depth of the landfill. Leachate constituents are detected in higher concentrations in the deeper landfills. If the waste thickness increases, leachate flow decreases due to longer residence time needed for the moisture entering the landfill to reach the bottom of the landfill. (Yıldız et al., 2004). Deeper landfills require more water to reach saturation, require a longer time for decomposition, and distribute the leached material over a longer period of time. Water entering into the landfill percolates down through the waste and it contacts the refuse and leaches chemicals from the waste. Greater contact time between the liquid and solid phases in deeper landfills increases leachate strength (Reinhart and Grosh, 1998).

2.2.3.4. Temperature

Landfill temperature fluctuates with the ambient air temperature. Greater temperature fluctuations are observed at the upper parts of the landfill due to ambient air temperature. Temperature is important for the activity of microorganisms and it reflects the types of the microorganisms and the reactions in the landfill. Solubility of leachate constituents are also influenced by temperature.

2.2.3.5. Oxygen

The availability of oxygen determines the type of microorganisms and reactions in the landfill (e.g. aerobic or anaerobic). During aerobic decomposition, microorganisms degrade organic matter to carbon dioxide, water, and partially degraded residual organics, producing considerable heat. While, during anaerobic decomposition, high concentrations of organic acids, NH_3, H, CO_2, CH_4 , and water are produced.

2.2.3.6. Acidity

The acidity of the waste in the landfill affects the type of active microorganisms and the reactions occurring in the landfill. Acid conditions, generally increase solubilization of chemical constituents (oxides, hydroxides and carbonate species), and decrease the sorptive capacity of the waste (Andreottola and Cannas, 1992). The pH of a typical landfill site would initially be neutral, followed by acidic phases, where organic acids are produced from waste degradation by the acetogenic microorganisms and pH falls to as low as 4 in the later stages (Williams, 1998).

2.2.3.7. Landfill Age

Waste stabilization and leachate quality are greatly affected by the age of the landfill. Since the chemicals are limited in the waste within the landfill, they reach a peak value after about two or three years from the start of the operation and decrease gradually after this time (Andreottola and Cannas, 1992). Organic compounds decrease more rapidly than the inorganics due to their biodegradable nature. Organic components are also removed by wash out process. However, inorganics are removed only by washout with infiltration (Reinhart and Grosh, 1998).

2.2.4. Leachate

Leachate is produced by the moisture in the landfill during the physical, chemical and biological processes of microorganisms. It is highly polluted wastewater containing organics and inorganics. The leachate producing mechanisms, leachate composition and leachate management are described below.

2.2.4.1. Leachate Generation

Leachate is produced by water input to the landfill and by microorganisms in the landfill during the biodegradation process by the extraction of contaminants in the waste into the liquid phase. The moisture sources entering the landfill include inherent moisture content of the waste, the amount of rainfall and snowfall entering the landfill, percolation of the surface water and groundwater. Leachate flow rate is dependent on a variety of factors including waste age, landfill cover, landfill area and depth. The moisture content of the waste disposed is generally below the saturation. Therefore, the waste absorbs the water within the landfills before leachate is generated. The landfill conditions are not uniform throughout the landfill and changes with time. At any time, the waste in the landfills ranges from new to old and is exposed to different amounts of percolation. Therefore, while calculating leachate flow rate, these factors should be taken into account. Leachate amount produced and the time length over which leachate is produced are significantly important in the sizing of treatment plants (Blakey, 1992). However, infiltration through the landfill is a site specific and seasonally variable value (Blight et al., 1992).

Mathematical models used in the prediction of leachate generation are valuable tools in the design of top cover materials and determination of flow rates to be treated. Amount of water infiltrating through a covered landfill can be determined using hydrological balance of the top cover precipitation, surface run-off, evapotranspiration and moisture content in waste. The water balance model (WBM) does not consider the period of time required for the refuse to reach its field capacity from its moisture content at placement. This period can take several months depending on the refuse type, compaction, percolation rate and depth. The WBM assumes that the refuse is at field capacity and a unit of percolation produces an equivalent unit of leachate. Therefore, this method is applicable after field capacity was reached (Farquhar, 1989). According to Tatsi and Zouboulis (2002), leaching by rainfall starts as the refuse approaches a moisture content of 45 % although it is mainly dependent on the initial moisture content of the waste. Bendz et al. (1997) stated that the field capacity is in the order of 40 %, that decreases with the age, and the initial moisture content of the waste is in the range of 15 %-20 %. Field capacity of refuse is also recorded in literature as 80 % for fresh waste and between 63 % and 74 % for the waste more than 4 years old depending on the waste composition (Blight et al., 1992).

A generalized water balance for a municipal landfill is given by:

$$P + SR + IR = I + R_o \tag{2.1}$$

$$PERC_S = I - AET - \Delta S_S \tag{2.2}$$

$$PERC_R = I - AET - \Delta S_S + W_D - \Delta S_R = PERC_S + W_D - \Delta S_R \tag{2.3}$$

$$L = PERC_R + W_{GW} \tag{2.4}$$

$$L = I - AET - \Delta S_S + W_D - \Delta S_R + W_{GW} \tag{2.5}$$

where;

P = input water from precipitation falling on the landfill.

SR = input from water surrounding surface runoff

IR = input from water irrigation

I = infiltration

R_o = precipitation flowing on the surface of the landfill

$PERC_S$ = percolation in soil

$PERC_R$ = percolation in refuse

W_D = water contributed by solid waste decomposition

ΔS_S = change in moisture storage in soil cover

ΔS_R = change in moisture storage in refuse

AET = actual evapotranspiration

W_{GW} = input water from underflow

L = leachate generation

A conceptual picture of leachate formation is presented in Figure 2.2.

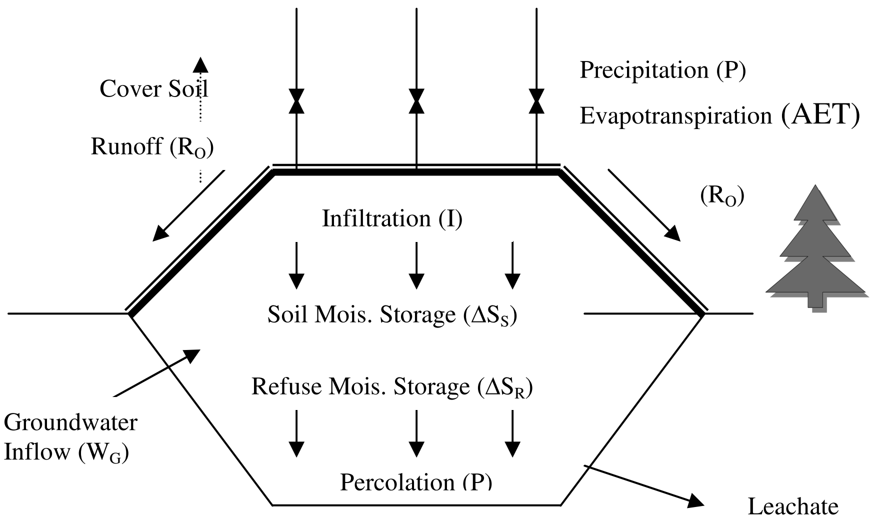


Figure 2.2. Leachate formation (Adopted from Farqhuar, 1989)

2.2.4.2. Leachate Composition

Andreottola and Cannas (1992) performed a review study on leachate characterization using more than 70 previously published technical papers about municipal solid waste sanitary landfills in Europe and the USA. Some of the findings of this review study can be summarized as follows. Leachate characteristics are highly variable and dependent upon many factors; composition of solid waste, industrial/hazardous waste co-disposal, precipitation rates, site hydrology, compaction, cover design, waste age, sampling procedures, interaction of leachate with environment, landfill design and operation. Leachate pollutant load generally reaches maximum values during the first 2-3 years of the operation. Leachate indicator parameters is given in Table 2.5 and Table 2.6, demonstrates the concentration ranges for the main landfill leachate chemical parameters. High fluctuations in leachate parameters and toxic substances were shown in Table 2.6. The study demonstrates significant decreasing trends in the concentrations of BOD and COD in leachate with years. The transition from acetogenic phase to methanogenic phase results in a decrease in the amount of these organics. The decrease in BOD is an indicator for the reduction of organic components and for the increase in biodegradation of organics. However, pH shows an increasing trend with the age of the landfill. SO_4 concentrations are higher in the fresh leachate samples and decreases with time. Because, SO_4 is reduced to SO_2 in the anaerobic environment and SO_2 may provide precipitation of various heavy metals. Moreover, iron (Fe), zinc (Zn) and manganese (Mn) are investigated as representatives of metals. In the first stages of waste stabilization, metal solubilization is high due to acidic pH values. With the age of the landfill, metals solubilization decreases due to increase in pH. The initial high Cl concentration decreases with the age due to washing phenomena. Many investigations showed no decreasing trend for NH_3 concentration.

There is lack of reported data investigating the microbiological composition of leachate. Municipal solid waste contains numerous microbial organisms and it may be contaminated with pathogenic microorganisms. These microorganisms may originate from animal excrement, animal carcasses, diapers, sewage sludges and hospital wastes. Microbiological composition of leachate consists of bacteria, viruses, fungi and parasites (Andreottola and Cannas, 1992).

Table 2.5. Leachate indicator parameters[a] (Andreottola and Cannas, 1992)

Parameter identity	Utility for phase description
Physical	
pH[a]	Acid-base/stabilization phase indicator
ORP[a] (oxidation reduction potential)	Oxidation-reduction/stabilization phase indicator
Conductivity	Ionic strength/activity indicator
Temperature	Reaction indicator
Chemical	
COD[a], TOC[a], TVA[a]	Substrate indicators
TKN[a], NH_3-N[a], PO_4-P[a]	Nutrient indicators
SO_4/S[a], NO_3/NH_3[a]	Stabilization phase indicators
TS, chloride	Dilution/mobility indicator
Total alkalinity[a]	Buffer capacity indicator
Alkali/alkaline earth metals	Toxicity/environmental effects indicators
Heavy metals	Toxicity/environmental effects indicators
Biological	
BOD_5	Substrate/biodegradability
Total/faecal coliforms	Health effect indicators
Faecal streptococci	Health effect indicators
Viruses	Health effect indicators
Pure/enrichment cultures	Stabilization phase indicators

[a]Parameters frequently used for evaluation.

Table 2.6. Concentration ranges for the main chemical leachate parameters[a] (Andreottola and Cannas, 1992)

Parameter	Range
COD (mg/l)	150-100000
BOD_5 (mg/l)	100-90000
pH	5,3-8,5
Alkalinity (mg $CaCO_3$/l)	300-11500
Hardness (mg$CaCO_3$/l)	500-8900
NH_4 (mg/l)	1-1500
N_{org} (mg/l)	1-2000
N_{tot} (mg/l)	50-5000
NO_3 (mg/l)	0,1-50
NO_2 (mg/l)	0-25
P_{tot} (mg/l)	0,1-30
PO_4 (mg/l)	0,3-25
Ca (mg/l)	10-2500
Mg (mg/l)	50-1150
Na (mg/l)	50-4000
K (mg/l)	10-2500
SO_4 (mg/l)	10-1200
Cl (mg/l)	30-4000
Fe (mg/l)	0,4-2200
Zn (mg/l)	0,05-170
Mn (mg/l)	0,4-50
CN^- (mg/l)	0,04-90
AOX[a] (µg/l)	320-3 500
Phenol (mg/l)	0,04-44
As (mg/l)	5-1600
Cd (mg/l)	0,5-140
Co (mg/l)	4-950
Ni (mg/l)	20-2050
Pb (mg/l)	8-1020
Cr (mg/l)	30-1600
Cu (mg/l)	4-1400
Hg (mg/l)	0,2-50

[a] Adsorbable organic halogen

2.2.4.3. Leachate Management

Over the years, leachate amount has been increasing significantly as the waste amount increases. Leachate constituents and quantity are highly variable with time and dependent on several factors. It is essential to describe leachate characteristics for the design of the landfills and leachate treatment plants. Christensen et al. (1992) discuss leachate management strategies including the control of the input (waste and water), the reactor (landfill) and the output (leachate).

Leachate amount generated can be reduced by the reduction of the waste amount disposed to the landfill. This can be achieved by increasing the recycling, composting and incineration of solid wastes. In addition, separation of hazardous fraction from the waste reduces the heavy metals and other toxic chemicals in leachate.

Reduction of leachate by decreasing the quantity of water entering into the landfill is also important in leachate management. However, the advantages of leachate reduction should be carefully balanced against the possible disadvantages of reduction in the waste degradation (Tatsi and Zouboulis, 2002). In order to decrease the water input to the landfill, if possible, landfills should be sited in low precipitation areas. Sludge disposal into the landfills should be limited and landfills should be covered with soil and vegetated after closure. High compaction of wastes also decreases leachate generation. Another way of leachate reduction is the drainage and diversion of surface water.

Leachate control can also be provided by increasing the biochemical processes in the landfill. It may be achieved by converting and transporting as much carbon as possible from the solid phase into the gas phase instead of liquid phase.

Leachate discharge into the environment is controlled by means of lining, drainage and collection system and treatment. The level of engineering, used technology and operation, and quality of materials are main constraints in leachate control by drainage and collection system. Leachate is a highly polluted wastewater and its quality and quantity are highly variable. Thus, different treatment technologies are required for the treatment. The cost of design and treatment should also be considered in leachate management systems.

Environmental monitoring on a long term basis is very important in the control of leachate. Because, the impacts of leachate may last many decades after the closure of the landfill.

2.2.4.4. Leachate Characterization

In this part, previous studies about leachate characterization were reviewed to make a comparison of leachate characteristics for different landfills having different site characteristics and waste sources.

Tatsi and Zouboulis (2002) investigated leachate quality and quantity from a municipal solid waste landfill in Thesseloniki, Greece in Mediterranean climate. The wastes consist of approximately 50 % of organic household origin, 18.7 % paper, and 6 % plastic and metals. The parameters analyzed include pH, ORP, COD, BOD_5, solids content (Total solids; suspended solids; dissolved solids; and volatile solids), electrical conductivity, color, turbidity, NO_2, NO_3, NH_3, TKN, SO_4, Cl, alkalinity, PO_4-P (total and ortho), and metal concentrations (Fe, Ni, Cd, Pb, Ca, Mg, Mn, Cr, Zn and Cu). Fresh and old leachate parameters were statistically evaluated to characterize leachate parameters and to investigate the relationships between leachate parameters. Finally, subsequent leachate treatment methods were proposed based on leachate quality and quantity data. Leachate characteristics in the landfill showed large fluctuations and varied significantly with the age of the landfill. Fresh leachate is generally characterized by higher values of pollution parameters. BOD concentrations for fresh and old leachates were between 27,000 and 1,000 mg/l, respectively. COD concentration varied between 70,000 and 5,300 mg/l for fresh and old leachate samples. As opposed to decrease in the organic content with time, ammonia-nitrogen concentration remained high with time. NO_3 and total P concentrations were found to be in relatively lower concentrations in old leachate. In general, pollution parameters and heavy metal concentrations decreased with time, while pH increased due to alkaline conditions. Some ratios including BOD/COD, VS/TS and SO_4^{2-}/Cl^- were also investigated to describe the composition of organic matter in leachate and degree of stabilization. The decrease in these ratios is an indicator for the stabilization of the waste with the age. It was noted that the major pollutants in the leachate are organics and ammonia. Leachate generation gradually decreases during the dry season due to reduced percolation.

Aluko et al. (2003) investigated leachate in a municipal solid waste landfill site in Ibadan, Nigeria for wet periods, dry periods and combined samples. The landfill receives domestic, industrial and institutional wastes. The objective of the study was to identify the quality of leachate and to estimate its polluting effects in order to design a sustainable and cost effective treatment method. The study deals with physical, chemical and trace metal characterization and includes pH, SS, BOD, COD, NH_3, NO_3, PO_4-P , SO_4, Pb, Ni, Cd, Fe, Mn, Zn. Leachate parameters were statistically evaluated calculating mean values and standard deviations. In the samples, pH values varied in the range of 8.03-8.28 and leachate color was amber. These properties demonstrated that samples were taken from the old waste. High concentrations of pollutants existed in leachate samples except for NO_3, SO_4 and PO_4. Leachate sample concentrations showed variations for wet and dry seasons. Iron concentration dominated the other metals in leachate samples. Leachates during wet season were more alkaline as compared to the dry season. In addition, during wet season leachate had higher pollution concentrations particularly for conductivity, SS, DS, NH_3, Ni, Cd and Mn. The reason for higher pollution content in wet season was attributed to the increase in water content that promotes the solubilization the pollutants from actively decomposing waste into leachate.

Abduli and Safari (2003) investigated the heavy metals in the Kahrizak landfill in Tehran. These metals include Cu, Zn, Pb, Cd, Co, Fe and Mn. During a 10 months period, four fresh and four old leachate sample were analyzed based on three phases of heavy metals: (1) Dissolved; (2) Adsorbed onto SS with particles larger than 0.45 μm filter size ; and (3) adsorbed onto suspended solids with particle sizes less than 0.45 μm termed as colloidal phase heavy metals. Maximum dissolved heavy metal concentrations were measured at minimum pH values. In other words, fresh leachate samples have higher concentration of heavy metals than the old leachate samples. There was no such a relationship for heavy metal concentrations adsorbed onto suspended solids. More than 90 % of heavy metal concentrations for fresh and old wastes were found to be adsorbed on SS. Fresh leachates had lower adsorbed metal concentration than old leachates.

In Kuwait, leachate characteristics and leachate generation mechanism for two unlined landfills were investigated by Al Yaqout and Hamoda (2003). One of the landfills analyzed was active and one was closed. The landfills receive all kind of wastes, such as food wastes, oil products, debris, agricultural wastes, chemical materials, hospital wastes, slaughterhouse waste and liquid wastes. Rainfall effects on leachate generation and composition were identified. Chemical parameters and heavy metals analyzed were pH, TDS, conductivity, alkalinity as $CaCO_3$, SS, volatile suspended solids (VSS), BOD, COD, SO_4 and Zn, Ni, Fe, Mg, Ca, Cu, aluminum (Al). Although Kuwait is an arid country with no fresh surface water and limited usable ground water sources, a large quantity of leachate was generated due to solid waste characteristics, such as co-disposal of liquid and sludge, moisture content and rising water table. Data analysis demonstrated that leachates from both landfills are contaminated with organics, salts and heavy metals. Values of pH were higher in the closed landfill than the active landfill due to the high alkalinity concentrations. Although the conductivity values were high in the active landfill, closed landfill had higher conductivity values than the active landfill. BOD and COD concentrations varied between 30-600 mg/l and 1,579-9,440 mg/l for the active and closed landfills, respectively. These parameters in the active and closed landfills were relatively lower than the values reported in the literature. Fe was the most common metal in leachate relative to other metals. The higher concentrations of iron in the closed landfill resulted in brown to black leachate color. The fresh leachate was characterized by higher organic strength and heavy metal concentrations. It was also observed that leachate strength for Kuwait landfills was generally lower than the literature values. Low strength leachate in Kuwait might be caused by the dilution effect of rising water table and mixing of leachate with subsurface water.

Salihoğlu et al., (2002) evaluated the characteristics of 4-year monitored leachate data (1998-2001) in Bursa Landfill including closed X-T Valleys and open Main Valley. pH, BOD/COD and BOD/total nitrogen variations were examined in the study. pH in 1-year old active Main Valley was between 6.2 and 6.8 showing a transition from aerobic to anaerobic acid phase. High BOD_5 and COD concentrations in this valley were observed. BOD/COD ratio in the Main Valley was ranged between 0.8 and 0.6 with an average of 0.68 showing the characteristics of young leachate. 7-years old closed X Valley had a BOD/COD ratio less than 0.5. After the closure of the T Valley, BOD/COD ratio decreased sharply. BOD/total N ratio decreased with waste age as well as BOD/COD ratio.

Kjeldsen and Christophersen (2000) made a comprehensive summary of findings of old landfill studies conducted in Denmark. Their objective was to evaluate the typical composition of leachates from old smaller landfills statistically by reviewing studies for 106 landfills. Nearly all types of wastes generated in the municipality are disposed of into most of the landfills. The waste age ranged from 10 to 40 years in the landfills. One sanitary landfill was selected in order to obtain better time series of leachate composition. This landfill is divided into small cells containing wastes of one year. The leachate was sampled directly from each cell; therefore, there was no dilution with groundwater or surface water. The BOD and COD concentrations were generally high in the first five years, but rapidly decreased to low values. The average BOD/COD ratio was 0.12 for this landfill. BOD, COD concentrations and

BOD/COD ratio were generally lower than the values reported in the literature. In addition to this landfill, old landfills avoided from dilution and degradation were evaluated to observe the dependencies of the pollutant concentration to typical landfill parameters. These landfills had no liners and leachate collection systems, therefore, the wastes were generally unsaturated. Na and COD concentrations decreased with time and a large variation observed between different landfills. In these landfills, the average BOD/COD ratio was 0.11. The average concentrations for the old landfills were similar to the selected landfill. Leachate parameter concentrations generally decreased with the age of landfill. They were generally lower than the values in literature probably because of the old age, thinner waste of the Danish landfills (3-15 m) and high leaching process due to lack of a low permeability top cover.

Urbini et al. (1999) performed a leachate characterization study for a sanitary landfill in Lombardy, Italy used to dispose municipal solid waste from 1983 to 1994. The study dealt with 242 leachate samples from 12 cells inside the landfill having their own leachate drainage systems. Data analysis for leachate parameters was firstly carried out on different leachate parameters inside each cell and then on the same parameters in different cells. The study was based on the leachate parameters including pH, COD, BOD, NH_3-N, N_{org}, TKN, volatile fatty acids (VFA). These parameters directly describe the various stages of municipal solid waste degradation processes. pH was acidic in the first few months of biodegradation phase, while it increased to 7.5 and 8 during the methanogenic stage in the following years. COD values increased during the first few months to very high values between 30,000 and 62,000 mg/l, then decreased with time and stabilized within 3-4 years from the beginning of the degradation process. BOD values showed similar trend as COD with maximum values ranging between 10,000 and 24,000 mg/l. NH_3-N values demonstrated great fluctuation and did not reach a stable value after about 10 years. VFAs started to decrease after about 3 years and depleted ultimately after approximately 7 years from the beginning of the landfill operation.

Armstrong and Rowe (1999) examined leachate quality and quantity, during landfill development using data from a large landfill in Ontario, Canada. The COD and calcium concentrations seemed to be directly related. These parameters were inversely related to pH. The chloride concentration also varied widely but can not be correlated with COD, Ca and pH. The BOD/COD ratio was in the range of 0.5 and 1.0 and there was no clear trend of this ratio to decrease with time. BOD/COD ratio and pH values showed that leachate mixing from different parts of the landfill was acetogenic. This suggested that continuing waste filling operations were providing sufficient sources of reduced carbon for microbial growth. The results of the study demonstrated that when fresh waste lifts are placed on older waste, the older waste behave as a bioreactor with respect to the fresh waste and treat leachate generated by fresh waste. In addition it was concluded that planned waste placement and fluid addition may play major roles in leachate treatment before removal from the landfill.

Kruempelbeck and Ehrig (1999) studied the leachate data from more than 50 German landfills in order to evaluate the emission behavior of leachate (BOD_5, COD, pH, electrical conductivity, TOC, NH_4-N, NO_3-N, NO_2-N, AOH, Cl, SO_4, Na, K, Mg, Ca, Mn, Fe, Pb, Zn, Cd, Ni, Cu, Cr, Ar) and landfill gas in municipal solid waste landfills. Several predictions have been performed for the understanding of the long-term behavior of the landfills. The landfills include different proportions of industrial waste similar to household waste, demolition waste and contaminated soil. Landfill operations started around 1970's and before. The diversity of leachate originated mainly from waste input and different landfill techniques. There was a rapid concentration decrease for many leachate parameters after 5 years from the beginning of landfill operation due to completion of the acidogenic phase, which took about 2-3 years, but no longer than 5 years. But, NH_4-N showed a different trend and reached the highest concentration in the period from 6 to 20 years of the landfill operation. Most of the salt ions had a decreasing trend.

Leachate quality and quantity, leachate treatment and degree of contamination of soil and surface waters at the Tre Monti Site (an active, 4 million m^3 landfill in Northern Italy) was investigated by Frascari et al. (2004) using 10 years of leachate data. The average composition of wastes consisted of 29 % organic material, 20 % paper and wood, 14 % plastic, 5 % metals, 3 % textile materials, 2 % glass, 3 % inert materials, 5 % other materials, and 19 % materials smaller than 20 mm. The analyzed leachate parameters included pH, BOD, COD, TKN, NH_3, conductivity, SO_4^{2-}, Cl^-, NO_3^-, P, Al, antimony (Sb), As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Zn, Ni and selenium (Se). Values of pH showed a constant trend in the range of 8.3-8.5 during the 10 year leachate monitoring period. This indicated that the landfill was already in the methanogenic phase at the beginning of the monitoring period. The BOD/COD ratio decreased from 0.5 to 0.18 over the period of 1992 to 2001, which is consistent with values reported in the literature. The annual average ammonia concentration and TKN concentration ranged between 900 and 1,900 mg/l and between 1,280 and 2,530 mg/l, respectively. The annual average phosphorus concentration varied between 10 and 25 mg/l. The electrical conductivity of leachate was in the range of 18,000 and 23,000 μS/cm. These values were 1.5 to 2 times higher than the values reported in literature. Relatively high concentrations of chloride were measured in the range of 2,400 and 3,800 mg/l. The decrease in SO_4 (from 500 mg/l to 100 mg/l) resulted from the reduction of sulphate to sulphide during the anaerobic phase of the landfill. The heavy metal concentrations had wide fluctuations and did not show any long-term trend. In addition, in the study it was showed that the fluctuations in the average leachate concentrations can be attributed only in part to the fluctuations in leachate flow rate. There was no correlation between the annual mass of leachate components and the annual amount of waste deposited.

Khattabi et al. (2002) conducted a study to investigate the composition and seasonal decomposition of leachates from recent and aged municipal solid wastes in the Etueffont Landfill, Belfort, France. The study was based on hourly (1999), monthly (1998-1999) and annual (1993-1998) measurements of several leachate parameters, including flow rate, rainfall, temperature, electrical conductivity, O_2, pH, Cl, SO_4, Zn, Cu, Fe, Ni, HCO_3, NO_3, NH_4, BOD and COD. It was observed that the peaks of monthly leachate flow rate did not correspond to the maximum rainfall values. The absence of a correlation between these parameters was thought to be resulted from the fact that the landfill did not immediately respond to the rainfall due to multiple preferential flow paths in the landfill or low humidity of the refuse. Dissolved oxygen (DO) values were low during the summer months, while high in winter months. They were higher than the concentrations reported in the literature because of open-air operation of the landfill and permanent mixing of wastes. Value of pH were more acidic during the winter months probably due to the high accumulation of CO_2. The high Cl values coincided with the electrical conductivity values and were higher in summer. SO_4 concentrations did not change greatly with seasons. The peak concentration value of Zn occurred during the highest rainfall level. The maximum Cu and Ni concentrations corresponded to the low leachate flow rate. Fe and HCO_3 concentrations were higher during the summer months. The NH_4 concentrations were also higher during summer. BOD concentrations increased slowly and reached the maximum values in the late summer with the increase in the amount of bacteria. This increase in the bacteria seems to be resulted from the high organic matter of the waste. Temperature also played an important role in the increasing bacterial activity. BOD concentrations decreased, while COD concentration increased with the age of the landfill. BOD/COD ratio was low during summer and decreased over the years. The results showed that electrical conductivity, chloride and COD values increased in the middle of the day due to high temperature values. Low concentrations of HCO_3, Cl, Fe, SO_4 in winter months were likely due to dilution or reversal of sorption and precipitation with low pH values in winter. There was a significant linear correlation between Cl and electrical conductivity. Therefore, Cl concentration could be an indication for the mineralization of leachate. The metal content of leachate (Zn, Ni, Cu) was lower than literature values, which was attributed to dilution except zinc. The young leachate contained less NO_3 and SO_4 concentrations. Large fluctuations were observed during hourly measurements and highest concentrations were measured during the middle of the day most likely due to temperature. During the late summer, leachate had higher biodegradable matter due to low rainfall and high temperature.

Çallı et al. (2004) conducted a leachate management study for Kömürcüada landfill in İstanbul, Turkey, which included the applications and alternatives of leachate treatment. Solid wastes generated from residential and commercial sources contain about 60 % of biodegradable fraction. COD, BOD,TSS and VSS, pH, alkalinity, NH_3, TKN, total P, color, SO_2, Cl and metals including Fe, Mn, Cu, Zn, Pb, Cr and Ni were analyzed for 3 years in order to determine the treatment steps for leachate. BOD/COD was usually above 0.6 indicating the high biodegradability of leachate. Heavy metal concentrations were generally low except Fe. Leachate parameters were generally in the range of literature values for young leachate except NH_3.

As seen from the studies listed here, leachate characteristics show wide variations for landfills in different countries, having different site characteristics, waste sources and landfill operations. Leachate composition also changes with the age of the landfill. Fresh leachates are generally characterized by high concentrations of organics and metals, and low pH values due to acidogenic conditions. BOD/COD ratio is generally used as an indicator for the waste stabilization and decreases with the age of the landfill. BOD/COD ratio is about 0.1 for old leachates and above 0.6 for fresh leachates. NH_3 concentrations show high fluctuation and generally remain high in leachate. Maximum metal concentrations generally occur in minimum pH levels because of the acidogenic nature of leachate. Fe is the most common metal in leachate compared to other metals. Leachate composition also changes seasonally within a year. Leachate pollutant concentrations are generally lower in the wet seasons due to the dilution effect of water. However, there are even hourly and daily fluctuations in leachate composition. A quantitative knowledge of variations in the leachate quality at various time scales can be useful for the design of sustainable and effective landfill and leachate management system in landfills having similar site conditions and climate.

CHAPTER 3

MATERIALS AND METHODS

3.1 Site Description

The landfill studied is located in Bursa, a city in the southeast of the Marmara Region in Turkey. Increasing industrialization in the city starting with the sixties resulted in extensive migration and population increase. The city of Bursa has a population of 2,125,140 according to 2000 census and with this population it is the fourth largest city, and one of the most developed cities in Turkey. Based on 2000 census, annual population growth rate of the city was 28.62 %o.

Bursa has an elevation of 155 m above the sea level. The city generally has a temperate climate; however the climate may show different local characteristics. In the north, the climate is warm due to the Marmara Sea, while it is cold in the south due to the presence of Uludağ. Bursa has an average annual temperature of 14.4 ^{o}C, calculated from a 42-year temperature data. Generally the hottest period occurs from July to September, while the coldest months are February and March. The annual average rainfall in Bursa is 706 mm based on 52 years of rainfall data. The average relative humidity is 69 % in Bursa (Aydın et al., 2003).

In the beginning of 1980's, solid waste problem has started to grow in Bursa due to rise in the amount of waste with the increase in population and industrial developments. In 1989, a feasibility report was prepared by the Bursa Municipality in order to follow the advances in science and technology of solid waste management practices. As a consequence, "Municipal and Industrial Solid Waste Management Preparation Plan" including the construction of Bursa MSWL and transfer station, rehabilitation of Demirtaş dumping area, purchase of equipment, and consultancy services was prepared and implemented.

Total project area of the Bursa MSWL Site is 175 ha and the available landfill area for waste disposal is 77 ha. Total storage capacity of the landfill is 20,000,000 m^3 and the expected landfill life is about 30 years from 1995 to 2025. Bursa MSWL site is located in Hamitler, in the northwest section of the city, and 12 km away from the city center. The landfill site has as approximate distance of 1 km from the nearby closest residential areas. A view of Bursa MSWL was shown in Figure 3.1.

Figure 3.1. A view of Bursa MSWL

The T Valley operated from November 1996 to October 2000 with an area of 8.8 ha. Bursa MSWL consists of one Main Valley and four adjacent valleys (X, T, Y, Z). A schematic map showing the approximate shapes and relative positions of the X, T and Main Valleys is given in Figure 3.2. The X and T Valleys constitute the 1st stage of Bursa MSWL. The X and T Valleys are closed valleys, whereas the Main Valley is still active and has been operating since October 2000. The X Valley was operational between August 1995 and October 1996. It is the smallest valley with a volume of 300,000 m^3 and an area of about 3.7 ha. It produces the smallest amount of leachate. The T Valley was operational from November 1996 to October 2000. The landfill area for the T Valley is 8.8 ha and the volume is 1,000,000 m^3. The Main Valley has an area of 18 ha with a volume of 1,100,000 m^3. The Main Valley includes the additional 2^{nd} and the 3^{rd} Stages. The 2^{nd} Stage is approximately 2/3 and the 3^{rd} Stage is approximately 1/3 of the total area of the Main Valley. After currently operating 2^{nd} Stage has been completed, the 3^{rd} Stage of the Main Valley will start to operate. The Y and Z Valleys also have not started to operate yet.

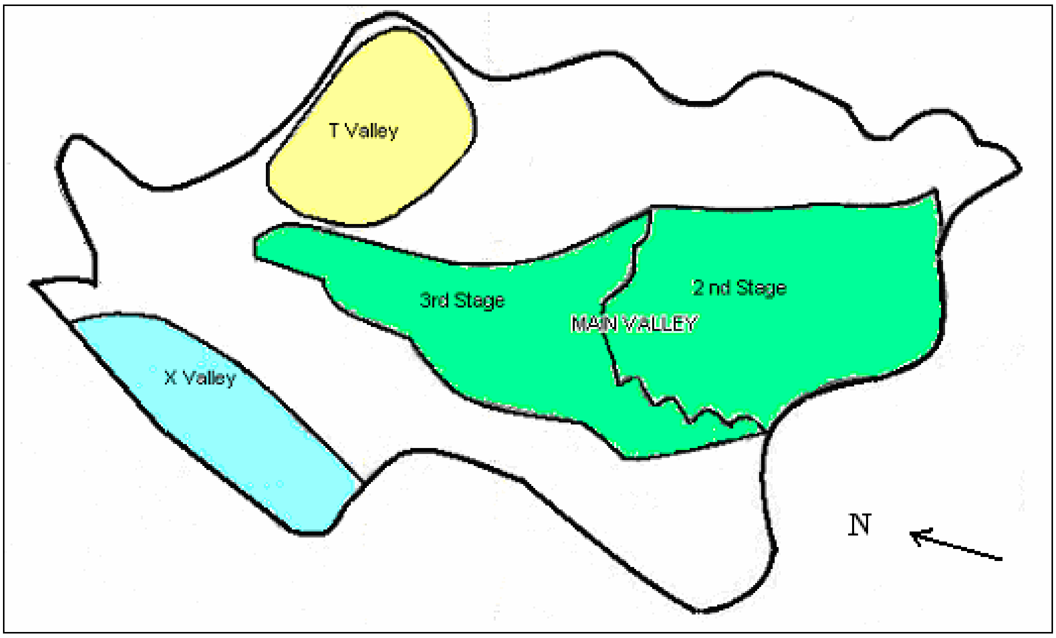


Figure 3.2. The approximate shapes and relative positions of the X, T and Main Valleys

At the present time, leachate produced in the Bursa MSWL originates from wastes of different ages up to 9 years. The vertical from top to bottom cross sections of the X, T and Main Valleys are presented in Table 3.1. Right and left bases of the Main Valley are also covered with about 30,000 m^2 of high density polyethylene geomembrane with a thickness of 2 mm on the top of the clay layer. The permeability of the natural ground, which was used as final cover, varied between 10^{-8} and 10^{-5} m/s in Bursa MSWL.

Table 3.1. Vertical top to bottom cross sections of X, T and Main Valleys

X Valley	T Valley	Main Valley
50-80 cm of soil cover(top)	50-80 cm of soil cover(top)	50-80 cm of soil cover(top)
Solid waste (7 m)	Solid waste (28 m)	Solid waste (~ 14 m)
30 cm of leachate drainage layer	30 cm of leachate drainage layer	30 cm of leachate drainage layer
-	-	Geomembrane (30,000 m^2)
60 cm of clay layer	120 cm of clay layer	120 cm of clay layer
30 cm of GW drainage layer	30 cm of GW drainage layer	30 cm of GW drainage layer
Natural ground (bottom)	Natural ground (bottom)	Natural ground (bottom)
6-8 % of slope	14-15 % of slope	4-5 % of slope

In order to separate and recycle the wastes (glass, paper, metals, plastics, etc.), Recycle and Source-Separation projects started in Nilüfer in 1995, and Yıldırım and Osmangazi in 1996. Before the start of the projects it was determined that 10 % on mass basis of the solid waste is recyclable. The projects are currently continuing covering a population of 110,000. Separation facility started waste separation operations and selling the recyclables in 1999. The facility works with three labor shifts, each having a capacity of 7-10 tons per shift.

Before the construction of the sanitary landfill, solid wastes generated in Bursa were disposed of in the dumping area located in Demirtaş. This area was rehabilitated and an area of 16 ha in this dumpsite was vegetated. A facility converting landfill gas to energy was built in 1998. The capacity of the facility is 1.4 MWh. In this way, it is aimed to eliminate the environmental impacts of this area and make use of landfill gas.

Municipal solid wastes disposed of in the Bursa MSWL comes from central municipalities, Osmangazi, Yıldırım, Nilüfer, and other surrounding municipalities, Mudanya, Güzelyalı, Demirtaş, Goral, Emek, Çalı, Ovaakça and Zeytinbağı.

Tipping solid wastes in Bursa MSWL started in 1996. Solid wastes disposed of mainly consist of three main classes: municipal waste, industrial waste and medical waste. Municipal solid wastes include the commercial waste, yard waste and domestic waste. The composition of industrial and commercial wastes is considerably wide. Industrial wastes consist of non-hazardous process waste, slaughterhouse waste, and wastewater sludge. Medical wastes generated from 15 hospitals and 180 health institutions are collected with the vehicles having coolers. These vehicles have a capacity of 5 ton and 6 containers with a volume of 0.75 m^3. Collected medical wastes are limed during disposal in the landfill. Medical wastes include human and animal tissue, blood, pharmaceutical products, dressings, needles or other instruments. There are 105 facilities producing hazardous waste in Bursa. Hazardous wastes generated are transferred to İzmit Waste and Residue Treatment, Incineration and Recycling Co. Inc. (İZAYDAŞ). Between 2000 and 2003, distributions of municipal solid wastes and industrial wastes disposed of in the landfill are given in Table 3.2-3.3, respectively. Monthly and annual solid waste amounts disposed of in the landfill between 1995 and 2003 were given in Appendix A (Tables A.1-A.7).

Table 3.2. Distribution of solid wastes in Bursa MSWL (Bursa Municipality, 2004)

Year	**Municipal W. (%)**	**Industrial W. (%)**	**Medical W. (%)**
2000	93.64	6.16	0.20
2001	94.08	5.69	0.23
2002	94.09	5.68	0.23
2003[a]	94.13	5.63	0.24

[a] includes up to October

Table 3.3. Distribution of industrial wastes in Bursa MSWL (Bursa Municipality, 2004)

Year	Non-hazardous Process W (%)	Sludge (%)	Slaughterhouse W. (%)
2000	78	15	7
2001	72	23	5
2002	68	28	4
2003[a]	85	7	8

[a] includes up to October

In Bursa MSWL, municipal solid waste is about 95 %, industrial solid waste is about 5-6 % and medical solid waste is about 0.3 % of all solid wastes. Industrial waste consists of mainly non-hazardous process wastes. Sludge produced in wastewater treatment plant is also disposed of in the landfill.

Solid wastes coming to the landfill are first weighted before disposal. The daily amount of municipal solid waste coming to the landfill is approximately 1200-1300 tons. The in-place density of the waste is 0.9 ton/m^3 and the compacted density including daily cover soil is 1.1 ton/m^3. Wastes are piled in the landfill as 0.5 m thick lifts, and then compacted to form a daily cell having a thickness of 7 m and a face slope of 1:3. Solid wastes in the landfill are covered daily with soil for odor prevention. Final covering of the waste was done using 0.5-0.8 m thick natural soil. Gas stacks are formed in the landfill to prevent odor and to reduce the landfill gas emission into the atmosphere. Leachate generated in the landfill was transferred to Bursa Municipality Wastewater Treatment Plant until June 2004. Since then, leachate has been treated in leachate treatment plant and effluent is transferred to wastewater treatment plant.

3.2 Available Landfill Data

Measured leachate data for the period of 1995-2004 were obtained from Bursa Municipality. In the X Valley, measurements of leachate parameters were irregular and covered the period from February 1995 to May 2003. Measured parameters include BOD, COD, pH values and less frequently measured parameters are SS, electrical conductivity (EC), total chromate (CrO_4), Cr^{6+}, Fe, Cd, Cu, CN^-, Cl, F), Zn, Pb, total P , NH_4-N, total N, SO_4, S^{2-} and total alkalinity as $CaCO_3$. Measured leachate parameters in the T Valley and Main Valley include BOD, COD, pH, SS and less frequently measured parameters including electrical conductivity, total CrO_4, Cr^{6+}, Fe, Cd, Cu, CN^-, Cl, F, Zn, Pb, total P, NH_4-N, total N, SO_4, S^{2-} and total alkalinity values. Measurements in the T Valley were taken on a weekly basis between 1998 and 2000. Starting with 2001, measurements have been taken on a monthly basis up to now. Measurements of leachate parameters in the Main Valley have been continuing from October 2000 up to now on a weekly basis. Available leachate quality data were presented in Appendix B (Tables B.1-B.2).

The leachate analyses were performed in the Municipality's Landfill Laboratory according to standard methods (AWWA, 1995). The instruments used for the analyses were Spectrophotometer (CECIL CE 4003), Photometer (Merck SQ 118), pH meter (Meterlab, Radiometer, PHM210), Conductivity Instrument (Corning), Suspended Solids Set (Sartorius N 022 AN.18), Filter Paper (Sartorius 0,45 μm) and Thermoreactor (Merck TR 300). BOD_5 test has been performed according to 5-Day BOD Test of Standard Methods 5210B. SS were measured gravimetrically. Merck Cell Test Sets were used for the other analyses (Salihoğlu et al., 2002).

The annual amount of municipal solid waste disposed of in the landfill increased from 224,000 ton/yr in 1996 to about 400,000 ton/yr in 2000. It has become nearly constant after 2000, within the range of 400,000–450,000 ton/yr as shown in Figure 3.3. Table 3.4 gives the annual amounts of waste for the valleys in Bursa MSWL. Bursa solid waste composition consists of 54 % of organics, 36 % of recyclables and 10 % ashes and residuals (Merkat A.Ş). Table 3.5 shows the seasonal composition of solid waste.

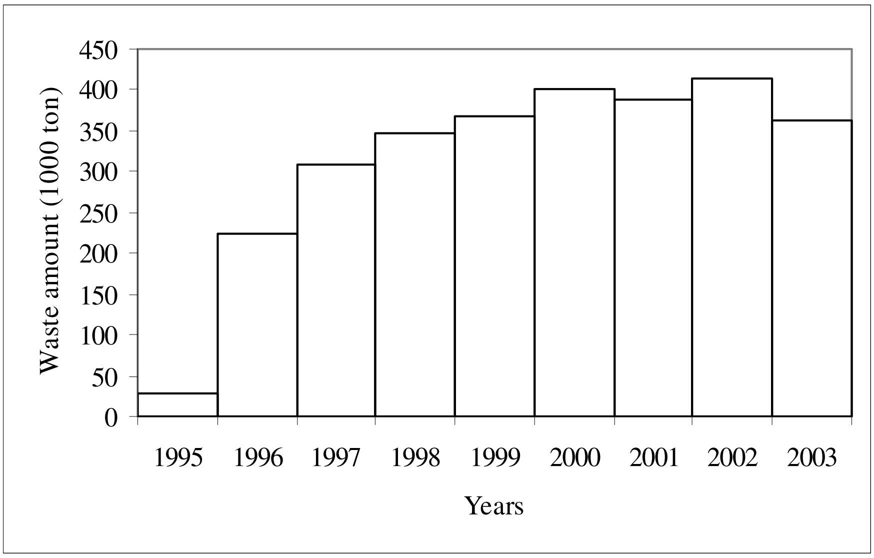


Figure 3.3. Annual amounts of waste deposited in Bursa MSWL between August 1995 and October 2003

Table 3.4. The amount of solid wastes in tons for valleys deposited between 1995 and 2003

Years	X Valley	T Valley	Main Valley
1995	27,543[a]	-	-
1996	176,974[b]	46,960[c]	-
1997	-	308,852	-
1998	-	346,946	-
1999	-	367,114	-
2000	-	299,304[d]	102,239[e]
2001	-	-	387,701
2002	-	-	413,612
2003	-	-	361,582[f]
Total	**204,517**	**1,369,176**	**1,265,134**

[a]: includes August-December
[b]: includes January-October
[c]: includes November-December
[d]: includes January-October
[e]: includes October-December
[f]: includes January-October

Table 3.5. Seasonal solid waste composition in Bursa MSWL (Atabarut, 2000)

Season	Food Remains (%)	Ashes and Residuals (%)	Recyclables (%)
Summer	77	3	20
Winter	34	57	8

3.3 Methods of Data Analysis

For data analysis, conventional statistical analysis, time series and factor analysis were conducted. Conventional statistical analysis shows the distribution characteristics (mean, median, mode, range, standard deviation and coefficient of variation) of leachate parameters and the deviation of distribution from normal (skewness). The objectives of performing time series analysis are to identify auto-cross correlation characteristics as well as trend, seasonality and randomness of leachate parameters. Factor analysis was used to determine interrelationships between several leachate parameters simultaneously.

Leachate parameters included in the statistical data analysis are BOD, COD, pH, electrical conductivity, SS, Cl, total CrO_4, Cr^{6+}, Fe, Cd, Cu, CN^-, Cl, F, Zn, Pb, total P, NH_4-N, total N, SO_4, S^{2-}, total alkalinity as $CaCO_3$ and leachate flow (generation) rate. For these leachate parameters sufficient time series data are available to observe various stages of waste stabilization process.

3.3.1. Conventional Statistical Analysis

Conventional statistical analysis of available leachate quality data was performed by calculating the mean (average), median, mode, range (minimum and maximum), standard deviation, coefficient of variation (CV)and standardized skewness.

Statistical characterization provides various distribution characteristics of data such as location, spread and shape. The location or central tendency for the distribution indicates the central value of the data. The spread and dispersion characterizes the amount of variation in the distribution. The shape is related to the tails of distribution including the tail length and the symmetry of the left and right tails. The most common statistics used for data characterization were presented in Jobson (1991) and described below.

The most commonly used measure of central tendency is the arithmetic mean, $\bar{x}$, or sample average, sum of the data points divided by the number of data points. The median, x_M, is the value dividing the frequency equally into left and right halves. If the width of the interval containing the right half of the distribution exceeds the left half, then the distribution is skewed to the right or vice versa. If the distribution is skewed to the right, the mean exceeds the median. The mode, x_m, is the value corresponding to the maximum frequency. Distributions may have several peaks and thus the mode is not necessarily unique.

The amount of variation or dispersion in the distribution is most commonly measured by using the sample variance. The variance, s^2, measures dispersion relative to the mean. The sample standard deviation, s, is the square root of the variance. Coefficient of variation is a measure of the relative dispersion that is the standard deviation divided by the mean and multiplied by 100 to give a percentage value.

Skewness, S_k, is a measure of the symmetry in the distribution shape of the data. A skewness of 0 indicates that the data are symmetrically distributed. Skewness is the inequality between the two tails. Positive values of skewness show that the upper tail of the curve is longer than the lower tail; negative values tell that the lower tail is longer. The relative positions of the mean and the median can be used to measure the direction of skewness. In the distribution of the data, if the right end of the plot has a longer tail; the mean is greater than the median or vice versa. Standardized skewness is a measure testing for significant deviations from the normal distribution. When the values for the standardized skewness coefficient are outside the range -2.0 to +2.0, the data may depart significantly from a normal distribution.

3.3.2. Time Series Analysis

A detailed explanation of the time series analysis is given by Chatfield (1996), however, a summary is presented in this section. A time series is a collection of observations occurring sequentially in time at uniformly spaced intervals. It is continuous when observations are made continuously in time. It is said to be discrete when observations are made only at specific times, usually at equal intervals. The special feature of time series analysis is that successive observations are usually dependent and the analysis must take into account the time order of the observations. When successive observations are dependent, future values of this parameter may be predicted from past values. If a time series can be predicted exactly it is said to be deterministic. However, time series are usually stochastic in that exact predictions are impossible and a series can be partly predicted using past data.

The statistical techniques for analyzing time series data range from straightforward to very complex, but the first step is always to identify data characteristics. Identifying the characteristics includes stationarity, seasonality and provides determination of any seasonal effects, cyclic changes, trends, errors, outliers, or turning points. These properties help in the selection of appropriate smoothing and forecasting methods.

In the time series analysis, the first step is usually to plot the data and to obtain simple descriptive measures of the main properties of the series (seasonal effect, cyclic changes, trend and irregular fluctuations). A graph does not only demonstrate the trend and seasonal variations, but it also makes possible to observe the outliers, which do not appear to be consistent with the rest of the data. Another feature of a graph of the time series is to see the possible presence of turning points, where an upward trend has suddenly changed to a downward trend or vice versa.

Long term trend in the time series is the tendency of the value of a variable to increase or decrease over a long period of time. If a long term trend is of increasing type, this does not imply that the time series has always moved upward from month to month or from year to year. Although a series fluctuates, the trend increases or decreases over the period of time. Seasonal variation of a time series is the fluctuations occurring during specific portions of the year (Mendenhall and Sincich, 2003). Cycle is the wavelike patterns of up and down, however, the length of time between peaks is not fixed as in the seasonal movement due to other physical causes. Residuals remain in a time series after trend, seasonality and cyclic changes are removed from the series. The residual effect is not systematic and may be random or not. This component is known as noise.

Time series analysis also covers the evaluation of autocorrelations within a variable (i.e., leachate parameters) and crosscorrelations between two variables. Autocorrelation function of a variable, $\rho(k)$, measures the correlation between the successive observations of the variable measured at time t, X_t, and at time t+k, X_{t+k}. Autocorrelation coefficient, r_k, gives the correlation between X_t and X_{x+t} , where k is the time interval (lag) between observations.

When observations are performed for two or more variables, it may be possible to use the variation in one time series to explain the variation in another series. Crosscorrelation function, $\rho_{XY}(k)$, measures the correlation between the two variables X and Y measured at time t, X_t, and at time t+k, Y_{t+k}. The crosscorrelation coefficient, r_{xy}, is always between -1 and +1. It is close to zero when there is no linear relationship between two parameters. It is close to +1 as both variables increase together and that the points are close to lying on a straight line. If the correlation is -1 it indicates that one of the variables increases as the other decreases, with points are close to falling on a straight line.

3.3.3. Factor Analysis

Factor analysis is a multivariate data analysis technique useful for reducing information in a large number of variables into a smaller set, while losing only a minimal amount of information. The general purposes of factor analysis are to identify a set of dimensions, which cannot easily observed in a large set of variables, devise a means for combining large numbers of observations into distinctly different groups within a larger population and create an entirely new set of a smaller number of variables to partially or completely replace the original set of variables (Statgraphics Plus User Manual, 1997). The main purpose of factor analysis is to describe the relationships among several variables in terms of a few underlying, but unobservable random quantities that are called factors. The variables within a group are highly correlated among themselves and have relatively small correlations with variables in different groups. Each group of variables represents a single underlying factor responsible for observed correlations (Johnson and Wichern, 2002). The number of factors to be extracted is determined by the eigenvalue-greater than-one rule in Statgraphics Plus Program.

Rotation is generally desirable for the factor analysis, because it simplifies the rows and/or columns of the matrix. Rotation means that the factors are turned until they reach another position. The primary reason for rotating factors is to attain a simpler and more meaningful solution (Statgraphics Plus User Manual, 1997). Varimax rotation, which simplifies the columns of the factor matrix, was applied for the determination of relationships among variables.

In the thesis, the factor analysis was applied in order to determine the inter-related leachate parameters that are evaluated in the development of leachate sampling strategies. In this study, factor analysis was applied to obtain correlated variables for 19 leachate quality parameters (BOD, COD, pH, S, EC, total CrO_4, Cr^{6+}, Fe, Cu, CN^-, F, Zn, Pb, total P, NH_4-N, total N, SO_4, S, total alkalinity) in both the T and Main Valleys using Statgraphics Plus Program.

3.3.4. Statgraphics Plus Package Program

Statgraphics Plus Program (STATGRAPHICS Plus for Windows 3.1) was used for conventional statistical, time series and factor analyses of leachate parameters from Bursa MSWL. Statgraphics Plus includes four types of analyses for time series data: descriptive methods, smoothing, seasonal decomposition, and forecasting. Further details of these analyses can be found in Statgraphics Plus User Manual (1997). Here, two types of time series analyses, namely descriptive methods and seasonal decomposition were used in order to evaluate the variations in leachate with time and season, and explained below.

Descriptive methods provide visualization of the shape, trend, and patterns of data and describe the history of time period. The descriptive methods in Statgraphics Plus Program provides several techniques for data analysis. These methods perform the statistical calculations showing correlations in the data, test for randomness of the data and various plots revealing the trends, cycles, data errors and outliers. The descriptive methods used include auto- cross-correlations and test for randomness. Autocorrelation function helps in determining whether data are random or have a correlation pattern. Crosscorrelation function measures the strength of the linear relationship between two different variables. The test for randomness is used for determining whether data are random or nonrandom. The program includes runs tests “Runs Above and Below the Median test” and “Runs Up and Down test”, and “Box-Pierce test”. Seasonal decomposition analysis performs a classical decomposition of the data. It breaks the time series data into trend, seasonality, cycle and irregular movement.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Leachate Production

The climatological conditions and characteristics of the landfill site should be identified to estimate leachate generation rate in the landfill. The produced leachate quantities in the closed T and open Main Valleys were predicted by most commonly used Water Balance Method (WBM), adopted from Rowe (1996). For this purpose average monthly temperature and precipitation data of 2003 obtained from Bursa Meteorological Station were used. The moisture content of the refuse is not taken into consideration in this method. It is also assumed that there is no surface and ground-water inflow to the landfill. Moreover, the WBM does not account for the time period required for the waste to reach its field capacity and assumes that the refuse is at field capacity (Farqhuar, 1988).

WBM requires monthly average temperature and rainfall data as input. This data for Bursa is given in Table 4.1-4.2. Basically, monthly average leachate generation is taken as the net difference between rainfall and the sum of the evapotranspiration and moisture detention at the cover. The details of computations and related formulations for WBM are presented in Rowe (1996). Using the Table 4.1-4.2 in an Excel spread-sheet program monthly leachate production for Bursa MSWL, T and Main Valleys, were calculated and presented in Table 4.1-4.2.

Table 4.1. Monthly leachate generation for Bursa MSWL-T Valley calculated using WBM and meteorological data of 2003

	Jan.	Feb.	Mar.	Apr.	May	June	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
t (ºC)	8.92	2.70	5.03	9.89	18.78	23.79	25.35	25.60	19.21	16.57	9.99	6.25	
It	2.40	0.39	1.01	2.81	7.42	10.61	11.67	11.85	7.68	6.13	2.85	1.40	66.23
PET (mm)	25.27	4.03	10.49	29.65	79.44	114.20	125.90	127.85	82.25	65.50	30.08	14.65	709.31
Adj Fac	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.81	0.81	
Adj PET	21.23	3.34	10.80	32.91	98.50	142.75	159.89	150.86	85.54	62.88	24.37	11.87	804.95
P (mm)	65.30	106.20	33.10	112.10	45.70	2.40	0.00	0	66.90	125.10	64.50	91.00	**712.30**
C	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
Ro (mm)	22.855	37.17	11.585	39.235	15.995	0.84	0	0	23.415	43.78	22.575	31.85	249.30
I	42.45	69.03	21.52	72.87	29.71	1.56	0	0	43.49	81.32	41.93	59.15	463.00
I-Adj PET	21.22	65.69	10.71	39.95	-68.80	-141.19	-159.89	-150.86	-42.05	18.44	17.56	47.28	-341.95
NEG(I-Adj PET)				0	-68.80	-209.99	-369.88	-520.74	-562.80	-544.36			
ST	58.20	58.20	58.20	58.20	11.57	3.20	1.00	1.00	1.00	1.00	18.56	65.84	
dST	0	0	0	0	-46.63	-8.37	-2.20	0	0	0	17.56	47.28	
AET (mm)	21.23	3.34	10.80	32.91	76.31	9.93	2.20	0	43.49	81.32	24.37	11.87	317.16
PERC (mm)	21.22	65.69	10.71	39.95	0	0	0	0	0	0	0	0	**137.6**

Table 4.2. Monthly leachate generation for Bursa MSWL-Main Valley calculated using WBM and meteorological data of 2003

	Jan.	Feb.	Mar.	Apr.	May	June	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Tot.
t (ºC)	8.92	2.70	5.03	9.89	18.78	23.79	25.35	25.60	19.21	16.57	9.99	6.25	
It	2.40	0.39	1.01	2.81	7.42	10.61	11.67	11.85	7.68	6.13	2.85	1.40	66.23
PET (mm)	25.27	4.03	10.49	29.65	79.44	114.20	125.90	127.85	82.25	65.50	30.08	14.65	709.31
Adj Fac	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.81	0.81	
Adj PET	21.23	3.34	10.80	32.91	98.50	142.75	159.89	150.86	85.54	62.88	24.37	11.87	804.95
P (mm)	65.30	106.20	33.10	112.10	45.70	2.40	0.00	0.00	66.90	125.10	64.50	91.00	**712.30**
C	0	0	0	0	0	0	0	0	0	0	0	0	
Ro (mm)	0	0	0	0	0	0	0	0	0	0	0	0	0
I	65.30	106.20	33.10	112.10	45.70	2.40	0.00	0.00	66.90	125.10	64.50	91.00	712.30
I-Adj PET	44.07	102.86	22.30	79.19	-52.80	-140.35	-159.89	-150.86	-18.64	62.22	40.13	79.13	-92.65
NEG(I-Adj PET)				0.00	-52.80	-193.15	-353.04	-503.91	-522.55	-460.32			
ST	0	0	0	0	0	0	0	0	0	0	0	0	
dST	0	0	0	0	0	0	0	0	0	0	0	0	
AET (mm)	21.23	3.34	10.80	32.91	45.70	2.40	0.00	0.00	66.90	62.88	24.37	11.87	282.40
PERC (mm)	44.07	102.86	22.30	79.19	0	0	0	0	0	62.22	40.13	79.13	***430***

The average monthly rainfall amount ranged between 0 and 125.10 mm in the landfill in 2003. Total annual rainfall amount on the landfill was 712 mm and rainfall amount was insignificant in the summer months. Calculated annual leachate amount for the closed T Valley was approximately 138 mm and comprised 19 % of the total annual amount of rainfall. This value is in the range of literature values that are between 15 % and 50 % for the controlled landfills depending mainly on the climate, landfill cover and waste compaction method. This ratio, for the landfill in Thessaloniki, Greece was calculated 24 % (Tatsi and Zouboulis, 2002). The leachate production in the T Valley was taking place during the months of January through April when the precipitation was higher. The maximum leachate generation was occurred as 66 mm in February. During the period of May through December, there was no leachate generation. This is because, soil cover smooths the time distribution of the rainfall due to the hydraulic resistance and storage capacity of the soil cover, and reduces total amount of rainfall due to evapotranspiration. Therefore, there was no significant direct effect of rainfall events on the leachate generation, during May through December.

The annual amount of leachate determined for the open Main Valley using WBM was 430 mm and comprised about 60 % of the total annual amount of rainfall. The leachate production in this valley was taking place from January to April and from October to December that corresponds to rainy months in 2003. The maximum precipitation was in October with 125 mm. Since the Main Valley was open, the amount of leachate generation was very high compared to the closed T Valley discussed above.

The measured annual leachate generation rates in 2003 for the T and Main Valleys were 50 mm and 700 mm, respectively. The measured annual leachate amount corresponded to 36 % of leachate amount determined using WBM in the T Valley in 2003. The difference can be attributed to the fact that WBM does not take into account time period required for waste to reach its field capacity. The estimation of

WBM for leachate flow rate was higher than the measured value in the closed T Valley.

The measured annual leachate amount in the Main Valley (700 mm), corresponded to 163 % of leachate amount determined by WBM for the Main Valley in 2003. The excess of measured leachate generation rate over the estimated amount in the open Main Valley was attributed mainly to high water content of waste, e.g., sludge, and other water inputs that are not taken into account in WBM.

Although the WBM is theoretically correct and comprehensive, it is difficult to predict leachate flow due to the uncertainties associated with estimating the various terms used in the method. Most of the equations used are empirical. Some of the data are poorly defined such as run-off coefficients, moisture storage capacities, cover density and compaction (Farquhar, 1988). In addition to these factors, heterogeneous nature of the waste in the landfill also affects leachate flow and may cause the uncertainties in the determination of leachate flow.

Figures 4.1-4.2 show the average monthly rainfall and leachate flow rates measured at the T and Main Valleys. Leachate flow rates were measured every 2-3 days for the T Valley and the Main Valley over 5 months in 2002 (from January to May) and over 10 months in 2003 (from January to November, excluding August). These data are presented in Tables C.1-C.2 in Appendix C, while monthly average rainfall and leachate generation rate data are given in Table C.3 of Appendix C. Average monthly rainfall amount varied between 0 and 126.5 mm.

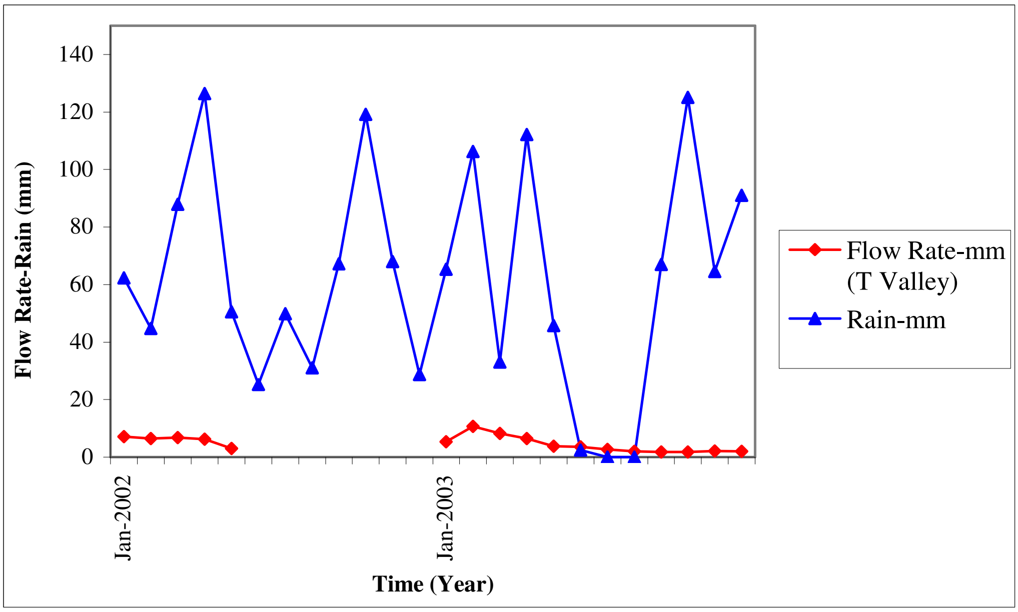


Figure 4.1. Monthly leachate flow rate and rainfall data for the T Valley measured between January 2002 and December 2003

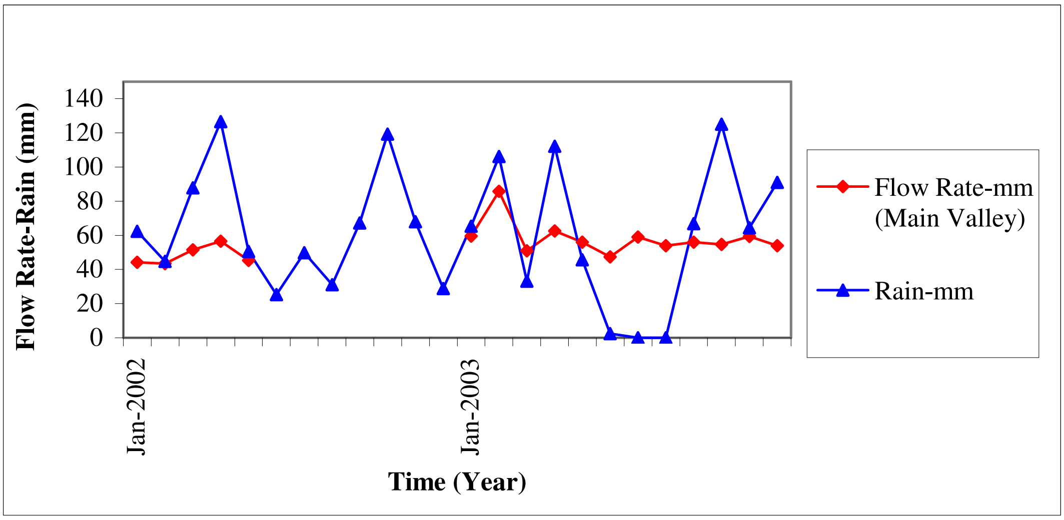


Figure 4.2. Monthly leachate flow rate and rainfall data for the Main Valley measured between January 2002 and December 2003

Since the T Valley was a closed landfill, high leachate generation rates were not expected. Average monthly leachate flow rates fluctuated over a narrow range between 1.77 mm and 10.60 mm with an average value of 4.86 mm. Relatively smooth behaviour of leachate flow rate can be explained by reduced rainfall infiltration, storage capacity and enhanced evapotranspiration potential of final soil cover. The leachate generation rate in the T Valley was about 7 % of the total annual rainfall amount in 2003. On the other hand, currently operational Main Valley had relatively high monthly leachate flow generation ranging between 47.30 and 85.75 mm with an average value of 55.39 mm. The leachate generation rate was about 98 % of annual rainfall amount in the open Main Valley implying significant moisture supply by the waste itself, such as wastewater sludge.

4.2. Leachate Characterization and Statistical Evaluation

Leachate is produced as a result of the extraction, solubilization and decomposition of solid wastes in the landfill by microbiological processes. Biodegradable components in the solid waste decompose and stabilize with time in the presence of moisture. On the other hand, conservative components including various metals, ammonia, chloride and sulphide remain in the waste long after the stabilization of biodegradable components.

Preliminary data inspection showed a wide variation in leachate quality parameters between the pre-closure and post-closure periods of the T Valley due to the stabilization of waste with time. The T and Main Valleys within the same landfill area also demonstrated extensive variation in leachate composition although the origin of the solid waste and the site characteristics were the same. Based on available data and reported visual inspections, leachate generated in the Main Valley was green in the first year of operation while its color turned to dark green and black in the following years. The quality of leachate varied extensively depending mainly upon the age of the waste and degree of stabilization. Leachate quality parameters usually showed high concentrations for fresh leachates and low concentrations for old leachates.

A preliminary data analysis was conducted to compare the results obtained from weekly versus monthly measured data showed that there were no significant differences between the statistical results of weekly measured and monthly averaged data sets. Therefore, monthly averages of the weekly measured leachate parameters were used in the statistical, time series and factor component analyses. Analyses were performed by omitting the leachate parameters measured in July and August, the months of emergency waste disposal over the closed T Valley due to sudden changes in parameters. Variations in leachate quality were quantified by means of conducting conventional statistical, time series and multivariate data analyses. Details are presented in the following sections.

4.2.1. Results of Conventional Statistical Analysis

Table 4.3 presents the average monthly leachate quality parameters in Bursa MSWL and permissible effluent wastewater concentrations for solid waste treatment and disposal facilities according to Turkish legislation (Turkish Water Pollution Control Regulation, 2004) in order to give a reference level for leachate pollution. In fact, these values indicate the target values for the leachate parameters to be treated. It was observed that Bursa MSWL leachate is a highly polluted wastewater according to the regulation and considered as a significant hazard for the environment if discharged without treatment.

Table 4.3. Monthly average leachate quality concentrations in Bursa MSWL and permissible effluent concentrations in Turkish Water Pollution Control Regulation (December 2004)

Parameter	Unit	2 hr Composite Sample	24 hr Composite Sample	Pre-closure (T Val.)	Post-closure (T Val.)	T Valley	Main Valley
COD	mg/l	700	500	16773	538	13159	36339
SS	mg/l	200	100	25482	3637	1230	2185
pH		6-9	6-9	7.4	8.1	7.8	6.8
Oil and Grease	mg/l	20	10	-	-	-	-
Total P	mg/l	2	1	26.1	19.8	22.4	29.4
Total CrO_4	mg/l	2	1	8.7	3.1	5.3	9.2
Cr^{6+}	mg/l	0.5	0.5	7.6	2.4	4.7	7.4
Pb	mg/l	2	1	20.8	0.7	9.2	12.6
CN^-	mg/l	1	0.5	3.7	0.7	1.9	1.4
Cd	mg/l	0.1	-	0.8	0.03	0.45	0.01
Fe	mg/l	10	-	61.7	8.1	31.5	96.1
F	mg/l	15	-	7.8	1.1	4.0	14.1
Cu	mg/l	3	-	14.0	3.1	7.8	6.9
Zn	mg/l	5	-	43.6	9.6	23.9	50.7

Table 4.4 presents the leachate characteristics for the acetogenic and methanogenic stages and the average of monthly leachate parameters in the closed T and open Main Valleys. The 8 years-old closed T Valley was in the advanced state of biodegradation and close to methanogenic conditions due to high pH and relatively lower pollutant concentrations. On the other hand, the 4 years-old Main Valley was in the acetogenic stage due to higher pollutant concentrations and lower pH values.

Table 4.4. Leachate composition in acidogenic and methanogenic stages (Williams, 1998) and in Bursa MSWL

Parameter	Acetogenic			Methanogenic			Post-Closure T Val.	Main Val.
	Min.	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Mean**	**Mean**
pH	5.12	7.80	6.73	6.80	8.20	7.52	8.1	6.8
COD	2,740	152,000	36,817	622	8,000	2,307	538	36,339
BOD	2,000	68,000	18,632	97	1,770	374	3,637	22,165
NH_4-N	194	3,610	922	283	2,040	889	1,331	1369
Cl	659	4,670	1,805	570	4,710	2,074	3,484	4217
TOC	1,010	29,000	12,217	184	2,270	733	-	-
Fatty acids (as C)	963	22,414	8197	<5	146	18	-	-
Alkalinity as ($CaCO_3$)	2,720	15,870	7,251	3,000	9,130	5,376	10,795	8,998
EC (µS/cm)	5,800	52,000	16,921	5,990	19,300	11,502	33,200	42,500
Nitrate-N	<0.2	18	1.8	0.2	2.1	0.86	-	-
Nitrite-N	0.01	1.4	0.2	<0.01	1.3	0.17	-	-
SO_4	<5	1,560	676	<5	322	67	332	906
Phosphate (as P)	0.6	22.6	5	0.3	18.4	4.3	-	-
Na	474	2,400	1,371	474	3,650	1,480	-	-
Mg	25	820	384	40	1,580	250	-	
K	350	3,100	1,143	100	1,580	854	-	-
Ca	270	6,240	2,241	23	501	151	-	-
Cr	0.03	0,3	0,13	<0,03	0,56	0,09	2.4	7.4
Mn	0.4	164	32.94	0.04	3.59	0.46	-	-
Fe	48.3	2,300	653.8	1.6	160	27.4	8.1	96.1
Nil	<0.03	1.87	0.42	<0.03	0.6	0.17	-	-
Cu	0.02	1.1	0.13	<0.02	0.62	0.17	3.1	6.9
Zn	0.09	140	17.37	0.03	6.7	1.14	9.6	50.7
Cd	<0.01	0.1	0.02	<0.01	0.08	0.015	0.45	0.01
Pb	<0.04	0.65	0.28	<0.04	1.9	0.2	0.7	12.6
As	<0.001	0.148	0.024	<0.001	0.485	0.034	-	-
Hg	<0.0001	0.0015	0.0004	<0.0001	0.0008	0.0002	-	-

Results of conventional statistical analysis for the complete set of monthly average leachate parameters in the T Valley were presented in Table 4.5. Table 4.6 and

Table 4.7 also present the same results for the pre- and post-closure periods of the T Valley, respectively. Table 4.8 presents the statistical evaluation results of the Main Valley. These results are useful in the comparison of leachate parameters for pre- and post-closure periods in a landfill and for open and closed landfills in the same area. In the following sections, such comparisons for the T and Main Valleys were made using the results of conventional statistical evaluation.

4.2.1.1. Mean and Range for Leachate Parameters

Mean and range values of the leachate parameters were discussed in this section in order to characterize fresh and old leachates from the T and Main Valleys, respectively (see Tables 4.5-4.8).

4.2.1.1.1. BOD – COD – BOD/COD Ratio

BOD and COD are organic indicators for the waste stabilization and reflect the biodegradation and wash out of organic materials in the landfill. Organic compounds in leachate decrease more rapidly than the inorganic compounds due to the readily biodegradable nature of the organics.

Figure 4.3 shows the monthly average BOD and COD variations between February 1997 and August 2004 in the T Valley. The average of monthly BOD for pre-closure and post-closure periods of the T Valley was 16,773 mg/l and 538 mg/l, respectively. The average COD concentrations were 25,482 and 3637 mg/l for the pre- and post- closure periods of the T Valley, respectively. The average BOD was 7615 mg/l and COD was 13159 mg/l for all monitoring period including pre- and post-closure periods (see Tables 4.5-4.7).

Table 4.5. Results of conventional statistical analysis for T Valley

Parameter	Number of measurements	Mean	Median	Mode	Range	Standard Deviation	Coefficient of Variation	Standardized Skewness
BOD_5	78	7615	400	-	58-32750	9701	1.27	3.65
COD	78	13159	4815	-	590-42588	13004	0.99	3.46
pH	76	7.8	7.8	7.9	6.8-8.7	0.5	5.83	-0.35
Total Alk.$CaCO_3$)	44	10795	11600	-	3020-15800	3411	0.32	-1.78
NH_4-N	47	1255	1397	-	32-2715	881	0.70	0.08
Total N	44	3545	3725	5100	26-5660	1154	0.33	-2.40
Total P	75	22.4	21.4	25.4	5.0-67.5	11.7	0.52	5.00
EC (mS/cm)	51	63.7	34.8	33.4	4.8-655.3	124.5	195.3	11.5
Fe	78	31.5	12.8	-	1.9-238.7	45.9	1.46	10.1
Zn	76	23.9	14.9	-	1.2-180	29.7	1.24	10.77
Pb	76	9.2	1.2	-	0.04-106.4	20.4	2.23	11.8
Cu	78	7.8	5.3	-	0.1-29.0	6.7	0.86	3.42
Cr^{6+}	78	4.7	3.4	-	0.2-20.6	4.1	0.87	5.12
Total CrO_4	73	5.3	3.8	2.6	0.3-21.9	4.5	0.84	4.76
CN^-	76	1.9	0.9	-	0.1-13.6	2.4	1.26	9.40
F	76	4.0	1.5	0.0	0.0-27.5	5.9	1.49	8.07
Cl	23	3378	3257	-	816-5450	1252	0.37	-0.33
SO_4	44	332	290	-	120-920	174	0.53	4.53
S^{2-}	44	0.5	0.4	0.4	0.1-1.0	0.2	0.50	1.90
Flow Rate(l/s)	19	0.4	0.2	-	0.1-1.0	0.4	1.07	2.50
SS	59	936	660	-	107-2768	700	0.75	3.31

Table 4.6. Results of conventional statistical analysis for T Valley (Pre-Closure Period)

Parameter	Number of measurements	Mean	Median	Mode	Range	Standard Deviation	Coefficient of Variation	Standardized Skewness
BOD_5	34	16773	15661	-	3189-32750	7914	0.47	0.53
COD	34	25482	23971	21200	7410-42588	10508	0.41	0.14
pH	32	7.4	7.3	-	6.8-8.1	0.3	0.04	1.21
Total Alk.($CaCO_3$)	-	-	-	-	-	-	-	-
NH_4-N	3	146	54	-	40-343	171	1.17	1.22
Total N	-	-	-	-	-	-	-	-
Total P	31	26.1	20.6	-	12.4-67.5	14.1	0.54	3.65
EC (mS/cm)	7	255.9	55.5	-	4.8-655.3	0.1	1.09	0.55
Fe	34	61.7	35	35	13.8-238.7	56.8	0.92	4.35
Zn	32	43.6	30.8	-	12.6-180	37.4	0.86	4.88
Pb	32	20.8	9.2	-	0.3-106.4	27.8	1.33	4.50
Cu	34	14	14.4	-	5.7-29	5.4	0.39	1.66
Cr^{6+}	34	7.6	6.5	-	2.8-20.6	3.6	0.48	3.56
Total CrO_4	29	8.7	8.1	4.8	3.2-21.9	4.0	0.46	2.79
CN^-	32	3.7	2.2	2.2	0.5-13.6	3.0	0.81	4.07
F	32	7.8	4.8	-	0-27.5	7.5	0.96	2.44
Cl	3	2663	2482	-	2224-3284	552.8	0.21	0.93
SO_4	-	-	-	-	-	-	-	-
S^{2-}	-	-	-	-	-	-	-	-
Flow Rate (l/s)	3	1.1	1.1	-	1-1.2	0.1	0.07	-0.41
SS	14	1871	1763	-	1135-2768	573	0.31	0.63

Table 4.7. Results of conventional statistical analysis for T Valley (Post-Closure Period)

Parameter	Number of measurements	Mean	Median	Mode	Range	Standard Deviation	Coefficient of Variation	Standardized Skewness
BOD_5	44	538	228	-	58-11428	1703	3.16	17.27
COD	44	3637	3428	-	590-16609	2282	0.63	11.75
pH	44	8.1	8.0	-	7.5-8.9	0.3	0.03	0.39
Total Alk.($CaCO_3$)	44	10795	11600		3020-15800	3411	0.32	-1.78
NH_4-N	44	1331	1447	-	32-2715	859	0.65	-0.22
Total N	44	3545	3725	5100	26-660	1154	0.33	-2.40
Total P	44	19.8	22.1	-	5.0-36.0	8.8	0.45	-0.58
EC (mS/cm)	44	33.2	33.9	33.4	8.1-62.8	10.5	0.32	-0.21
Fe	44	8.1	7.3	8.8	1.9-25.9	3.9	0.48	6.43
Zn	44	9.6	7.3	-	1.2-32.5	6.2	0.65	3.32
Pb	44	0.7	0.6	-	0.04-1.8	0.5	0.75	1.70
Cu	44	3.1	3.0	-	0.1-10.9	2.3	0.76	2.00
Cr^{6+}	44	2.4	2.0	-	0.2-15.9	2.8	1.13	9.43
Total CrO_4	44	3.1	2.6	2.6	0.3-16.8	3.1	10.1	8.22
CN^-	44	0.7	0.6	-	0.1-2.5	0.5	0.67	5.16
F	44	1.1	1.0	0.0	0.0-3.9	0.9	0.76	3.69
Cl	20	3484	3371	-	816-5450	1300	0.37	-0.71
SO_4	44	332	290	-	120-920	174	0.53	4.53
S^{2-}	44	0.5	0.4	0.4	0.1-1.0	0.2	0.50	1.90
Flow Rate(l/s)	16	0.2	0.2	-	0.1-1.0	0.2	1.01	4.98
SS	44	639	559	-	107-1990	419	0.66	3.36

Table 4.8. Results of conventional statistical analysis for Main Valley

Parameter	Number of measurements	Mean	Median	Mode	Range	Standard Deviation	Coefficient of Variation	Standardized Skewness
BOD_5	47	22165	18768		6950-50150	10366	0.47	2.13
COD	47	36339	35064		12548-63325	13946	0.38	0.60
pH	47	6.8	6.7	6.7	6.2-7.8	0.4	0.06	0.75
Total Alk. ($CaCO_3$)	46	8998	9098	12100	5120-12950	2253	0.25	-0.15
NH_4-N	45	1369	1286		115-2908	731	0.53	0.61
Total N	46	3401	3708		697-6090	1248	0.37	-0.75
Total P	47	29.4	23.9		7.9-167.6	24.3	0.83	11.76
EC (mS/cm)	47	42.5	42		24.5-58.2	8.2	0.19	-0.22
Fe	47	96.1	47.5		1.2-307.8	104	1.08	2.93
Zn	47	50.7	53.5		6.7-91.9	25.4	0.50	-1.18
Pb	47	12.6	9		1.1-48	11.6	0.93	4.61
Cu	47	6.9	8.1	9.7	0-16.1	4.6	0.66	-0.94
Cr^{6+}	47	7.4	8.1		0.2-19.6	4.8	0.66	0.80
Total CrO_4	46	9.2	10		0.2-22.9	5.6	0.61	0.02
CN^-	47	1.4	1.4	1.2	0.3-2.9	0.7	0.47	0.67
F	47	14.1	10	12.2	0.2-59.4	15.9	1.13	4.53
Cl	21	4217	4440		1552-6730	1309	0.31	-0.38
SO_4	46	906	963		245-1595	394	0.43	-0.10
S^{2-}	46	0.4	0.4		0.1-0.8	0.2	0.39	0.01
Flow Rate(l/s)	17	2.5	2.5	2.6	1.7-4.0	0.5	0.21	2.08
SS	47	2185	2315	1825	762-3394	657	0.30	-0.50

After 48 months of operation, the T Valley closed, and BOD and COD concentrations decreased significantly after this time. However, due to the emergency waste disposal in July 2002, when the T Valley had been closed for about 2 years, a sharp increase in BOD and COD concentrations was observed at this time. Such sudden variations in leachate indicated the acidogenic conditions in leachate quality due to fresh waste deposition over the closed landfill. BOD and COD concentration seemed to be constant after 50 months, about 4 years, from the beginning of the biodegradation process in the T Valley. Figure 4.4 shows BOD and COD fluctuations in the Main Valley between October 2000 and August 2004. Monthly average BOD ranged between 6,950 mg/l and 50,150 mg/l, and COD was between 12,548 and 63,325 mg/l in this valley. Average BOD and COD over the monitoring period in the Main Valley were 22,165 mg/l and 36,339 mg/l, respectively (see Table 4.8).

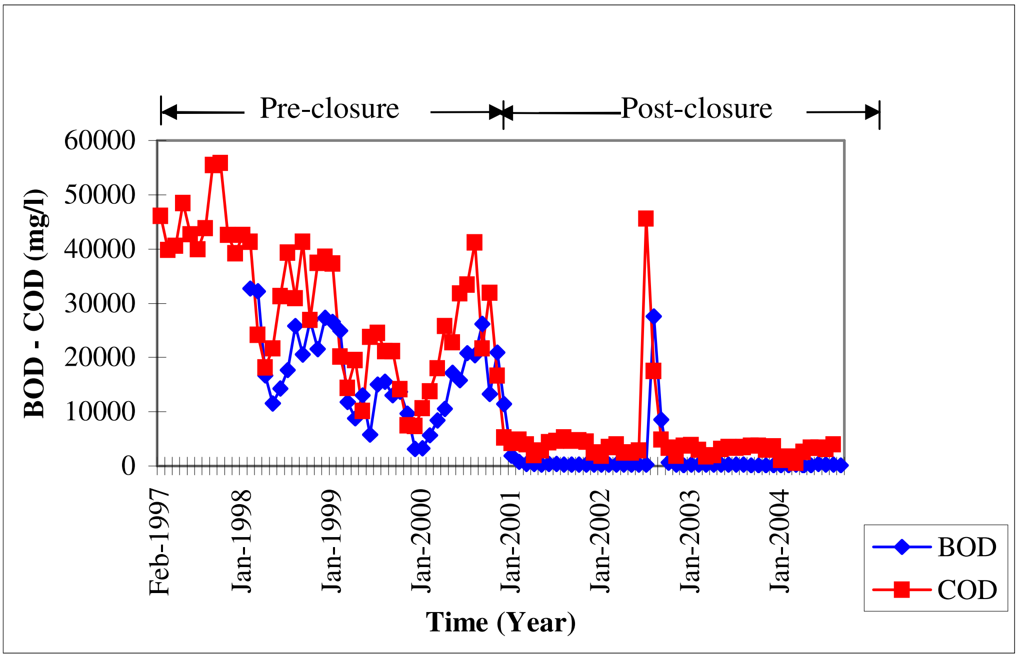


Figure 4.3. Monthly BOD-COD variations in the T Valley
(February 1997-August 2004)

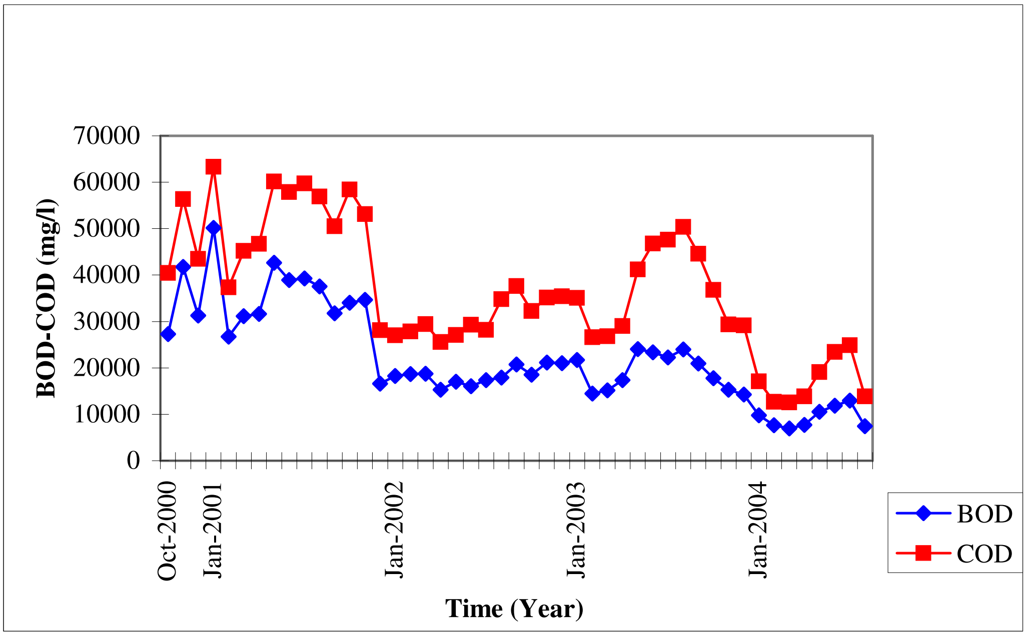


Figure 4.4. Monthly BOD-COD variations in the Main Valley (October 2000-August 2004)

Central tendency values including mean, median and mode for BOD and COD concentrations in the open Main Valley were higher than the concentrations in the T Valley. It is clearly shown that fresh leachate is generally characterized by higher organic content. Organic concentrations decreased with the age in both the T Valley, which includes pre- and post-closure periods, and in the Main Valley. The values for average BOD and COD were consistent with the literature (see table 2.6). The inspection of changes in organic concentrations makes it possible to observe the transition of the landfill from acidogenic to methanogenic condition. Acid formation phase lasts up to 5 years from the initial waste placement and transition from the acid formation phase to the methanogenic phase takes 4 to 10 years. (Kruempelbeck and Ehrig, 1999; Armstrong and Rowe, 1999; Reinhart and Grosh, 1998).

Use of some indicator ratios to observe the decomposition stage of the landfills would be more descriptive (Tatsi and Zouboulis, 2002), because pollutant concentrations change extensively even in short time periods. There are several indicator ratios used for this purpose including BOD/COD, COD/TOC, VOA/TOC, VS/TS and SO_4^{2-}/Cl^-, COD/DOC, TKN/COD, VFA/COD, NH_3/TKN that are related with the landfill age (Reinhart and Grosh, 1998; Tatsi and Zouboulis, 2002; Armstrong and Rowe, 1999; Urbini et al., 1999). In this study, based on available data, BOD/COD ratio was used to examine the degree of waste stabilization in Bursa MSWL. The ratio decreased with the age of the landfill for both valleys. A low BOD/COD ratio is an indication of low concentration of volatile fatty acids (VFA) and relatively higher amounts of humic and fulvic-like compounds (Kjeldsen et al., 2002).

Monthly BOD/COD ratio was in the range of 0.02 and 0.80 with an average value of 0.33 in the T Valley. After the closure of this valley, there was a sudden decrease in the ratio (see Figure 4.5). However, this ratio increased with the disposal of fresh waste after the closure of the valley. BOD/COD ratio remained nearly constant after December 2000, except the emergency waste disposal.

Monthly BOD/COD ratio variations in the Main Valley were presented in Figure 4.6. This ratio was ranging between 0.47 and 0.79 with an average of 0.60 in this valley. It was seen that the Main Valley had been in the acidogenic stage by the end of August 2004.

Monthly BOD/COD ratio was higher in the Main Valley than in the T Valley due to the fresh waste deposition. BOD/COD ratio in the T Valley reached a steady-state after December 2000 with a value of about 0.1, excluding the period of emergency waste disposal. The acidogenic phase lasted about 4 years in the T Valley. BOD/COD ratio in the Main Valley was still high in August 2004 with a value of about 0.5-0.6 due to acidogenic conditions.

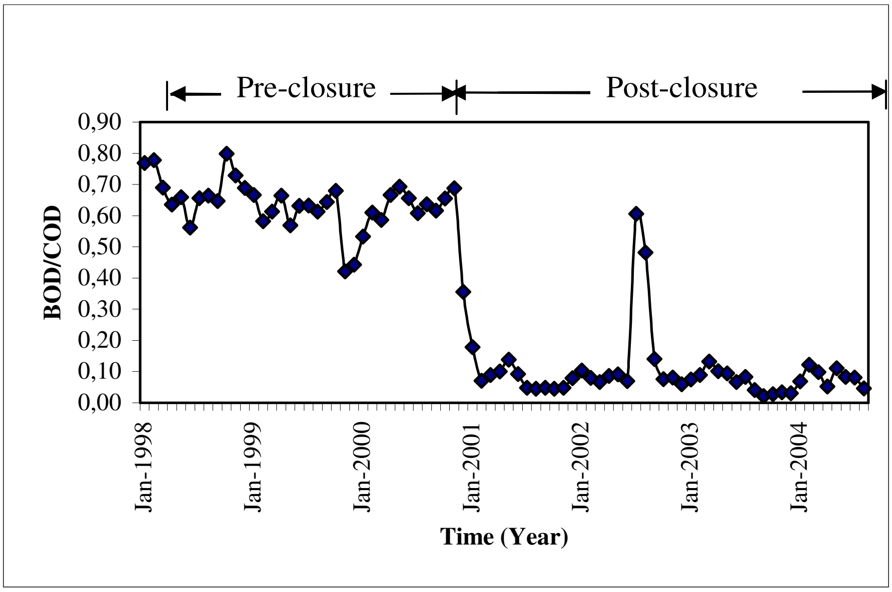


Figure 4.5. Monthly BOD/COD variations in the T Valley

(January 1998-August 2004)

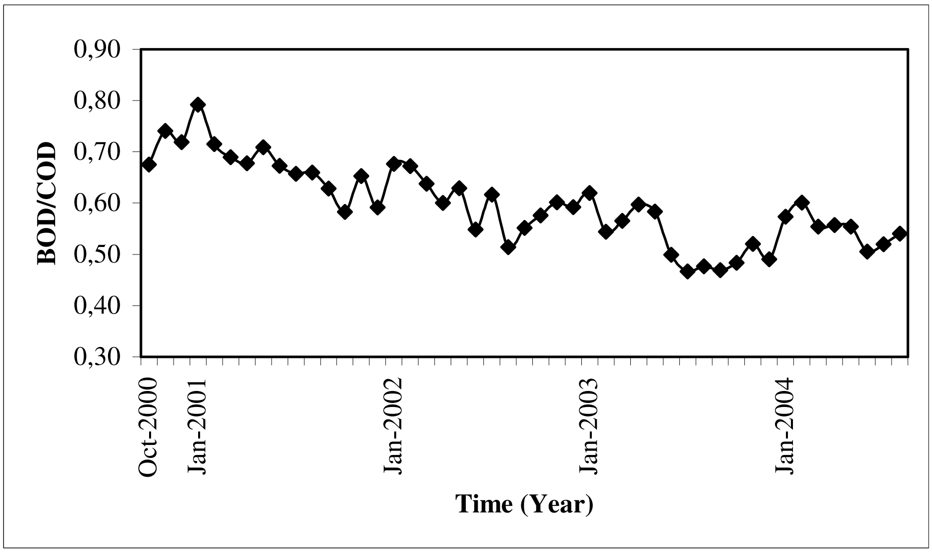


Figure 4.6. Monthly BOD/COD variations in the Main Valley

(October 2000-August 2004)

4.2.1.1.2. pH

Figure 4.7 demonstrates the monthly average values of pH in the T Valley. pH had several cycles and seasonal variations over the monitoring period due to fresh waste disposal at the bottom of the valley. The monthly average pH values for pre- and post- closure periods in the T Valley were 7.4 and 8.1, respectively. Monthly average pH values varied between 6.8 and 8.7 with an average of 7.8 in the T Valley, including both pre- and post- closure periods (see Tables 4.5-4.7). pH showed a sudden decrease after the closure of the valley due to the emergency waste disposal on the closed landfill in July 2002.

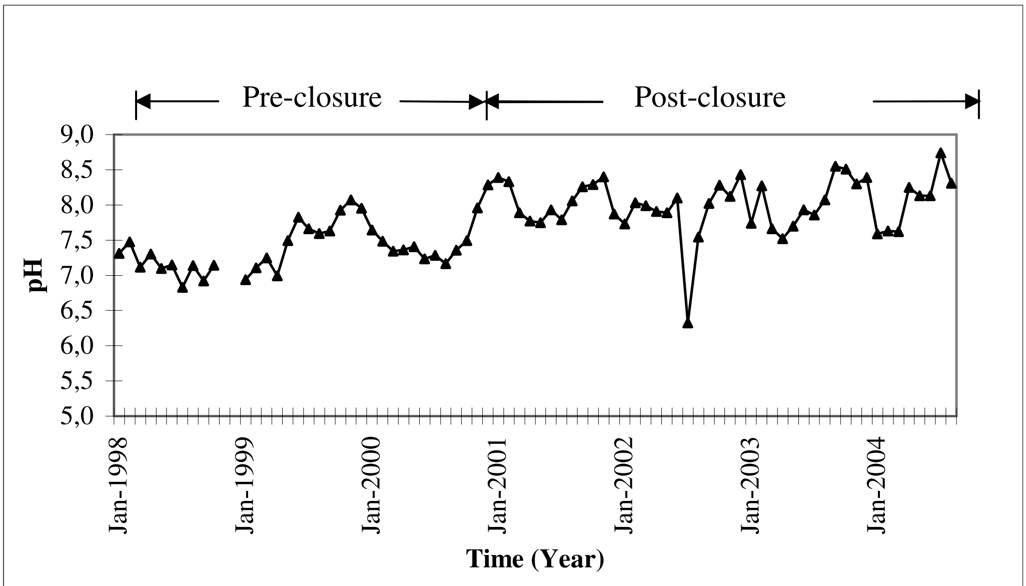


Figure 4.7. Monthly pH variations in the T Valley (January 1998-August 2004)

The average monthly values of pH in the Main Valley were presented in Figure 4.8. pH values varied between 6.2 and 7.8 with an average of 6.8 in this valley (see Table 4.8).

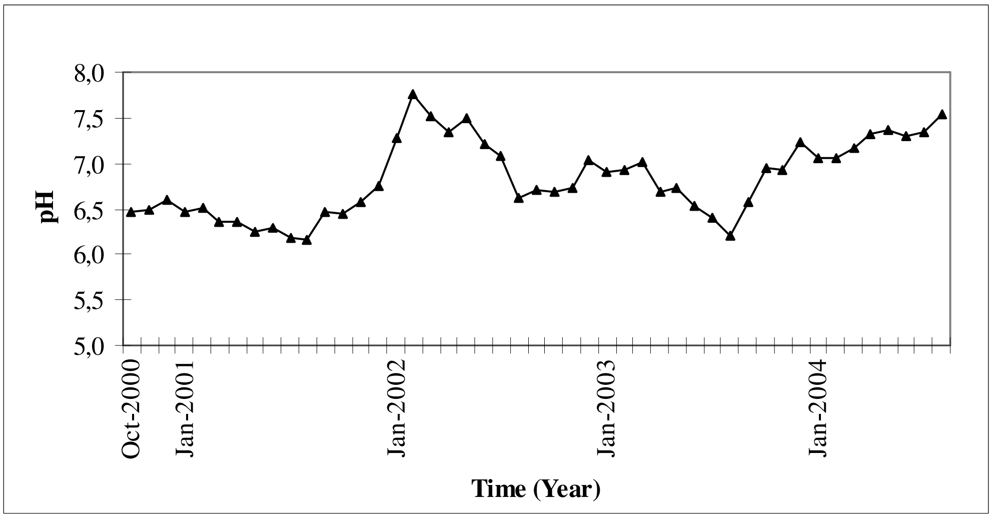


Figure 4.8. Monthly pH variations in the Main Valley (October 2000-August 2004)

pH had an increasing trend with time in both valleys, because in the first months of landfill deposition, acidogenic decomposition proceeds, during which VOA concentrations are high. The average pH value was smaller in the Main Valley than the T Valley. The average value of pH is in the methanogenic stage in the T Valley, while in the acidogenic stage in the Main Valley.

4.2.1.1.3. Nutrients (NH_4-N, Total N, Total P)

Ammonia is produced by decomposition of nitrogeneous substances in the waste. Ammonia is the primary cause of acute toxicity in municipal landfill leachate and ammoniacal nitrogen from the landfills containing degradable waste has the potential to act as a significant environmental problem. Ammonia is generally at high levels in leachate and is the most frequent groundwater pollutant (Slack et al., 2004; Kjeldsen et al., 2002). NH_4-N and total N variations in the T and Main Valley were presented in Figure 4.9 and Figure 4.10.

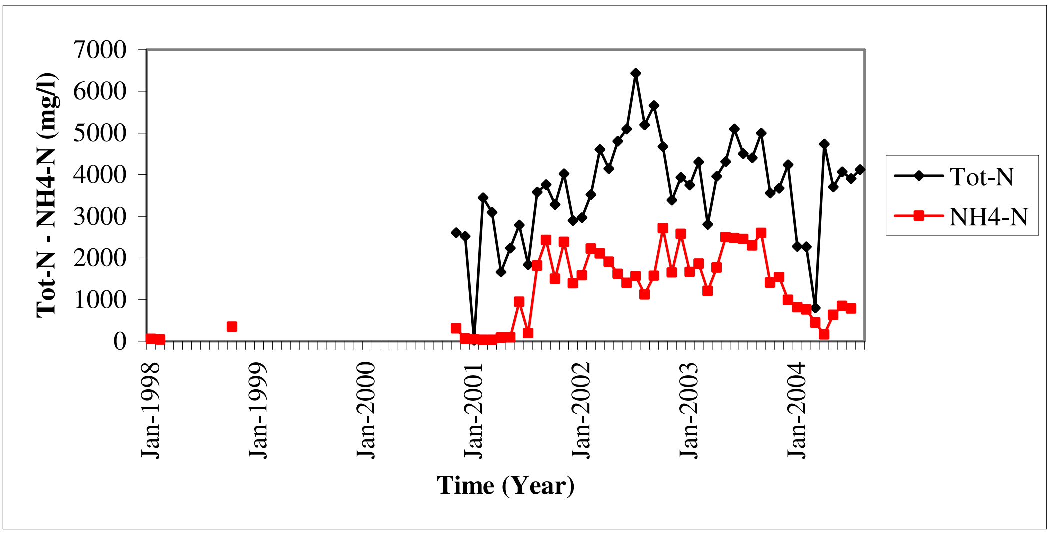


Figure 4.9. Monthly NH_4-N and total N variations in the T Valley (January 1998-August 2004)

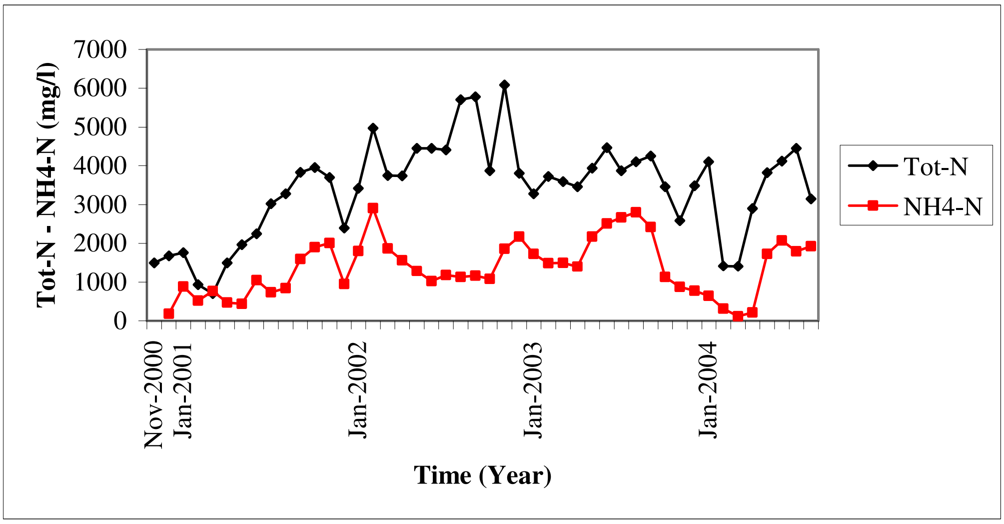


Figure 4.10. Monthly NH_4-N and total N Variations in the Main Valley (November 2000-August 2004)

There was no NH_4-N and total N measurement in the first 4 year of the operation in the T Valley. For the following years, average monthly NH_4-N had minimum and maximum concentrations of 32 and 2,715 mg/l, respectively, with an average value of 1,255 mg/l in this valley. Total N ranged from 26 to 5,660 mg/l with an average of 3,545 mg/l in the T Valley (see Table 4.5). NH_4-N and total N had several peaks during measurement period in the T Valley. During the period from February 2002 to July 2002 NH_4-N had a decreasing trend, whereas, tot-N had an increasing trend. NH_4-N concentration reached its peak value with the emergency waste disposal in July 2002, while total N concentration reached its peak value 3 months after this disposal.

NH_4-N concentration was between 114 and 2,907 mg/l with an average value of 1,369 mg/l in the Main Valley. Total N varied between 697 and 6,090 mg/l with an average of 3,401 mg/l (see Table 4.8). NH_4-N and total N also had several peaks in the Main Valley. During the period, covering from April 2002 to September 2002, NH_4-N had an increasing trend, while, total N had a slowly decreasing trend.

NH_4-N and Tot-N concentrations did not show a decreasing trend with landfill age in the T and Main Valley. NH_4-N and total N concentrations usually showed similar trends over measurement periods in each valley. The average monthly NH_4-N and tot-N concentrations for the closed T valley and open Main Valley were close to each other.

Total P variations in the T Valley were presented in Figure 4.11. The average of monthly total P concentration was 26.1 mg/l and 19.8 mg/l for the pre- and post-closure periods of the T Valley, respectively. The monthly total P ranged between 5.0 and 67.5 mg/l with an average of 22.4 mg/l in the T Valley, including both pre- and post- closure periods (see Tables 4.5-4.7). There was no a clear trend in total P concentrations during the measurement period. Total P concentration had several peaks in this valley during the measurement period. One of the peaks corresponded to September 2000, one month before the closure of the valley, and other peak corresponds to emergency waste disposal in July 2002.

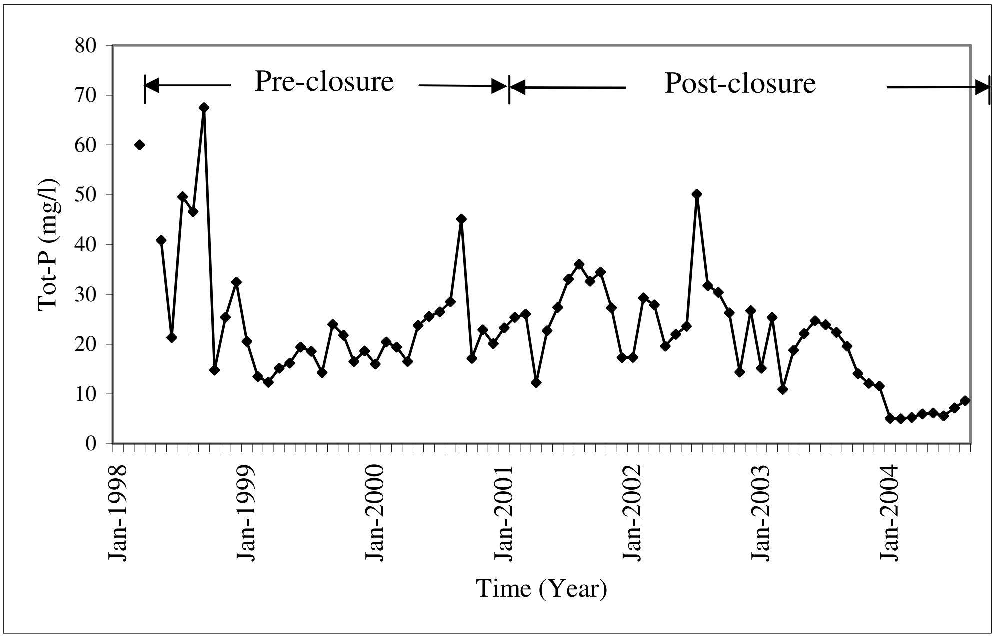


Figure 4.11. Monthly Total P variations in the T Valley
(January 1998-August 2004)

Figure 4.12 shows total P variations in the Main Valley. The monthly total P concentration in this valley was in the range of 7.9-167.60 mg/l with an average of 29.4 mg/l (see Table 4.8). It generally showed a smooth trend with the landfill age, except for June 2002, when there was a sudden increase in total P concentration most likely due to fresh waste disposal over the bottom of the valley. The average concentrations of total phosphorus were similar in both closed T Valley and open Main Valley.

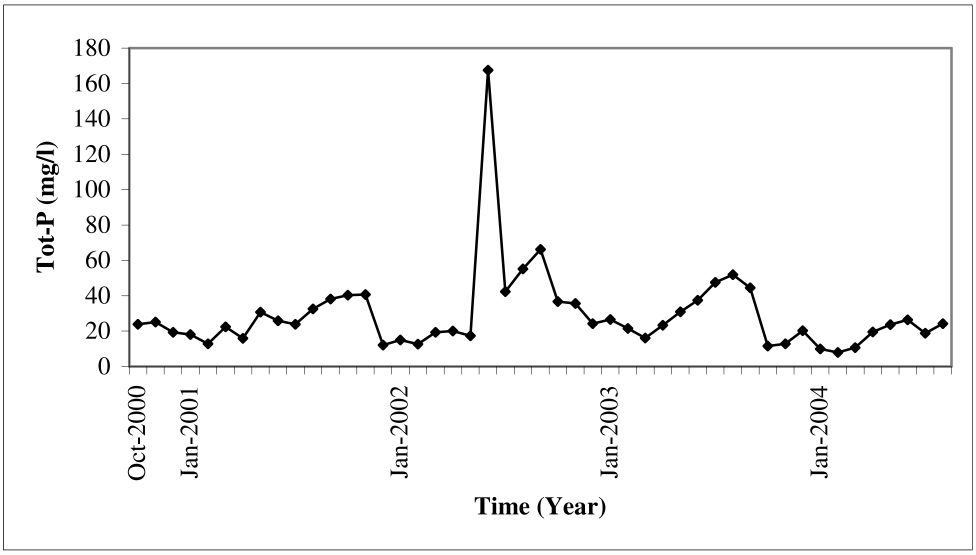


Figure 4.12. Monthly Total P variations in the Main Valley
(October 2000-August 2004)

4.2.1.1.4. Total Alkalinity

Figure 4.12 shows total alkalinity variations in the T Valley. There was no total alkalinity measurement for the first 4 year of the operation in the T Valley. Total alkalinity did not show a specific trend for the following years, which corresponds to post-closure period of the T Valley. The monthly total alkalinity values as $CaCO_3$ were between 3,020 and 15,800 mg/l with an average of 10,795 mg/l in the T Valley (see Table 4.5).

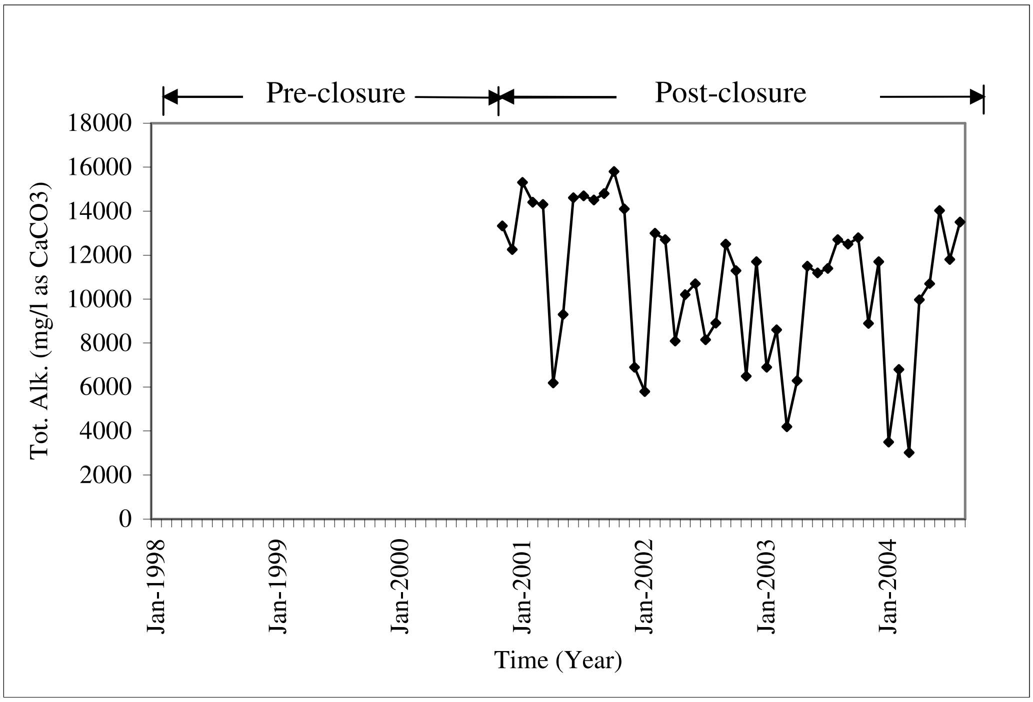


Figure 4.13. Monthly total alkalinity variations in the T Valley (January 1998-August 2004)

Figure 4.14 presents total alkalinity variations in the Main Valley. Total alkalinity concentration was in the range of 5,120-12,950 mg/l with an average of 8,998 mg/l in the Main Valley (see Table 4.8).

The average of monthly total alkalinity values had several peaks and did not demonstrate a specific trend during the measurement periods in both valleys. The average total alkalinity was higher for the T Valley due to methanogenic conditions and high pH values.

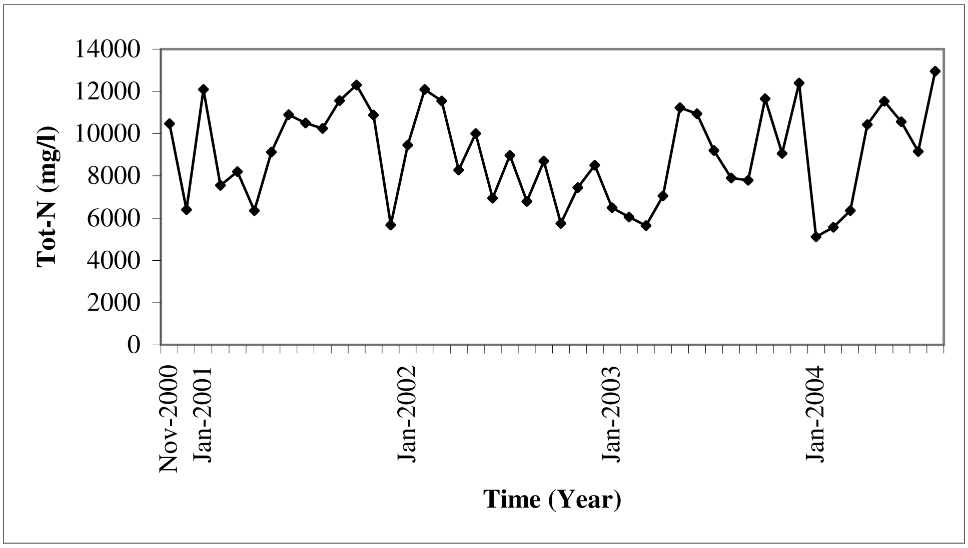


Figure 4.14. Monthly total alkalinity variations in the Main Valley (November 2000-August 2004)

4.2.1.1.5. $SO_4 – S^{2-}$

SO_4 concentration is expected to decrease with time in the landfill due to the reduction of SO_4 to SO_2 by bacteria under anaerobic conditions. It is used as an electron acceptor during the oxidation process of organics and decreases with time (Manahan, 1993).

The average monthly SO_4 concentrations in the T Valley were presented in Figure 4.15. SO_4 measurement started after the first 4 year of the operation i.e. during the post-closure period in the T Valley. The monthly SO_4 concentration varied in the range of 120-920 mg/l with an average of 331.5 mg/l in the T Valley during the measurement period (see Table 4.5). There were two distinct peaks in SO_4 during the measurement period in this valley. One of the peaks in SO_4 concentration was in July 2002 due to emergency disposal of fresh waste into the T Valley and November 2003.

The variations in the average monthly SO_4 concentration in the Main Valley were shown in Figure 4.16. Monthly SO_4 concentration was in the range of 240 and 1,595 mg/l with an average of 906 mg/l (see Table 4.8). There was no clear trend for SO_4 concentration, while it showed fluctuations over time in both valleys.

The average monthly SO_4 concentration was higher in the Main Valley than in the T Valley due to placement of fresh waste and prevailing aerobic conditions in the Main Valley.

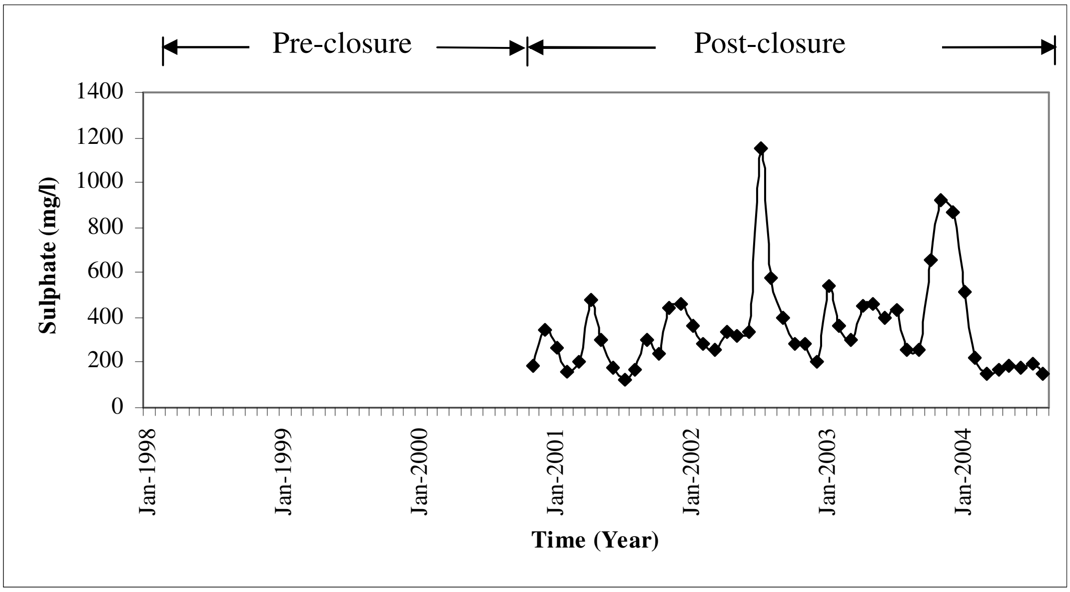


Figure 4.15. Monthly SO_4 variations in the T Valley (January 1998-August 2004)

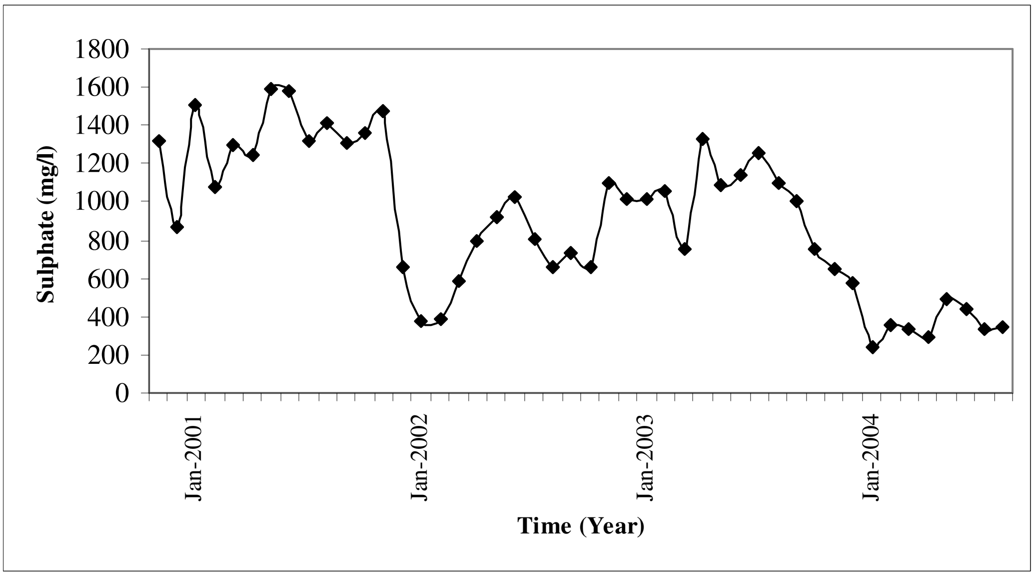


Figure 4.16. Monthly SO_4 variations in the Main Valley
(November 2000-August 2004)

4.2.1.1.6. Total CrO_4

Total CrO_4 variations in the T and Main Valleys were presented in Figures 4.17-4.18. The average of monthly total CrO_4 in the pre- and post- closure periods of the T Valley were 8.7 mg/l and 3.1 mg/l, respectively (see Tables 4.6-4.7). It reached its peak value in October 2000, the last month of the operation in the T Valley. Total CrO_4 concentration decreased after this time except for the period of the emergency waste disposal in June 2002.

Monthly total CrO_4 concentration was 5.5 mg/l in the closed T Valley and 9.2 mg/l in the open Main Valley (see Table 4.8). It decreased with waste age and had a nearly constant value during 2004 in both valleys.

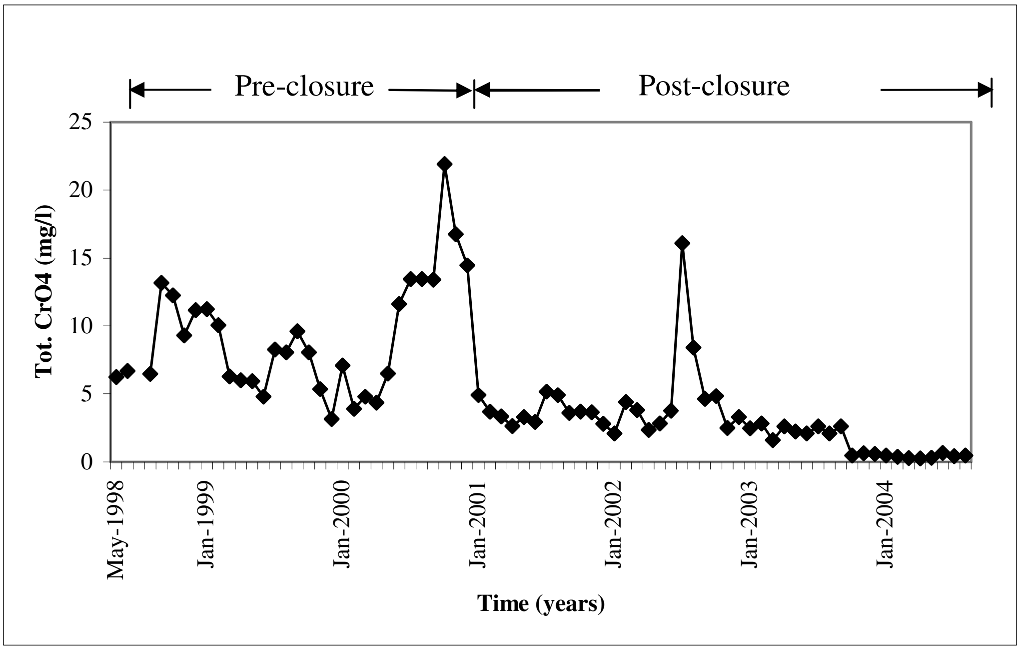


Figure 4.17. Monthly total CrO_4 variations in the T Valley
(May 1998-August 2004)

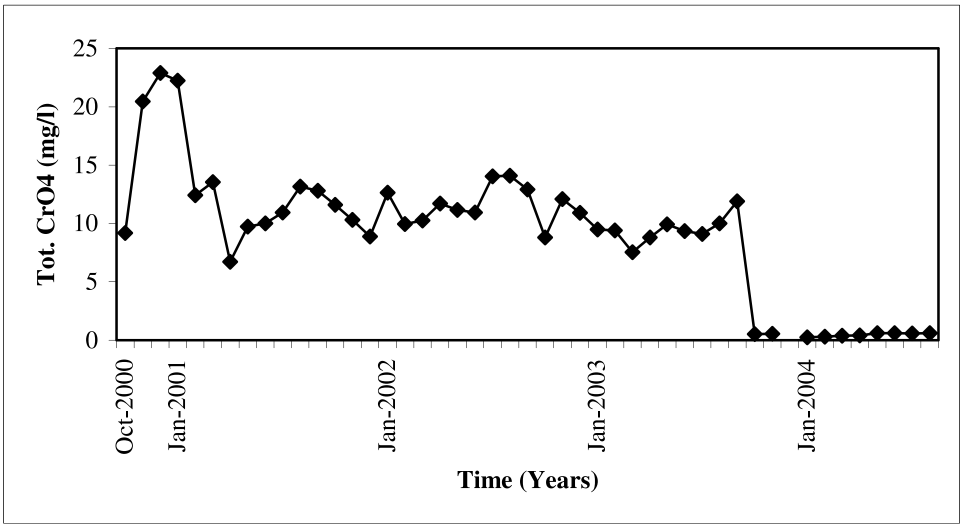


Figure 4.18. Monthly total CrO_4 variations in the Main Valley
(October 2000-August 2004)

4.2.1.1.7. Electrical Conductivity – SS – Cl

Electrical conductivity is an indication for the total dissolved ions content of a solution. The high values of leachate conductivity are the indicator for the large content of soluble inorganics in leachate. The primary metals contributing the conductivity are calcium, magnesium, sodium and potassium (Reinhart and Grosh, 1998).

The average electrical conductivity values for pre- and post-closure periods of the T Valley were 255.8 mS/cm and 33.2 mS/cm, respectively. The average monthly electrical conductivity values in the T Valley fluctuated in a wide range between 4.8 and 655.3 with an average of 63.7 mS/cm for all monitoring period in the T Valley (see Tables 4.5-4.7).

In the Main Valley, monthly average electrical conductivity values varied between 24.5 and 58.23 mS/cm with an average value of 42.5 mS/cm (see Table 4.8). The closed T Valley, covering both pre- and post- closure periods, had higher electrical conductivity values than the Main Valley. Electrical conductivity increased with the age of the landfill.

The suspended solids indicate the presence of inorganic and organic solids in leachate. Monthly average SS concentrations for the pre-closure and post-closure periods of the T Valley were 1,871 mg/l and 639 mg/l, respectively. The overall range for SS, including pre- and post- closure periods, was 107-2,768 mg/l with an average of 936 mg/l (see Tables 4.5-4.7).

In the Main Valley, SS concentration ranged between 762 and 3,394 mg/l with an average of 2,185 mg/l. The average of SS was higher in the Main Valley than in the T Valley (see Table 4.8).

Cl is not degraded and precipitated in the landfill and only diluted by water. Its concentration decreases with the landfill age due to the leaching and dilution (Rowe, 1995). Available data covered the first 3 months of 1998 and the time period from January 2003 to August 2004 and in for the T Valley. The average monthly Cl concentrations varied in a wide range between 816 and 5,450 mg/l with an average of 3,378 mg/l during the measurement period of in this valley (see Table 4.5).

Cl measurements covered the time period from December 2002 to August 2004 for the Main Valley. Its concentration fluctuated in the range of 1,552 and 6,730 mg/l with an average of 4,217 mg/l (see Table 4.8).

Measured Cl concentrations were limited for both valleys in order to observe the trend with the age of the landfill. The average of Cl concentrations were in the same order of magnitude in the T and Main Valley.

4.2.1.1.8. CN^-

The sources of CN^- in the waste are pest poisons, fumigants, metal polishes, photographic chemical solutions and mineral processing operations. (Manahan, 1993; Manahan, 2003).

The average monthly CN^- concentration was 3.7 mg/l and 0.7 mg/l for pre- and post- closure periods of the T Valley, respectively. It showed a decreasing trend with the closure of the T Valley. CN^- concentration ranged between 0.1 and 13.6 mg/l with an average of 1.9 mg/l in the T Valley (see Tables 4.5-4.7).

Monthly CN^- concentration was in the range of 0.3 and 2.9 mg/l with an average of 1.4 mg/l in the Main Valley (see Table 4.8).

4.2.1.1.9. Metals

A variety of inorganic components, including heavy metals, present in leachate. Municipal solid waste includes hazardous substances in the form of paints, vehicle maintenance, pharmaceuticals, batteries and other diffuse products (Slack et al., 2004). Heavy metals in leachate are hazardous for the environment and living organisms. Metals, such as lead, mercury and cadmium build up in soil, water and animals. Heavy metals have toxic health effects including carcinogenic, neurological, hepatic, renal and hematopoitic (Williams, 1998). The metals in leachate are present in the form of soluble component or complexation, precipitation, adsorption and corrosion products. Metal concentrations are mainly dependent on pH, flow rate, complexation agents and dissolution rate of inorganics into leachate and dilution rate (Rainhart and Grosh, 1998; Yıldız et al., 2004). Precipitation and sorption processes result in metal solubilization and subsequent low concentrations, while complexation to inorganic and organic ligands and sorption to colloids mobilize the heavy metals by increasing the concentration in the mobile aqueous phase (Kjeldsen et al., 2002). Heavy metals forming sorption and precipitation products cause the metals not to be detected directly as free metals in the leachate and prevent the metals from contaminating the water resources around the landfill.

Figure 4.19 and Figure 4.20 show monthly metal concentration variations in the T and Main Valleys, respectively. Tables 4.5-4.8 were also applied in the evaluation of metals.

<u>Fe:</u>

Main sources of iron in municipal solid waste are durable goods, including appliances, furniture, tires and miscellaneous items such as small appliances (Tchobanoglous and Kreith, 2002).

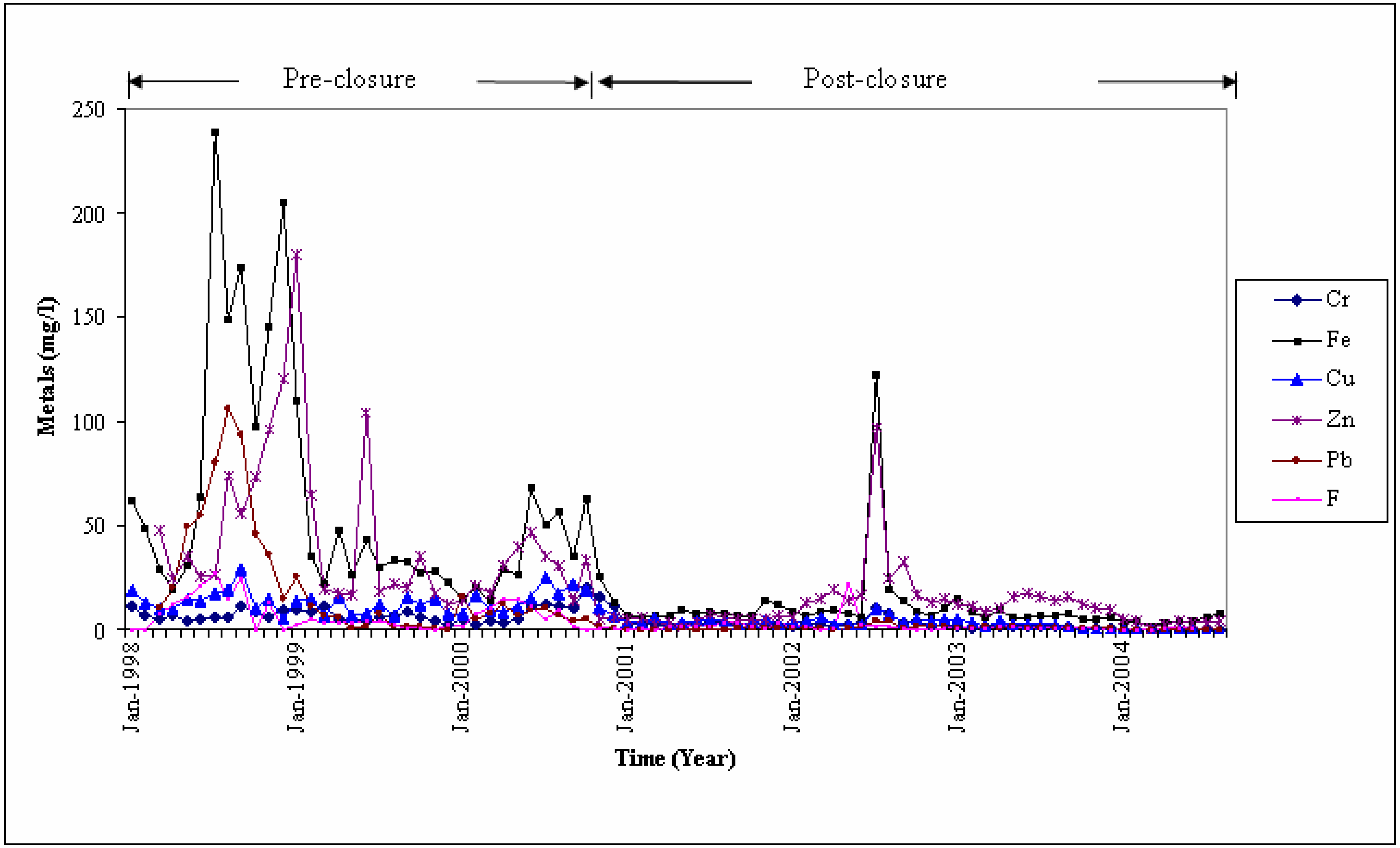


Figure 4.19. Monthly metal variations in the T Valley (January 1998-August 2004)

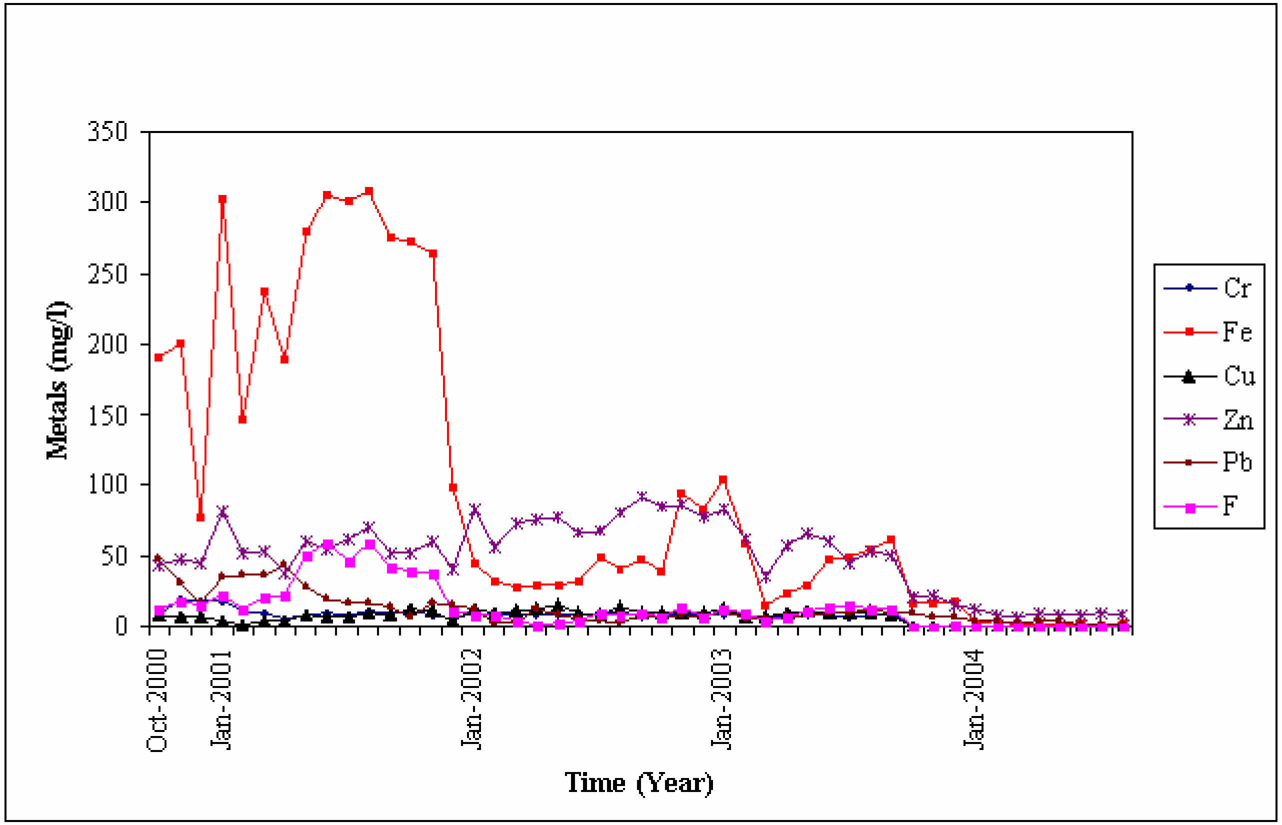


Figure 4.20. Monthly metal variations in the Main Valley (October 2000-August 2004)

The average monthly iron concentrations for the pre- and post- closure periods of the T Valley were 61.7 mg/l and 8.1 mg/l, respectively. Fe concentration decreased with the age of waste. Based on available measurements, Fe concentration ranged between 1.9 and 238.7 mg/l with an average of 31.5 mg/l. A sudden increase was observed after emergency waste disposal in July 2002 due to the fresh waste disposal on the closed T Valley (see Figure 4.19).

The monthly Fe concentration in the Main Valley ranged between 1.2 and 307.8 mg/l with an average of 96.1 mg/l. Fe was the metal having the highest concentration in leachate in both valleys (see Figures 4.19-4.20). Fe concentration showed a decreasing trend in the closed T Valley due to prevailing high pH values with waste age. Fe was lower in the T Valley than in the Main Valley, because the T Valley was more stabilized and pH was higher. Similar observations were also made by Aluko et al. (2003) in a landfill in Ibadan, Nigeria and Çallı et al. (2004) in Odayeri Landfill in İstanbul, Turkey. Its presence in high concentrations causes reddish-brown color in leachate.

Zn:

Zn concentration is the indicator of the durable goods, waste batteries and fluorescent light bulbs in the landfill. It is acutely toxic for the plant and aquatic life (Al-Yaqout and Hamoda, 2003; Tchobanoglous and Kreith, 2002).

The average of monthly Zn concentration was 43.6 mg/l for pre-closure and 9.6 m/l for post-closure period of the T Valley. It decreased with the age of the landfill. The range of Zn concentration based on the all measurement period was between 1.2 mg/l and 180 mg/l with an average of 23.9 mg/l in the T Valley. A sudden increase in Zn concentration was observed after emergency waste disposal in July 2002 due to the fresh waste disposal on the closed T Valley (see Figure 4.19)

The monthly Zn concentration varied between 6.7 mg/l and 92 mg/l with an average of 50.67 mg/l in the Main Valley. The average of monthly Zn was higher in the open Main Valley than in the T Valley. Slack et al. (2004) stated that Zn concentrations are generally orders of magnitude greater than other metals, as in the case of leachate from Bursa MSWL.

Pb:

Possible sources of lead contamination may be durable goods, batteries, photography, old lead-based paints and lead pipes disposed of in the landfill. Lead is toxic to all forms of life and human carcinogen (Al-Yaqout and Hamoda, 2003; Tchobanoglous and Kreith, 2002). It may also result in failure in the hematological system and central nervous system (Williams, 1998).

The average of monthly Pb concentrations was 20.8 mg/l and 0.7 mg/l for the pre- and post- closure periods of the T Valley, respectively. Its concentration decreased with the age of the landfill. Pb concentration ranged between 0.04 mg/l and 106.4 mg/l with an average of 9.2 mg/l in the T Valley for all measurement period.

The monthly Pb concentration was ranged between 1.1 mg/l and 48 mg/l with an average of 12.6 mg/l in the Main Valley. Although not monotonically, Pb showed a decreasing trend with the age of the landfill.

Cr^{6+}:

Chromium is toxic in the +6 oxidation state and commonly called as chromate. The carcinogenicity of chromate was also showed by several studies (Manahan, 2003).

The average of monthly chromium concentrations for the pre- and post- closure periods of the T Valley were 7.6 mg/l and 2.4 mg/l, respectively. Cr^{6+} concentration covering both pre- and post- closure periods was in the range of 0.2-20.6 mg/l with an average of 4.7 mg/l for the T Valley. Its average monthly concentration decreased from 7.5 mg/l in 1998 to 0.3 mg/l in 2004 in the T Valley.

Cr^{6+} concentration was ranged between 0.2-19.6 mg/l with an average of 7.36 mg/l in the Main Valley. The average of monthly Cr^{6+} concentration decreased from 15.8 mg/l to 0.3 mg/l within the first 4 years of the operation in the Main Valley.

Monthly Cr^{6+} concentrations in Bursa MSWL were less than the average literature values shown in Table 2.6. This low concentration may be attributed to the differences in the waste compositions in different landfills.

Cu:

Major sources of copper are durable goods including appliances. Copper is also a toxic substance for the aquatic life (Tchobanoglous and Kreith, 2002).

The average of monthly Cu concentrations for pre- and post- closure periods in the T Valley were 14 mg/l and 3.1 mg/l, respectively, showing a decreasing trend with the age of the waste. It ranged between 0.1 and 29.0 mg/l with an average of 7.8 mg/l in the T Valley for the entire measurement period.

Monthly Cu concentrations varied in the range of 0.04 and 16.1 mg/l with an average of 6.9 mg/l in the Main Valley. The average monthly Cu concentrations in the closed T Valley and open Main Valley were more or less the same.

Cd:

Cadmium is caused by batteries, inks, paints, appliances and some plastics in the waste (Tchobanoglous and Kreith, 2002; Manahan, 2003). Cadmium is one of the most poisoned heavy metals along with mercury and lead. It is carcinogenic and represents a health risk by accumulating in living tissue resulting in respiratory illnesses, kidney damage, and hypertension and in some extreme cases damage to bones and joints (Williams, 1998).

Monthly cadmium concentration in both valleys was generally below 0.25 mg/l and poses little threat for groundwater pollution (see Appendix B-Table B.1-B.2).

4.2.1.1.10. Overall Evaluation of Metals in Leachate

Metal concentrations in Bursa MSWL showed fluctuations during the monitoring period for both open and the closed valleys. Frascari et al. (2004) also reported that heavy metal concentrations show wide fluctuations and not have any clear long term trend for the Tre Monti site, Northern Italy. In both the T and Main Valleys, some metals were present with relatively high concentrations e.g., Fe, Zn and Pb. Cd and Cr^{6+} concentrations were relatively low in both valleys. Metals in leachate are mainly dependent on the solid waste characteristics disposed of and decomposition stages in the landfill. Acidic conditions in the first years of the landfill operation in Bursa MSWL resulted in metal solubility from wastes. Therefore, metal concentrations were generally high during the initial years of landfill operation. Metal content decreases from acidic to methanogenic phases mainly due to adsorption and precipitation reactions by co-existing sulphide, carbonate or hydroxide ions. Metal concentrations showed an obvious decreasing trend and remained nearly constant after the closure of the T Valley. However, concentrations generally increased with the unexpected fresh waste disposal after the closure of the valley. Average metal concentrations in the Main Valley were generally higher than that of the T Valley, because the Main Valley was an open valley and fresh waste resulted in higher metal solubilization due to the acidic conditions. Wastewater treatment sludge disposed of in Bursa MSWL may also contribute to the metal content of leachate. Sludge includes Zn, Mn, Cu, Ni, Pb, Cd, Cr^{6+} and therefore increases the toxicity of leachate (Robinson et al., 2005; Fjallborg et al., 2004; Poulsen, 2003). The average concentrations of metals in

Bursa MSWL except Cr^{6+} and Cd were consistent with the values reported in literature (see Table 2.6).

As explained before, leachate quality composition demonstrated extensive variation for closed and open valleys (T and Main Valleys) in the same landfill area. Pre- and post- closure leachate composition differed greatly for the T Valley due to the stabilization of waste with the age of the landfill. Generally, leachate quality parameters had higher concentrations for fresh leachate and decreased with the age of the landfill.

4.2.1.1.11. Comparison of Bursa MSWL with Kömürcüada Landfill

Bursa MSWL (T and Main Valleys) and Kömürcüada Landfill in İstanbul (Çallı et al., 2004) were compared in order to observe the effects of similar types of wastes and climatological conditions in the same country (see Table 4.9). The solid waste composition in İstanbul consists of 80.53 % food remains, 1.29 % ashes and residuals, and 18.18 % recyclables during summer season, whereas, includes 43.59 % food remains, 47.69 % ashes and residuals, and 8.77 % recyclables during winter (Atabarut, 2000). The solid waste composition in İstanbul was similar to the solid waste in Bursa (see Table 3.5) except the food remains and ashes and residuals during winter season. The T Valley was closed and 8 years old, and the Main Valley was open and 4 years old, when the leachate quality data were analyzed. Kömürcüada Landfill is currently open and has been operating since 1995. Leachate quality data of Kömürcüada Landfill covered the time period between July 1998 and June 2001 when the landfill was 6 years old. Average BOD and COD concentration was higher in the Main Valley, and lower in the T Valley than in Kömürcüada Landfill. The ranges of BOD and COD were similar for Bursa and Kömürcüada Landfills. The ranges of pH values were very close to each other for Bursa MSWL and Kömürcüada Landfill. Total alkalinity was higher in the T Valley and lower in the Main Valley than Kömürcüada Landfill in accordance with the age of the valleys and Kömürcüada landfill. SS concentrations were similar for the

Main Valley and Kömürcüada Landfill and higher than the concentration in the T Valley. Average NH_4-N concentration of Kömürcüada Landfill was higher, while total P concentration was lower than that in Bursa MSWL. Metal concentrations (Fe, Cu, Zn, Pb, and Cr) in Kömürcüada Landfill leachate were lower than in Bursa MSWL. The leachate quality parameters in both Bursa MSWL and Kömürcüada landfill were consistent with the age of the landfills. The differences could be attributed to the waste composition, and operational conditions of the landfills.

Table 4.9. Comparison of leachate from Bursa MSWL and Kömürcüada Landfill

	T Valley			Main Valley			Kömürcüada Landfill		
Parameters	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
BOD	58	32750	7875	6950	50150	22165	3500	28500	12200
COD	590	45533	13619	12548	63325	36339	5850	47800	20700
pH	6.3	8.7	7.7	6.2	7.8	6.8	6.2	8.4	-
Total Alk	3020	15800	10696	5120	12950	8998	3800	13040	9850
NH_4-N	32	2715	1258	115	2908	1369	1380	3260	2330
SS	107	18250	1261	762	3394	2185	670	2720	2170
Total P	5.03	67.5	22.8	7.9	167.6	29.4	0.67	20.9	9.8
Cl	816	5450	3377	1552	6730	4217	725	8500	3670
Fe	32.5	1.9	238.7	1.2	307.8	96.1	4.9	365	62
Cu	0.06	29	7.9	0.04	16.1	6.9	<0.10	1.1	0.25
Zn	1.2	180	24.9	6.7	91.9	50.7	0.17	3.6	0.98
Pb	0.04	106.4	9	1.1	48	12.6	<0.10	3.6	0.78
Cr^{6+}	0.2	20.6	4.8	0.2	19.6	7.4	<0.10	10.2	0.52
Cd	0	11.2	0.45	0	0.3	0.01	<0.10	30.4	1

4.2.1.2. Coefficient of Variations for Leachate Parameters

In order to get more information about the pattern of the data, the spread (or variability) of the data should be measured in addition to the mean, median and mode. Coefficient of variation gives the magnitude of standard deviation relative to the magnitude of the mean. It is a relative measure of variability (dispersion) and comparable across distributions. When the data are widely dispersed, the central location is less representative of the data than the data would be more closely centered around the mean (Levin and Rubin, 1980). Leachate parameters with high variabilities should be measured more frequently due to the fact that when the data are widely dispersed it does not located close to the central value. CV's were used in the determination of sampling strategies for leachate monitoring programs along with standardized skewness coefficients.

Table 4.10 gives the values and the degree of CV of leachate quality parameters for the pre- and post- closure of the T Valley, T Valley and the Main Valley. Due to the lack of data of total alkalinity, total N, SO_4 and S, CV could not be calculated for the pre-closure of the T Valley. A few number of measured leachate parameters for NH_4-N, electrical conductivity, Cl and flow rate result in unreliable values of CV in the pre-closure period of the T Valley and thus CV calculations were omitted for these parameters.

The highest variability in leachate data were in the T Valley including both pre- and post closure periods. The degrees of variations for leachate pollutant concentrations in the T Valley were usually more than the variations in the Main Valley. In the post-closure period of the T Valley, leachate quality parameters having high variability were BOD, $Cr^{6+}$and total CrO_4. In the Main Valley, Fe and F had high variability. BOD and COD had low variations in both the pre-closure of the T Valley and the open Main Valley. The pH was the leachate parameter having the lowest variability in both closed T and open Main Valleys. pH, total alkalinity, total N, Cl and S had low variability in both closed and open valleys. NH_4-N, Pb and Cu had moderate variability in both the post-closure period of the T Valley and Main Valley.

Table 4.10. Values and degrees of coefficient of variations for leachate parameters

	Coefficient of Variation (%)			
Parameter	Pre closure (T)	Post closure (T)	T Val.	Main Val.
BOD	47	316	127	47
COD	41	63	99	38
pH	4	4	6	6
Total Alk($CaCO_3$)	-	32	32	25
NH_4-N	-	65	70	53
Total N	-	33	33	37
Total P	54	45	52	83
EC	-	32	195	19
Fe	92	48	146	108
Zn	86	65	124	50
Pb	133	75	223	93
Cu	39	76	86	66
Cr^{6+}	48	114	87	66
Total CrO_4	46	101	84	61
CN^-	81	67	126	47
F	96	76	149	113
Cl	-	37	37	31
SO_4	-	53	53	43
S	-	50	50	39
Flow Rate	-	101	107	21
SS	31	66	75	30

: 50>=CV - low variability
: 100>=CV>50 - moderate variability
: CV>100 - high variability

4.2.1.3. Standardized Skewness Coefficients and Distributions for Leachate Parameters

As mentioned in Section 3.3, skewness is a measure of symmetry in the distribution shape of the data. Standardized skewness is a measure that tests for significant deviations from the normal distribution. When the values for the standardized skewness coefficient are outside the range -2.0 to +2.0, the data may depart significantly from a normal distribution. Standardized skewness greater than 2 shows that the data are positively (right) distributed. If the standardized skewness is less than -2, the data is negatively (left) distributed. When the distribution is skewed negatively or positively, the median is often the best measure for central tendency, because it is between the mean and mode. The median is not affected by the frequency of the occurrence of a single value as is the mode, and not influenced by extreme values as is the mean (Levin and Rubin, 1980). In a right skewed distribution, the values are concentrated at the left end at the horizontal axis. The mode is at the highest point of distribution; the median is at the right of the mode, and the mean is at the right of both the mode and median in this case. In a left skewed distribution, the median is at the left of the mode, and the mean is at the left of both mode and median. Standardized skewness coefficients determined for leachate parameters were applied in determining sampling strategies for leachate monitoring programs. When the data deviates from normal distribution, leachate parameter should be measured more frequently.

The values of standardized skewness coefficients were presented in Table 4.11. There were no total alkalinity, total N, SO_4 and S measurements during the pre-closure period of the T Valley. In addition, due to the lack of measurements of NH_4-N, electrical conductivity, Cl and flow rate in the pre-closure period of the T Valley, standardized skewness values were omitted in the pre-closure period of the T Valley (see Table 4.6).

Leachate parameters usually showed more skewed distributions in the closed the T Valley than in the open Main Valley. This could be attributed to the fact that the T Valley was older and covered both pre- and post- closure periods of landfill operation.

Table 4.11. Values of standardized skewness coefficients for leachate parameters

Parameter	Standardized Skewness Pre closure (T)	Post closure (T)	T Val.	Main Val.
BOD	0.5	17.3	3.7	2.1
COD	0.1	11.8	3.5	0.6
pH	1.2	0.4	-0.4	0.8
Total Alk	-	-1.8	-1.8	-0.2
NH_4-N	-	-0.2	0.1	0.6
Total N	-	-2.4	-2.4	-0.8
Total P	3.7	-0.6	5.0	11.8
EC	-	-0.2	11.6	-0.2
Fe	4.3	6.4	10.1	2.9
Zn	4.9	3.3	10.8	-1.2
Pb	4.5	1.7	11.8	4.6
Cu	1.7	2.0	3.4	-0.9
Cr^{6+}	3.6	9.4	5.1	0.8
Total CrO_4	2.8	8.2	4.8	0.0
CN^-	4.1	5.2	9.4	0.7
F	2.4	3.7	8.1	4.5
Cl	-	-0.7	-0.3	-0.4
SO_4	-	4.5	4.6	-0.1
S	-	1.9	1.9	0.0
Flow Rate	-	5.0	2.5	2.1
SS	0.6	3.4	3.3	-0.5

: 2>=|Std. Sk.| - Normal distribution

: |Std. Sk.|>2 – Skewed distribution

Leachate parameters showing normal distribution in the post-closure period of the T Valley were pH, total alkalinity, NH_4-N, total P, EC, Pb, Cu, Cl and S. BOD, COD, total N, Fe, Zn, Cr^{6+}, total CrO_4, CN^-, F, SO_4, flow rate and SS in the post-closure of the T Valley had skewed distributions and deviate from normality. Leachate quality parameters, including COD, pH, total alkalinity, NH_4-N, total N, EC, Zn, Cu, Cr^{6+}, total CrO_4, CN^-, Cl, SO_4, S and SS had standardized skewness values in the normal distribution range in the Main Valley. However, BOD, total P, Fe, Pb, F and flow rate distribution was skewed to the right and not normally distributed in the Main Valley. Standardized skewness values for COD, pH, Cu and SS were in the normal distribution range in both pre-closure of the T Valley and open Main Valley.

Since, positive skewness does not necessarily indicate a log-normal frequency distribution, Kolmogorov-Smirnov statistic, which is goodness of the fit test, was applied for leachate parameters having rightly skewed distribution. When the leachate parameters are log-normally distributed, log transformation of the data is useful for statistical data evaluation. Kolmogorov-Smirnov test were applied closed and open valleys in Bursa MSWL for major leachate quality parameters (BOD, COD, Fe, Zn, Pb) having skewed distribution (see Table 4.11).

Results of goodness of the fit test showed that Fe, Zn and Pb were log-normally distributed for 90 % or higher confidence level for the pre-closure period of the T Valley. In the open Main Valley, BOD, Fe and Pb had log-normal distributions at 90 % or higher confidence level. The goodness of the fit test showed that BOD, COD, Zn did not have a log-normal distribution, whereas Fe had log-normal distribution with 90 % or higher confidence for the post closure period of the T Valley.

4.2.2. Results of Time Series Analysis

Using Statgraphics Plus Program, the time series analyses was performed for the monthly leachate quantity and quality parameters in order to provide information about the auto- and cross- correlations within and between the leachate parameters as well as randomness and seasonality of the leachate parameters.

As stated in Section 3.3.2, autocorrelation coefficient at lag k, r_k, gives the degree of correlation between the value of a parameter at time t, X_t and k months later, X_{t+k}, where k is the lag period between observations. If the 95 % probability limits calculated at a particular lag do not contain the estimated autocorrelation coefficient, there is a statistically significant correlation at that lag implying that the time series may not be completely random (Statgraphics Plus User Manual, 1997).

"Runs above and below median", "runs up and down" and "Box-Pierce" tests were performed using Statgraphics Plus Program to determine whether or not a leachate parameter is a random sequence of values. Runs above and below median test counts the number of times the sequence was above or below the median. Runs up and down test counts the number of times the sequence rise or fall. Box-Pierce test is based on the sum of squares of the autocorrelation coefficients. These three randomness tests are sensitive to different types of departures from random behaviour. Therefore, failure to pass any test suggest that the time series may not be completely random. (Statgraphics Plus User Manual, 1997).

The crosscorrelation coefficients for couples of leachate parameters at lag 0 for the T and Main Valleys are presented. In addition, the various lags, at which couples of leachate parameters had statistically significant relationships were determined for both closed T Valley and open Main Valley. The crosscorrelation coefficient at lag k measures the strength of the linear relationship between variables X at time t and Y, k periods earlier. The p^* values in the Analysis of Variance (ANOVA) tables were obtained by the simple regression analysis between two leachate parameters to determine whether or not there is a statistically significant relationship between these parameters at lag 0. If the p^* value is less than 0.05 there is a statistically significant relationships between the variables at 95 % confidence level (Statgraphics Plus User Manual, 1997).

4.2.2.1. Leachate Flow Rate

Leachate flow rate data were available only for 10 months in 2003, excluding August and November, as given in Table C.3 of Appendix C. Analyses were performed using the available data.

4.2.2.1.1. Autocorrelations for Leachate Flow Rate

Autocorrelation coefficients at 95 % confidence level for monthly leachate flow rates were calculated in order to measure the correlations of leachate flow rates in the T and Main Valleys (see Table 4.12). In addition, to determine whether or not the flow rate data is a random sequence, runs above and below median, runs up and down and Box-Pierce tests were performed. The autocorrelations and probability limits written in bold shows the lags, at which the autocorrelation coefficients were outside of the probability limits and there is no statistically significant correlation.

Table 4.12. Autocorrelation coefficients at lag 1 for leachate flow rates in the T and Main Valleys

Valley	Lag (k-month)	Autocorrelation Coefficient (r_k)	Lower 95 % Probability Limit	Upper 95 % Probability Limit
T	*1*	*0.71*	*-0.59*	*0.59*
Main	***1***	***-0.20***	***-0.59***	***0.59***

Since, the probability limits calculated at a lag 1 do not contain the estimated autocorrelation coefficient, there was statistically significant relationship at lag 1 at 95 % confidence level in the T Valley. However, none of the autocorrelation coefficients was statistically significant in the Main Valley. The leachate flow rate in the T Valley measured at a certain time can be used to predict the flow rate 1 month later.

For the T Valley the p values determined by runs above and below median test, runs up and down test and Box-Pierce test were 0.02, 0.01 and 0.07 at 95 % confidence level, respectively. Since the p values for two of the test were less than 0.05, flow rate failed to pass randomness tests and thus the flow rate data series may not be completely random in the T Valley. The p values for the Main Valley were 0.8, 1.0 and 0.9, respectively, all of which were greater than 0.05, indicating that the leachate flow rate data may be completely random.

4.2.2.1.2. Crosscorrelations between Leachate Flow Rate and Rainfall

The strength of correlations between leachate flow rate and rainfall amounts in the closed T and open Main Valleys were determined using available data in 2003 and given in Table 4.13.

For the T and Main Valleys, the crosscorrelation coefficients at lag 0 between leachate flow rate and rainfall were estimated as 0.30 and 0.46 at 95 % confidence level, respectively. The p^* values calculated to determine whether there is a statistically significant relationships between leachate flow rate and rainfall in the T and Main Valleys were 0.36 and 0.13, respectively, and greater than 0.05. Therefore, there was not a statistically significant relationship between leachate flow rate and rainfall amount at lag 0 for 95 % confidence level in both valleys. The absence of statistically significant relationship between rainfall and leachate could be attributed to insufficient leachate flow rate data. As pointed out before the crosscorrelation coefficient at lag k measures the strength of the linear relationship between variables X at time t and Y, k periods earlier. Relatively high crosscorrelation coefficient between leachate flow rate and rainfall at lag 2 in the Main Valley could be attributed to 2 months time lag between rainfall and leachate flow rate.

Table 4.13. Crosscorrelation coefficients between rainfall and leachate flow rates in the T and Main Valleys calculated using 2003 data

	Crosscorrelation Coefficient	
Lag (k-month)	**T Valley**	**Main Valley**
-3	0.27	-0.04
-2	0.39	-0.01
-1	0.27	0.12
0	0.30	0.46
1	-0.34	0.01
2	0.04	0.50
3	0.03	-0.11

The reason for the weak relationship between leachate flow rate and rain can be attributed to the final soil cover over the T Valley that may decrease the water infiltration through the landfill by evapotranspiration and moisture detention, and reduces the leachate generation in the landfill. The correlation coefficient in the open Main Valley was higher than that of the T Valley due to the lack of final soil cover over the Main Valley. Bendz et al. (1997) observed a 1-2 month time lag in the net water input-leachate discharge relation in a 7-years old closed landfill in Sweden. Khattabi et al. (2002) also did not found a correlation between precipitation and leachate flow rate in an old closed landfill in France, however there was a lag period between the rainfall event and leachate production due to multiple preferential flow paths and humidity of the refuse.

4.2.2.1.3. Crosscorrelations between Leachate Flow Rate and Leachate Quality Parameters

The crosscorrelation coefficients between leachate flow rate and leachate quality parameters at lag 0 were determined using available monthly flow rate and leachate quality data of 2003 and given in Tables 4.14-4.15. Generally, there were no statistically significant relationships found between leachate flow rate and leachate quality parameters in the T and Main Valleys. Different crosscorrelations were observed between flow rate and leachate quality parameters in the T and Main

Valleys due to the different stabilization stages and waste ages in the valleys. The p^* values were evaluated to determine whether there was a statistically significant relationship or not. In the T Valley, flow rate had a statistically significant correlation with total alkalinity and electrical conductivity, whereas, flow rate had a statistically significant correlation with only electrical conductivity in the Main Valley. Small number of statistically significant correlations with other leachate quality parameters could be attributed to insufficient leachate flow rate data. There were also moderately strong relationships found between flow rate and leachate quality parameters at different lag periods based on crosscorrelation coefficients between leachate flow rate and leachate parameters (see Table 4.16).

Table 4.14. Crosscorrelation coefficients between leachate parameters in the T Valley

Parametre	BOD	COD	pH	SS	Flow rate	EC	Tot. CrO4	Cr^{6+}	Fe	Cu	Zn	Pb	CN	Cl	F	Tot. P	NH_4-N	Tot. N	SO_4	S^{2-}	Tot. Alk.
BOD	1.00																				
COD	0.99	1.00																			
pH	-0.78	-0.77	1.00																		
SS	0.86	0.87	-0.53	1.00																	
Flow rate	0.54	-0.61	-0.39	-0.26	1.00																
EC	0.63	0.61	-0.44	0.52	-0.70	1.00															
Tot. CrO_4	0.74	0.74	-0.52	0.80	0.40	0.33	1.00														
Cr^{6+}	0.73	0.73	-0.54	0.78	0.15	0.35	0.97	1.00													
Fe	0.77	0.79	-0.65	0.82	0.35	0.57	0.50	0.50	1.00												
Cu	0.82	0.84	-0.71	0.86	0.45	0.55	0.77	0.76	0.62	1.00											
Zn	0.71	0.70	-0.55	0.63	-0.52	0.66	0.45	0.42	0.67	0.45	1.00										
Pb	0.65	0.65	-0.59	0.64	0.03	0.79	0.31	0.31	0.78	0.60	0.44	1.00									
CN	0.56	0.55	-0.46	0.70	-0.02	0.34	0.48	0.46	0.52	0.43	0.56	0.29	1.00								
Cl	0.43	0.71	0.56	0.26	-0.52	0.24	-0.02	-0.02	0.16	-0.03	0.01	-0.16	0.12	1.00							
F	0.79	0.79	-0.61	0.74	-0.13	0.79	0.53	0.51	0.75	0.74	0.54	0.79	0.51	0.31	1.00						
Tot. P	0.40	0.43	-0.34	0.52	0.06	0.15	0.38	0.33	0.46	0.52	0.24	0.54	0.08	0.11	0.42	1.00					
NH_4-N	-0.23	-0.13	0.10	-0.12	-0.39	-0.07	-0.15	-0.13	0.04	0.06	0.55	0.48	0.39	0.03	0.39	0.37	1.00				
Tot. N	-0.15	0.01	0.29	-0.04	-0.34	0.10	-0.12	-0.08	0.05	-0.09	0.69	0.44	0.31	0.75	0.20	0.23	0.59	1.00			
SO_4	-0.14	-0.17	0.01	-0.13	-0.29	-0.09	-0.19	-0.18	-0.02	-0.25	0.27	0.16	-0.04	-0.21	-0.01	-0.16	0.21	0.16	1.00		
S^{2-}	0.42	0.67	0.29	0.80	-0.35	0.56	0.72	0.69	0.54	0.67	0.11	0.15	0.24	0.50	0.41	0.74	0.02	0.07	-0.21	1.00	
Tot. Alk.	0.15	0.53	0.58	0.55	-0.73	0.66	0.33	0.29	0.19	0.31	0.05	-0.04	0.12	0.79	0.39	0.60	0.05	0.22	-0.27	0.72	1.00

Statistically significant relationship

Table 4.15. Crosscorrelation coefficients between leachate parameters in the Main Valley

Parametre	BOD	COD	pH	SS	Flow rate	EC	Tot. CrO4	Cr^{6+}	Fe	Cu	Zn	Pb	CN	Cl	F	Tot P	NH_4-N	Tot. N	SO_4	S^{2-}	Tot. Alk.
BOD	1.00																				
COD	0.95	1.00																			
pH	-0.76	-0.83	1.00																		
SS	0.75	0.87	-0.71	1.00																	
Flow rate	-0.44	-0.43	0.17	-0.53	1.00																
EC	0.63	0.73	-0.48	0.76	-0.54	1.00															
Tot. CrO_4	0.70	0.64	-0.47	0.53	0.11	0.23	1.00														
Cr^{6+}	0.73	0.66	-0.48	0.56	0.12	0.27	0.98	1.00													
Fe	0.91	0.84	-0.73	0.60	0.25	0.53	0.51	0.54	1.00												
Cu	0.31	0.38	-0.20	0.38	0.02	0.13	0.63	0.60	0.20	1.00											
Zn	0.44	0.45	-0.29	0.39	0.24	0.10	0.75	0.70	0.32	0.85	1.00										
Pb	0.70	0.58	-0.61	0.33	-0.31	0.25	0.44	0.47	0.67	0.00	0.17	1.00									
CN	-0.03	0.00	-0.01	0.15	0.04	0.00	0.28	0.27	-0.16	0.44	0.41	0.12	1.00								
Cl	0.36	0.26	0.06	0.45	-0.06	0.43	0.39	0.39	0.41	0.44	0.46	0.10	0.73	1.00							
F	0.82	0.82	-0.72	0.62	0.05	0.60	0.43	0.44	0.91	0.29	0.32	0.43	-0.20	0.35	1.00						
Tot P	0.05	0.16	-0.11	0.35	-0.14	0.13	0.22	0.17	0.00	0.35	0.32	-0.13	0.18	0.42	0.07	1.00					
NH4-N	-0.08	0.01	0.14	0.27	-0.24	0.18	0.07	0.08	-0.18	0.43	0.22	-0.35	0.28	0.57	-0.09	0.16	1.00				
Tot N	-0.32	-0.16	0.28	0.13	-0.20	-0.02	-0.05	-0.10	-0.37	0.45	0.32	-0.65	0.38	0.38	-0.21	0.40	0.61	1.00			
SO_4	0.85	0.88	-0.80	0.74	0.18	0.63	0.60	0.61	0.80	0.44	0.49	0.63	0.09	0.34	0.77	0.22	0.06	-0.20	1.00		
S^{2-}	0.12	0.25	-0.10	0.42	0.00	0.18	0.40	0.38	0.06	0.71	0.63	-0.21	0.34	0.50	0.15	0.31	0.56	0.64	0.30	1.00	
Tot Alk	0.27	0.29	0.12	0.33	-0.47	0.55	-0.02	0.02	0.25	-0.02	-0.06	-0.02	-0.01	0.49	0.25	-0.07	0.34	0.11	0.14	0.17	1.00

Statistically significant relationship

Table 4.16. Crosscorrelation coefficients between leachate flow rate and leachate quality parameters calculated using 2003 data[a]

	Lag (k-month)			
	k=1		k=2	
Parameters	**T**	**Main**	**T**	**Main**
BOD	0.51	-	-	-
COD	-	-	-	-
pH	-	-	-	-
SS	-	-	-	-
EC	-0.67	-	-	-
Total CrO_4	-	-	-	-
Cr^{6+}	-	-	-	-
Fe	0.70	0.57	-	-
Cu	-	-	-	-
Zn	-	-	-	-
Pb	-	-	-	-
CN^-	-	-	-	-
Cl	-	-	-	-
F	-0.66	-	-0.51	-
Total P	-	-	-	-
NH_4-N	-0.50	-	-	-
Total N	-	-	-	-
SO_4	-	-	-	-
S	-0.72	-	-	-
Total Alk.	-0.71	-	-	-

[a] Terminology used in Statgraphics Program:
- MS: $|0.5| <$ Correlation coefficient $< |0.9|$ – "Moderately strong relationship"

It was observed that the closed T Valley had more leachate parameters correlated with leachate flow rate at lags 1 and 2 than the Main Valley. Flow rate had a moderately strong relationship with Fe at lag 1 in both closed and open valleys. Flow rate had inversely moderately strong relationship with electrical conductivity, F, NH_4-N, S and total alkalinity at lag 1 at 95 % confidence level in the T Valley.

4.2.2.2. BOD – COD

Autocorrelation coefficients for BOD and COD in the T and the Main Valleys were given in Tables 4.17-4.18. Crosscorrelation coefficients between BOD and COD at lag 0 in the T and Main Valleys were given in Table 4.14-4.15. These tables also present the crosscorrelation coefficients between BOD, COD and other leachate parameters. The autocorrelations and probability limits written in bold shows the lags, at which the autocorrelation coefficients were outside of the probability limits and there is no statistically significant correlation.

4.2.2.2.1. Autocorrelations for BOD and COD

There was a statistically significant correlation up to lags 5 and 3 at 95 % confidence level for BOD in the T and Main Valleys, respectively. While COD had a statistically significant correlation up to lag 5 in the T Valley and up to lag 2 in the Main Valley at 95 % confidence level (see Tables 4.17-4.18). BOD content at a given month would be estimated using BOD measurement taken during prior 3 months in both valleys. COD content at a given time would be estimated using COD measurements of earlier 3 months in the closed T Valley, and earlier 2 months in the open Main Valley. These results were useful in determination of the sampling strategies and frequencies for the leachate monitoring program.

The p values for the randomness of BOD data determined by runs above and below median, runs up and down and Box-Pierce tests were 0, 0.48 and 0 at 95 % confidence level, respectively. Since two of the p values were less than 0.05 they failed to pass randomness tests, and therefore BOD data series may not be completely random. The p values for the Main Valley were found 0, 0.11 and 0 at 95 % confidence level, respectively. Since two of the p values were less than 0.05 and failed to pass randomness tests, BOD data series may not be completely random in the Main Valley. This was also consistent with autocorrelation coefficients showing statistically significant correlations up to 3 lags.

Table 4.17. Autocorrelation coefficients for BOD in the T and Main Valleys

Lag (k-month)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.86*	*-0.22*	*0.22*
1	***Main***	*0.77*	*-0.29*	*0.29*
	T	*0.74*	*-0.34*	*0.34*
2	***Main***	*0.74*	*-0.42*	*0.42*
	T	*0.65*	*-0.41*	*0.41*
3	***Main***	*0.60*	*-0.52*	*0.52*
	T	*0.59*	*-0.46*	*0.46*
4	***Main***	**0.56**	**-0.57**	**0.57**
	T	*0.54*	*-0.50*	*0.50*
5	***Main***	**0.45**	**-0.62**	**0.62**

Table 4.18. Autocorrelation coefficients for COD in the T and Main Valleys

Lag (k-month)	Valley	Autocorrelation Coefficient	Lower 95 % Probability Limit	Upper 95 % Probability Limit
	T	*0.85*	*-0.22*	*0.22*
1	***Main***	*0.78*	*-0.29*	*0.29*
	T	*0.75*	*-0.34*	*0.34*
2	***Main***	*0.68*	*-0.43*	*0.43*
	T	*0.65*	*-0.42*	*0.42*
3	***Main***	**0.50**	**-0.51**	**0.51**
	T	*0.60*	*-0.46*	*0.46*
4	***Main***	**0.39**	**-0.55**	**0.55**
	T	*0.55*	*-0.50*	*0.50*
5	***Main***	**0.23**	**-0.57**	**0.57**

The p values for the randomness of COD data determined from runs above and below median, runs up and down and Box-Pierce tests were 0, 0.03 and 0, respectively, for both valleys at 95 % confidence level. Since the p values were less than 0.05, COD data series may not be completely random in the T and Main Valley. This is consistent with the autocorrelation coefficient having statistically significant correlations at various lags.

4.2.2.2.2. Crosscorrelations between BOD, COD and Other Leachate Quality Parameters

The crosscorrelation coefficients between BOD and COD the T and Main Valleys were 0.99 and 0.95 respectively at 95 % confidence level. The p^* value determined for the relationship between BOD and COD was 0 for both valleys and less than 0.05 indicating that there was a statistically significant relation between BOD and COD at 95 % confidence level in the T and Main Valleys. The measurement of one of these parameters can be used in the prediction of the unmeasured one at the same period.

There was an inverse relationship between BOD, COD and pH in both closed T and open Main Valleys. The p^* values determined for the relationship between BOD and pH in both valleys were 0, thus there was a statistically significant relationship between BOD and pH at 95 % confidence level in both valleys. The p^* values determined for the relationship between COD and pH were also 0 (less than 0.05) in both valleys, showing that COD and pH had a statistically significant relationship in both valleys at 95 % confidence level. Therefore, the increases or decreases in BOD and COD would be estimated observing fluctuations of pH or vice versa.

BOD and COD had statistically significant relationships with SS, electrical conductivity, total CrO_4, Cr^{6+}, Fe, Cu, Zn, Pb, CN^-, F, total P and S^{2-} at lag 0 in both closed T and open Main Valleys. The p^* values for the relationships between BOD, COD and these parameters were all less than 0.05.

COD had a moderately strong relationship with BOD up to lags 6 and 4 for the T and Main Valleys, respectively (see Table 4.19-4.20). BOD had a moderately strong relationship with COD up to lags 5 and 3 in the T and Main Valleys, respectively. BOD and COD had moderately strong relationships with other leachate parameters at various lags. Table 4.19-4.20 shows the lag periods, at which there was a moderately strong relationship between BOD, COD and other leachate parameters.

Table 4.19. Crosscorrelation coefficients between BOD and leachate parameters[a]

	Lag (k-month)													
	1		2		3		4		5		6		7	
Parameters	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**
COD	0.86	0.73	0.75	0.65	0.65	-	0.59	-	0.54	-	-	-	-	-
pH	-0.73	-0.69	-0.69	-0.61	-0.64	-0.53	-0.60	-	-0.54	-	-	-	-	-
SS	0.86	0.59	0.80	0.52	0.76	-	0.67	-	0.60	-	-	-	-	-
Flow rate	0.52	-	-	-	0.59	-	-	-	-	-	-	-	-	-
EC	0.76	-	0.69	-	0.73	-	0.52	-	-	-	-	-	-	-
Total CrO_4	0.59	0.60	-	0.56	-	-	-	-	-	-	-	-	-	-
Cr^{6+}	0.58	0.62	-	0.58	-	-	-	-	-	-	-	-	-	-
Fe	0.68	0.72	0.61	0.69	0.51	0.59	-	0.51	-	-	-	-	-	-
Cu	0.73	-	0.67	-	0.60	-	0.55	-	-	-	-	-	-	-
Zn	0.60	-	0.50	-	-	-	-	-	-	-	-	-	-	-
Pb	0.67	0.70	0.70	0.72	0.69	0.76	0.65	0.60	0.56	0.56	-	0.55	-	0.53
CN	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	0.75	0.68	0.74	0.61	0.64	-	0.50	-	-	-	-	-	-	-
Total P	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4-N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4	-	0.67	-	0.65	-	0.51	-	-	-	-	-	-	-	-
S	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Alk.	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[a] Terminology used in Statgraphics Program:

- MS: |0.5| < Correlation coefficient < |0.9| – "Moderately strong relationship"

Table 4.20. Crosscorrelation coefficients between COD and Leachate Parameters[a]

	Lag (k-month)											
	1		2		3		4		5		6	
Parameters	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**
BOD	0.85	0.75	0.75	0.71	0.65	0.56	0.61	0.51	0.56	-	0.52	-
pH	-0.72	-0.76	-0.70	-0.66	-0.65	-0.55	-0.62	-	-0.56	-	-0.50	-
SS	0.79	0.71	0.69	0.60	0.56	-	-	-	-	-	-	-
Flow rate	-0.80	-	-	-	-	-	-	-	-	-	-	-
EC	0.78	0.53	0.72	-	0.73	-	-	-	-	-	-	-
Total CrO_4	0.58	0.57	-	0.53	-	-	-	-	-	-	-	-
Cr^{6+}	0.58	0.58	-	0.54	-	-	-	-	-	-	-	-
Fe	0.68	0.67	0.62	0.63	-	0.52	-	-	-	-	-	-
Cu	0.74	-	0.67	-	0.60	-	0.56	-	0.51	-	-	-
Zn	0.60	-	-	-	-	-	-	-	-	-	-	-
Pb	0.66	0.59	0.67	0.62	0.66	0.65	0.63	0.54	0.55	0.52	-	0.51
CN	0.57	-	-	-	-	-	-	-	-	-	-	-
Cl	0.57	-	-	-	-	-	-	-	-	-	-	-
F	0.74	0.70	0.72	0.63	0.62	-	-	-	-	-	-	-
Total P	-	-	-	-	-	-	-	-	-	-	-	-
NH_4-N	-	-	-	-	-	-	-	-	-	-	-	-
Total N	-	-	-	-	-	-	-	-	-	-	-	-
SO_4	-	0.74	-	0.72	-	0.56	-	0.50	-	-	-	-
S	-	-	-	-	-	-	-	-	-	-	-	-
Total Alk.	-	-	-	-	-	-	-	-	-	-	-	-

[a] Terminology used in Statgraphics Program:
- MS: |0.5| < Correlation coefficient < |0.9| – "Moderately strong relationship"

4.2.2.3. pH

Autocorrelation coefficients for pH in the T and Main Valleys were given in Table 4.21. Crosscorrelation coefficients between pH and other leachate parameters at lag 0 are presented at Table 4.14-4.15. Leachate parameters that were statistically correlated with pH were given in Table 4.22.

4.2.2.3.1. Autocorrelations for pH

There was a statistically significant correlation up to lags 4 and 2 for pH in the T and Main Valleys at 95 % confidence level, respectively, implying that pH data may not be completely random, and measurements made within a couple of months expected to have close values.

The *p* values for the randomness of pH determined by runs above and below median, runs up and down and Box-Pierce tests were 0, 0.04 and 0, respectively at 95 % confidence level in the T Valley. In the Main Valley, the respective *p* values were 0, 0.2 and 0. Since at least one of the *p* values was less than 0.05, pH data series may not be completely random in both valleys.

Table 4.21. Autocorrelation coefficients for pH in the T and Main Valleys

Lag (k-month)	Valley	Autocorrelation Coefficient	Lower 95 % Probability Limit	Upper 95 % Probability Limit
	T	*0.80*	*-0.22*	*0.22*
1	***Main***	*0.84*	*-0.29*	*0.29*
	T	*0.67*	*-0.33*	*0.33*
2	***Main***	*0.67*	*-0.44*	*0.44*
	T	*0.53*	*-0.39*	*0.39*
3	***Main***	***0.49***	***-0.52***	***0.52***
	T	*0.43*	*-0.42*	*0.42*
4	***Main***	***0.29***	***-0.56***	***0.56***

4.2.2.3.2. Crosscorrelations between pH and Other Leachate Quality Parameters

pH was inversely correlated with Fe, F and Pb in both closed T and open Main Valleys. The p^* values for the relationships between pH and these parameters were all 0 and less than 0.05 at 95 % confidence level in both valleys indicating the statistically significant relationship between pH and these parameters.

Table 4.22. Leachate parameters statistically correlated with pH in T and Main Valleys

Parameters	Degree of Crosscorrelations[a] T Valley	Main Valley
SS	(-)	(-)
Flow rate	-	-
EC	(-)	(-)
Total CrO_4	(-)	(-)
Cr^{6+}	(-)	(-)
Fe	(-)	(-)
Cu	(-)	-
CN^-	(-)	-
Cl	(+)	-
F	(-)	(-)
Zn	(-)	-
Pb	(-)	(-)
Total P	-	-
NH_4-N	-	-
Total N	-	-
SO_4	-	(-)
S	-	-
Total Alk.	(+)	-

- : no correlation
(-): inverse correlation
(+): positive correlation

The p^* values for the relationship between pH and SS in the T and Main Valleys were 0. Therefore, there were statistically significant relationships at 95 %

confidence level between pH and SS in both closed T and open Main Valleys. Tatsi and Zouboulis (2002) also found statistically significant correlation between pH and SS in the landfill in Thessaloniki, Greece. This relation for the landfills in Turkey and Greece is possibly due to the similar climate and waste composition.

There were statistically significant correlations between pH and total CrO_4, Cr^{6+}, Fe, Cu, Cl, F, Zn, Pb, CN^- and total alkalinity in the T Valley. The p^* values determined by regression analysis were 0, 0, 0, 0, 0.01, 0, 0, 0, 0.001 and 0, respectively at 95 % confidence level for these parameters.

In the T Valley, more metal concentrations were correlated to pH values than in the Main Valley. Heavy metals (Cr^{6+}, Cu^{2+}, Zn^{2+} and Pb^{2+}) had statistically significant relationships with p^* values less than 0.05 in the T Valley. Pb had inversely strong relationship with pH in the Main Valley with a p^* value of 0 at 95 % confidence level. Heavy metals (Cr^{6+}, Cu^{2+}, Zn^{2+} and Pb^{2+}) decreased with increase in pH due to methanogenic conditions in the closed T Valley.

The correlation of the higher number of leachate parameters to pH in the T Valley could be attributed to the age of the T Valley. Since, the T Valley was closed and older than the Main Valley, the wastes in this valley were more stabilized. The leachate pollutants and pH had nearly constant values after the closure of the valley due to methanogenic conditions.

The p^* values for the relationships between pH and total alkalinity were 0 and 0.4 for the T and Main Valleys, respectively. Therefore, there was a statistically significant relationship between pH and total alkalinity in the T Valley, but not a statistically significant relationship in the Main Valley. Al-Yaqout and Hamoda (2003) reported higher pH values with higher alkalinity conditions for both active and closed landfills in Kuwait, which was an arid climate country with waste composition including liquid and sludge.

The lag periods, at which moderately strong relationships were found between pH and leachate parameters, are presented in Table 4.23. pH had moderately strong relationship with electrical conductivity at lag 1 in the closed T Valley and up to lag 2 in the open Main Valley. Fe, Cu, and Zn had a moderately strong relationship with pH at lags 4, 3 and 2, respectively, in the T Valley. However, there were not moderately significant relationships between pH and Cu-Zn in the Main Valley. SO_4 concentration was inversely moderately related to pH up to lag 3 in the Main valley, while not related in the T Valley. These relationships were evaluated and considered in sampling strategies for leachate monitoring.

4.2.2.4. Other Leachate Quality Parameters

The lag periods, up to which leachate parameters (SS, electrical conductivity, total CrO_4, Cr^{6+}, Fe, Cu, Zn, Pb, CN^-, F, total P, NH_4-N, total N, SO_4 and S) are statistically correlated, were given in Table 4.24. The autocorrelation coefficients for these parameters were given in Table D.1-D.16 in Appendix D. The crosscorrelation coefficients between each couple of leachate quality parameters were calculated using available leachate data for the T and Main Valleys and presented respectively, in Table 4.14 and 4.15.

4.2.2.4.1. Autocorrelations for Other Leachate Quality Parameters

The randomness for the leachate parameters at 95 % confidence level were determined using the p values obtained from runs above and below median, runs up and down and Box-Pierce tests and given in Tables 4.25 and 4.26.

Table 4.23. Crosscorrelation coefficients between pH and leachate parameters at different lags

	Lag (k-month)									
	1		2		3		4		5	
Parameters	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**	**T**	**Main**
BOD	-0.72	-0.70	-0.68	-0.64	-0.61	-0.50	-0.56	-	-0.52	-
COD	-0.73	-0.75	-0.67	-0.64	-0.60	-	-0.55	-	-0.51	-
SS	-	-0.72	-	-0.60	-	-	-	-	-	-
EC	-0.51	-0.55	-	-0.54	-	-	-	-	-	-
Total CrO_4	-	-	-	-	-	-	-	-	-	-
Cr^{6+}	-	-	-	-	-	-	-	-	-	-
Fe	-0.60	-0.64	-0.58	-0.54	-0.52	-	-0.51	-	-	-
Cu	-0.62	-	-0.56	-	-0.50	-	-	-	-	-
Zn	-0.54	-	-0.52	-	-	-	-	-	-	-
Pb	-0.59	-0.56	-0.58	-0.53	-0.56	-0.54	-0.54	-0.53	-0.53	-
CN	-	-	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-	-	-
F	-0.57	-0.64	-0.53	-0.54	-	-	-	-	-	-
Total P	-	-	-	-	-	-	-	-	-	-
NH_4-N	-	-	-	-	-	-	-	-	-	-
Total N	-	-	-	-	-	-	-	-	-	-
SO_4	-	-0.76	-	-0.72	-	-0.55	-	-	-	-
S	-	-	-	-	-	-	-	-	-	-
Total Alk.	-	-	-	-	-	-	-	-	-	-

[a] Terminology used in Statgraphics Program:
- MS: $|0.5| <$ Correlation coefficient $< |0.9|$ – "Moderately strong relationship"

Leachate parameters had more statistically significant correlations at various lags in the T Valley than in the Main Valley (see Table 4.24). All leachate parameters, except for total alkalinity, had a statistically significant autocorrelation up to different lags in both valleys; that is they would be predicted using the measurement made k months earlier.

Table 4.24. Lag periods, up to which leachate parameters are statistically correlated

	Lag (k-months)	
Parameter	**T Valley**	**Main Valley**
SS	4	2
EC	2	1
Total CrO_4	3	2
Cr^{6+}	4	2
Fe	5	2
Cu	5	3
Zn	3	4
Pb	3	3
CN^-	3	1
F	3	3
Total P	2	3
NH_4-N	3	1
Total N	2	3
SO_4	1	2
S	1	2
Total Alkalinity	1	-

Pb and F had a statistically significant correlation up to lag 3 in both closed T and open Main Valleys. SS and Cr^{6+} had a statistically significant correlation up to lag 4 and 2 for the T and Main Valleys, respectively. Fe and Cu in the T Valley were the parameters having the highest lag periods (k=5), at which these parameters were statistically correlated. None of the autocorrelations was statistically significant for total alkalinity data in the Main Valley. The data series for all leachate parameters were found to be random based on p values determined from the randomness tests (see Tables 4.25-4.26).

Table 4.25. The *p* values for the randomness of leachate parameters in the T Valley

	p Values		
Parameters	**Runs above and below median test**	**Runs up and down test**	**Box-Pierce test**
SS	0.0	0.11	0.0
EC	0.0	0.0	0.0
Total CrO_4	0.0	0.06	0.0
Cr^{6+}	0.0	0.04	0.0
Fe	0.0	0.08	0.0
Cu	0.0	0.23	0.0
Zn	0.0	0.01	0.0
Pb	0.0	0.03	0.0
CN^-	0.0	0.04	0.0
Cl	0.0	0.051	0.0
F	0.0	0.0	0.0
Total P	0.0	0.0	0.0
NH_4-N	0.0	0.01	0.0
Total N	0.10	0.51	0.0
SO_4	0.0	0.04	0.0
S	0.04	0.0	0.0
Total Alk.	0.01	0.51	0.03

Table 4.26. The *p* values for the randomness of leachate parameters in the Main Valley

	p Values		
Parameters	**Runs above and below median test**	**Runs up and down test**	**Box-Pierce test**
SS	0.0	0.0	0.0
EC	0.01	0.4	0.1
Total CrO_4	0.02	0.01	0.0
Cr^{6+}	0.01	0.1	0.0
Fe	0.0	0.2	0.0
Cu	0.0	0.1	0.0
Zn	0.0	0.9	0.0
Pb	0.0	0.01	0.0
CN^-	0.0	0.0	0.0
F	0.0	0.02	0.0
Total P	0.0	0.05	0.7
NH_4-N	0.0	0.03	0.0
Total N	0.04	0.01	0.0
SO_4	0.0	0.5	0.0
S	0.0	0.2	0.0

4.2.2.4.2. Crosscorrelations between Other Leachate Quality Parameters

The statistically significant relationships between leachate quality parameters at lag 0 were listed in Tables 4.27 and 4.28 that were determined based on p^* values at 95 % confidence level.

The tables showed that there are statistically significant correlations for the couples of leachate quality parameters for both the T and Main Valleys. However, different crosscorrelation combinations between different leachate parameters were observed for closed and open valleys due to stabilization stages.

Total alkalinity had a strong relationship with SS, electrical conductivity, Cl and NH_4-N in the open Main Valley, while with pH, SS, electrical conductivity, total CrO_4, Cu, Cl, F, total P and S in the closed T Valley. Electrical conductivity had statistically significant relationship with pH, SS, total CrO_4, Cr^{6+}, Fe, Cu, Zn, Pb, CN, F, S and total alkalinity in the T Valley, while it had statistically significant relationships with pH, SS, Fe, F, SO_4 and total alkalinity in the open Main Valley. Such variations were due to the different stabilization stages prevailing in these two valleys.

Several organic and inorganic components and metals were observed to have statistically significant relationships with SS concentrations in both valleys. Colloidal matters have a high affinity for heavy metals and therefore, heavy metal concentrations depend on the colloids (Kjeldsen et al., 2002). Abduli and Safari (2002) found that more than 90 % of the total heavy metal contents are sorbed on suspended solids in their leachate samples. Various lag periods, at which there were moderately strong relationships between couples of parameters, were given in Table D.17-D.18 in Appendix D. The statistically significant correlations between different leachate parameters at various lags reduce the required number of sample analysis for leachate monitoring before and after closure.

Table 4.27. The couples of leachate parameters correlated with each other in the T Valley

Parametre	pH	SS	Flow rate	EC	Tot. CrO4	Cr^{6+}	Fe	Cu	Zn	Pb	CN	Cl	F	Tot. P	NH_4-N	Tot. N	SO_4	S^{2-}	Tot. Alk.
pH																			
SS	(+)																		
Flow rate																			
EC	(-)	(+)	(-)																
Tot. CrO_4	(-)	(+)		(+)															
Cr^{6+}	(-)	(+)		(+)	(+)														
Fe	(-)	(+)		(+)	(+)	(+)													
Cu	(-)	(+)		(+)	(+)	(+)	(+)												
Zn	(-)	(+)		(+)	(+)	(+)	(+)	(+)											
Pb	(-)	(+)		(+)	(+)		(+)	(+)	(+)										
CN	(-)	(+)		(+)	(+)	(+)	(+)	(+)	(+)										
Cl	(+)																		
F	(-)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)								
Tot. P		(+)			(+)	(+)	(+)	(+)	(+)	(+)			(+)						
NH_4-N									(+)	(+)			(+)	(+)					
Tot. N									(+)	(+)	(+)	(+)			(+)				
SO_4																			
S^{2-}		(+)		(+)	(+)	(+)	(+)	(+)				(+)	(+)	(+)					
Tot. Alk.	(+)	(+)	(-)	(+)	(+)			(+)				(+)	(+)	(+)				(+)	

(-): inverse correlation
(+): positive correlation

Table 4.28. The couples of leachate parameters correlated with each other in the Main Valley

Parametre	pH	SS	Flow rate	EC	Tot. CrO4	Cr^{6+}	Fe	Cu	Zn	Pb	CN	Cl	F	Tot P	NH_4-N	Tot. N	SO_4	S^{2-}	Tot. Alk.
pH																			
SS	(-)																		
Flow rate																			
EC	(-)	(+)	(-)																
Tot. CrO_4	(-)	(+)																	
Cr^{6+}	(-)	(+)			(+)														
Fe	(-)	(+)		(+)	(+)	(+)													
Cu		(+)			(+)	(+)													
Zn		(+)			(+)	(+)	(+)	(+)											
Pb	(-)	(+)			(+)	(+)	(+)												
CN								(+)	(+)										
Cl		(+)						(+)	(+)		(+)								
F	(-)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)									
Tot P								(+)	(+)										
NH4-N								(+)		(-)		(+)							
Tot N							(-)	(+)	(+)	(-)	(+)			(+)	(+)				
SO_4	(-)	(+)		(+)	(+)	(+)	(+)	(+)	(+)	(+)			(+)						
S^{2-}		(+)			(+)	(+)		(+)	(+)		(+)	(+)		(+)	(+)	(+)	(+)		
Tot Alk		(+)		(+)								(+)			(+)				

(-): inverse correlation

(+): positive correlation

4.2.2.5. Seasonalities

Seasonal indices were determined by Statgraphics Plus program. In order to determine the seasonal indices, firstly centered moving average of the seasonal length (12 months) is applied to the variable. Then, in order to get a seasonality ratio, data are divided by the moving average calculated in the first step and multiplied by 100. The program calculates the seasonal indices for each season by averaging the ratios across all the observations in that season, then scales seasonal indices for each season so an average season (month) equals 100. The indices show the average seasonal swing throughout one complete cycle being 1 year.

Seasonality indices for the leachate quality parameters in the T and the Main Valley were given in Tables 4.29-4.30. Seasonal indices for each month were calculated for leachate quality parameters (BOD, COD, pH, SS, electrical conductivity, total CrO_4, Cr^{6+}, Fe, Cu, CN^-, F, Zn, Pb, total PO_4, NH_4-N, total N, S, SO_4, total alkalinity) in both valleys.

In both valleys, leachate quality parameters generally showed clear seasonal trends having lower concentrations during the wet seasons and higher concentrations during dry seasons. On the other hand, pH had higher values during the winter and spring seasons.

Table 4.29. Seasonality indices for leachate quality parameters in T Valley

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
COD	76	77	75	77	79	117	125	132	135	122	95	91
BOD	78	88	74	85	91	121	127	121	138	113	88	76
pH	98	100	98	96	98	100	97	100	101	102	105	104
Total Alk.	53	92	79	70	96	110	118	127	129	130	94	101
NH_4-N	78	92	83	91	72	102	87	140	139	109	112	94
Total N	77	86	91	98	102	117	88	110	130	104	100	97
Total P	72	90	82	74	96	110	122	122	152	97	88	96
EC	99	96	84	70	95	117	114	121	129	118	77	81
Fe	90	69	57	88	79	107	123	121	125	111	111	118
Zn	97	88	66	88	91	149	108	101	113	120	85	94
Pb	104	70	84	77	99	97	160	105	119	109	89	87
Cu	81	92	97	95	79	96	118	118	142	104	105	72
Cr^{6+}	74	76	87	65	84	103	108	107	147	140	105	103
Total CrO_4	83	84	72	69	80	94	125	119	143	130	102	98
CN^-	55	70	91	70	94	101	91	154	110	130	134	99
SO_4	128	79	78	108	105	84	84	63	90	100	145	137
S^{2-}	50	90	81	91	81	104	101	127	153	130	80	112
F	51	85	51	89	109	137	129	131	129	136	106	49
SS	78	95	80	74	105	107	101	103	161	113	94	89

Table 4.30. Seasonality indices for leachate quality parameters in Main Valley

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
COD	78	68	79	82	104	111	114	125	121	115	110	92
BOD	87	73	83	84	111	107	111	117	114	109	113	92
pH	103	104	106	101	101	99	97	93	97	98	98	102
Total Alk.	88	97	90	115	107	107	94	107	111	103	102	79
NH_4-N	99	87	100	104	100	106	120	97	109	87	91	98
Total N	85	88	87	96	103	106	119	125	103	107	85	96
Total P	54	45	48	63	89	212	122	151	159	97	98	62
EC	89	78	95	86	115	112	114	103	103	105	98	101
Fe	89	60	32	58	81	105	128	139	157	100	142	109
Zn	107	77	84	93	114	105	103	124	120	91	102	81
Pb	114	65	52	137	110	94	87	98	114	84	126	118
Cu	88	61	97	102	140	115	118	146	124	80	76	53
Cr^{6+}	83	76	102	85	103	111	116	152	150	77	78	67
Total CrO_4	72	65	85	84	98	99	114	132	144	67	74	165
CN^-	82	64	80	134	145	111	91	117	144	79	72	80
SO_4	63	73	72	115	117	125	114	108	107	99	118	88
S^{2-}	78	108	96	90	105	115	128	105	103	110	87	77
F	68	59	41	56	106	140	163	163	161	80	112	51
SS	78	57	83	76	103	115	123	132	116	124	108	86

Although inorganics and metal concentrations did not show a clear seasonal trend in both valleys, they were generally lower during wet season and higher during dry season. However, SO_4 concentration in the T Valley and Pb concentration in the Main Valley had lower concentrations during summer season. The decreases in leachate quality parameters could be attributed to dilution of leachate by higher rainfall during wet seasons as also observed by other authors (Tatsi and Zouboulis, 2002; Khattabi et al., 2002; Al Yaqout and Hamoda, 2003). On the other hand, Aluko et al. (2003) reported that during wet season leachate has a higher pollution concentration particularly for electrical conductivity, SS, DS, NH_3, Ni, Cd and Mn due to the increase in water content that promotes the solubilization the pollutants from actively decomposing waste into leachate. The high amount of food remains in the waste composition during the summer season increases the organic content of the leachate and microbial activity. Food originated compounds have high biodegradability because of their organic nature. In addition, the increase in the temperature in the summer months may increase the microbial activity by activating the bacterial enzymes in order to degrade the organics (Khattabi et al., 2002). Temperature affects the biological reactions and acidogenic degradation is less sensitive to temperature. Solubility could also increase with increasing temperature depending on the component (Kylefors et al., 2003). In accordance with the forgoing discussion, BOD and COD concentrations in the Main Valley was not affected from temperature enhancements as much as the T Valley during summer months and at the beginning of the autumn. Because, seasonality indices in the open Main Valley were less than in the closed T Valley during dry season. Acidic decomposition stage in the Main Valley was less responsive to temperature increases during summer months than the T Valley, which was very close to methanogenic stage.

The differences in the Main and T Valleys within the same landfill were most likely due to the different stabilization stages and reactions in the valleys. The thickness of the wastes in the landfill also affects the seasonality. The waste thickness of the T Valley was 28 m, and about 14 m in the Main Valley. Leachate quality would not be affected from ambient air temperature and rainfall as the waste thickness increases.

The seasonal variations in leachate quality are due to seasonal differences in waste composition, rainfall and temperature. The design of the landfills and leachate treatment plants should consider the seasonal variations in the leachate quality and quantity.

4.2.3. Results of Factor Analysis

As mentioned in Section 3.3.3, factor analysis, which is a MVDA method, useful for reducing information in a large number of variables into a smaller set. Factor analysis was used to determine interrelationships between several leachate parameters simultaneously. Varimax rotation, which simplifies the columns of the factor matrix, was applied for the determination of relationships among variables. Evaluating the results of correlations between leachate parameters simultaneously, some of the analyses can be excluded from the leachate monitoring program.

In this study, factor analysis was used to obtain inter-correlated parameters for 19 leachate quality parameters (BOD, COD, pH, S, EC, total CrO_4, Cr^{6+}, Fe, Cu, CN^-, F, Zn, Pb, total P, NH_4-N, total N, SO_4, S, total alkalinity) in both closed T and open Main Valleys. In the case of leachate parameters from the T Valley 5 principal component factors have been extracted, corresponding to 81 % of the variability in the original data. In the Main Valley 4 principal component factors have been generated accounting for 82 % of the variability in the data. The grouped leachate parameters were determined based on their loadings for extracted factors. For the closed T Valley and the open Main Valley factor loadings of leachate parameters after Varimax rotation are given in Table 4.31 and 4.32.

Table 4.31. Varimax Rotated Factor Matrix for Leachate Parameters in closed T Valley

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
BOD	0.92				
COD	0.88				
pH			0.85		
SS	0.75				
EC			0.70		
Tot CrO_4	0.93				
Cr^{6+}	0.95				
Fe	0.88				
Cu	0.78				
CN^-		0.73			
F				0.82	
Zn		0.86			
Pb		0.74			
Tot.P				0.67	
NH_4 N		0.79			
Tot.N		0.74			
SO_4					-0.75
S^{2-}	0.60				
Tot.Alk			0.82		

SO_4 in the closed T Valley was not correlated with other leachate parameters. The leachate parameters that were grouped by their correlations for the closed T Valley were as follows:

- BOD, COD, SS, total CrO_4, Cr^{6+}, Fe, Cu, S
- CN, Zn, Pb, NH_4-N, total N
- pH, EC, total alkalinity
- F, total P

Table 4.32. Varimax Rotated Factor Matrix for Leachate Parameters in open Main Valley

	Factor 1	Factor 2	Factor 3	Factor 4
BOD	0.92			
COD	0.94			
pH				
SS	0.81			
EC	0.81			
Tot CrO_4		0.83		
Cr^{6+}		0.81		
Fe	0.90			
Cu		0.82		
CN^-		0.52		
F	0.89			
Zn		0.90		
Pb	0.64			
Tot P				0.79
NH_4-N			0.80	
Tot N			0.67	
SO_4	0.86			
S^{2-}		0.57	0.59	
Tot. Alk.				

Leachate parameter, not correlated with other parameters, was pH and total P in the Main Valley. Leachate parameters grouped by their correlations for the open landfill were as follows:

- BOD, COD, SS, EC, Fe, F, Pb, SO_4
- Total CrO_4, Cr^{6+},Cu, CN, Zn, S
- NH_4-N, total N, S, total alkalinity

The results for the closed and open landfills obtained from factor analysis were different due to the different degree of waste stabilization in the valleys. For example, total P was correlated with F in the closed T Valley, while not correlated with any parameters in the open Main Valley. However, BOD, COD and Fe were correlated in both valleys.

4.2.4. Sampling Strategies for Leachate Monitoring Program

Evaluating the results of conventional statistical analysis (standardized skewness coefficient and CV), time series analysis (auto- and cross- correlation coefficients) and factor analysis sampling strategies were developed for the closed and open landfills similar to closed T and open Main Valleys. The lag periods, at which leachate parameters had statistically significant correlation, statistically correlated leachate parameters, and distribution and variability of leachate parameters were the basis of the sampling strategies. If a leachate parameter had statistically correlated at lag k, it can be measured once at k month. In addition, leachate parameters with non-normal distributions and high variabilities should be analyzed more frequently due to higher fluctuations in data.

The leachate parameters, which are statistically auto- and cross- correlated, the ones which can be excluded from the leachate monitoring program, and the time periods required for the measurement of these leachate parameters were listed in Sections 4.2.4.1 and 4.2.4.2 for the closed and open valleys, respectively.

As mentioned in Section 3.1., Bursa has an average annual temperature of 14.4 ^{o}C based on 42-year temperature data, and annual rainfall of about 706 mm based on 52-years rainfall data. The solid waste disposed of in Bursa MSWL consists of mainly municipal solid waste with a fraction of about 95 %. The solid waste consists of an organic fraction of 54 %, recyclables of 36 % and 10 % of ashes and residuals.

The 8 years-old closed T Valley had a waste thickness of 28 m with an area of 8.8 ha. The waste amount in this valley was about 1,400,000 ton by the end of October 2003. The T Valley was close to the methanogenic conditions due to its low BOD/COD ratio. Whereas, the 4 years-old open Main Valley-2nd Stage had a waste thickness of about 14 m with an area of about 12 ha. The amount of solid waste in this valley was about 1,300,000 ton by the end of October 2003. This valley is still in acidogenic phase due to the high BOD/COD ratio.

For the T Valley, the lag periods, at which leachate parameters had statistically significant correlations, were more than that for the Main Valley (see Table 4.24). In addition, the T Valley usually had higher number of leachate parameter couples that have statistically significant correlations up to different lags (see Tables D.17 and D.18). For a parameter, the number of lag periods, having statistically significant relationship affects the sampling frequency and thus the number of leachate sample need to be analyzed in a monitoring program. The longer the statistically significant lag periods, the longer the sampling frequency; and the higher the number of statistically significant cross-correlated leachate parameters, the lower the number of leachate parameters to be monitored. For example, in order to observe the variations, SS can be measured once in 4 months in the T Valley, while once in 2 months in the Main Valley based on autocorrelation coefficients.

The findings of the conventional statistical analyses shows that the leachate parameters had generally normal distributions and less variation in the open Main Valley than in the closed T Valley. As a result, the leachate parameters with non-normal distributions and high variabilities should be measured more frequently in the T Valley.

Leachate parameters usually had higher concentrations during dry seasons due to low rainfall amount and high food remains. Therefore, leachate parameters should be analyzed more often during summer seasons in order to observe the fluctuations and overloads of the pollutants.

Leachate flow rate in the closed T Valley had a statistically significant relationship up to lag 1 at 95 % confidence level. That is, the leachate flow rate in the T Valley can be measured once a month. There was no statistically significant correlation at different lags for the leachate flow rate in the Main Valley. Therefore, flow rate is more critical in the open valley and needs to be measured more frequently, once a week.

4.2.4.1. Recommendations for Sampling Strategies for the Closed Landfills

Since BOD and COD had a relatively strong relationship at lag 0, measuring only one of these parameters is enough in order to observe the variation in other parameter. Although the lags, at which BOD and COD were statistically correlated, were 5 months, it is suggested to measure these parameters once in 4 months in order to reduce the cost of analyses in the leachate monitoring program on the basis of the high variability in these parameters. In addition to statistical and time series analyses, critical parameters for leachate composition were also considered for recommendation of sampling sampling strategies. For example, although pH was statistically correlated with both BOD and COD, pH is recommended to measure instead of being estimated.

Total CrO_4 and Cr^{6+} had relatively strong relationship at lag 0. Thus, one of these parameters is enough to be included in the leachate monitoring program.

Two different options for measurement of Fe, Cu, Pb, Zn, CN^- and F were recommended based on the result of data analyses. The difference for these options were the leachate parameters to be measured and required measurement time periods. Although the 1st option requires measurement of more parameters than the 2nd option, the choice for the measurement option depends on the available sources (such as staff and time) and parameters considered critical.

Since SO_4 had not any crosscorrelation with other leachate parameters and statistically correlated at lag 1 it should be measured each month. The groups of leachate parameters, one of which can be included in the leachate monitoring program and help estimate the other parameter(s), and required time period for measurement were listed as follows.

- BOD, COD	(4 months)			
- pH	(4 months)			
- Total CrO_4, Cr^{6+}	(3 month)			
- Fe, Cu	(4 months)		Fe, Cu, Pb	(2 months)
- Pb, F	(2 months)	or		
- Zn, CN^-	(2 months)		F, Zn, CN^-	(3 months)
- SS, total P	(2 months)			
- Total N, NH_4-N	(2 months)			
- SO_4	(1 month)			
- Total alk., EC, S	(1 month)			

4.2.4.2. Recommendations for Sampling Strategies for the Open Landfills

The leachate parameters in the open Main Valley should be measured more often than in the T Valley due to the shorter lag periods, at which leachate parameters had statistically significant correlations. For example, pH can be measured once at 2 months in the Main Valley, while once in 4 months in the T Valley based on the autocorrelation coefficient.

Observing the lag periods, at which BOD and COD had statistically significant correlations, COD was a more critical parameter than BOD due to the lag periods of 3 and 2 months, respectively. Therefore, it was suggested that BOD or COD measurements should be performed at least 2 month period to estimate the unmeasured parameter.

In the open Main Valley, total CrO_4 and Cr^{6+} had also relatively strong relationship at lag 0 as in the closed T Valley. Thus, one of these parameters is enough to be analyzed in the leachate monitoring program, each month.

CN^- had not any statistically significant crosscorrelation with other leachate parameters and statistically correlated at lag 1. Therefore, instead of being estimated it should be measured once a month. Total P had not any crosscorrelation with other leachate parameters and statistically correlated at lags 2, it should be measured once in every 2 months.

One of NH_4-N and total N should be measured to estimate the other and should be mesured each month. Total alkalinity should be measured at least one or twice each month due to the lack of statistically significant correlations at any lags.

The groups of leachate parameters, one of which can be included in the leachate monitoring program and help estimate the other parameter(s), and required time period for measurement were as follows.

- BOD, COD (2 months)
- pH (2 months)
- Total CrO_4, Cr^{6+} (1 months)
- Pb (3 months)
- F, SO_4, SS (2 months)
- Fe, EC (1 month)
- Cu, Zn, S (2 months)
- NH_4-N, total N (1 month)
- Total P (2 months)
- Total Alkalinity (Once or twice a month)
- CN^- (1 month)

4.2.5. Implication of Leachate Quantity and Quality Data for Leachate Treatment

Water input to the landfill is an important factor affecting decomposition of the waste. High water input may result in higher pollutant concentrations due to the solubilization of pollutants from actively decomposing waste mass into leachates. Rain water percolating through the landfill extracts and solubilizes several constituents, producing a larger volume of dilute leachate and decreasing the pollutant concentrations. In Mediterranean type climates, it is expected to have higher leachate contamination in the summer months due to low rainfall amount.

Landfill operation and the sequence of waste deposition into the landfill are also important in the amount of organic matter in leachate and decomposition of waste. Fresh waste deposited on old waste layers results in decrease in pollutant concentrations of fresh leachate in acid phase. Because, old waste under the fresh waste behave as a bioreactor and treats the highly concentrated fresh leachate deposited on it. The high amount of COD concentration in the fresh leachate is consumed as the fresh leachate passing through the well-decomposed and thus carbon limited refuse (Kjeldsen et al., 2002). Therefore, the ratio of the area covered by the old waste to the area covered by fresh waste is an important operational parameter affecting waste degradation and thus organic composition of leachate. As this ratio increases, organic matter concentrations in leachate decrease. Based on a modeling study, Yıldız et al. (2004) reported that waste placement sequence can be an important factor affecting leachate quality. If there is no old waste below the fresh waste, leachate will be highly concentrated, because it will directly be carried to the leachate drainage system without treatment by old waste. The amount of water infiltration and the landfill development are important factors affecting leachate composition and can be controlled by the landfill design and operational procedures.

Sewage treatment methods are different than landfill leachate treatment. There are several biological, chemical and physical treatment methods for leachate treatment. In order to design a sustainable and cost-effective leachate management system, site specific leachate quality and quantity data is required. Analysis of available leachate data for Bursa landfill can be used to develop alternative leachate treatment methods in Turkey due to the similar climatological conditions and waste composition. It was demonstrated that leachate has a strong pollutant loads and requires advanced treatment techniques. Most commonly used biological leachate treatment methods are activated sludge, sequencing batch reactor (SBR), aerated stabilization basin, fixed film processes (trickling filters, rotating biological contactors), anaerobic lagoons, and nitrification/denitrification (Tchobanoglous and Kreith, 2002).

As mentioned in Section 1.2 leachate treatment methods should take the maximum pollutant concentrations into account in order to handle the overload of leachate pollutant concentrations. Leachate treatment methods should be flexible enough in order to account for transition from fresh to old leachate. In addition, leachate treatment alternatives should adopt the leachate strength, seasonal variations and variations of leachate pollutants with the age of the landfill.

The maximum average monthly BOD and COD during the post-closure period of the 8 years-old closed T Valley were 11,428 mg/l and 16,609 mg/l, excluding BOD and COD measurements in the month of the emergency waste disposal, July and August 2002, which caused a sudden increase in leachate strength due to fresh waste disposal over the closed valley. BOD and COD remained nearly constant after March 2001 and after December 2000, respectively in the T Valley. High concentrations of monthly average BOD and COD, with maximum concentrations of 50,150 mg/l and 63,325 mg/l, respectively, were observed in young leachate from the 4 years-old open Main Valley.

BOD/COD ratio showed a decreasing trend after the closure of the T Valley and it was higher in the open Main Valley. BOD/COD ratio in the T Valley was almost steady after December 2000 with a value of about 0.1. It can be said that the acidogenic phase lasted about 4 years (3-years pre-closure, 1-year post closure period) in the T Valley. BOD/COD ratio in the Main Valley was still high in August 2004 with a value of about 0.5-0.6 due to acidogenic conditions prevailing due to fresh waste deposition.

NH_4-N in leachate from Bursa MSWL was an important pollutant parameter having a maximum concentration above 2,500 mg/l in both fresh and old leachates from the T and Main Valleys. Leachate included several inorganics including heavy metals. Metal, inorganic and SS concentrations usually showed a decreasing trend with waste age. Metal content was generally quite low except iron, zinc and lead in acidogenic leachate. Leachate strength usually increased during summer season due to the increase in temperature and food remains resulting in high microbial activity. On the other hand, leachate pollutants showed a decreasing trend during wet season due to dilution effect of rainfall.

Due to significant differences in old and fresh leachates from the T and Main Valleys different treatment processes are required. The change in the leachate quality and quantity with the age of the landfills should be taken into account when designing leachate treatment processes. After the closure of the landfill BOD, COD and metal concentrations generally showed significant decreasing trends with waste age, while NH_4-N concentration was still high for the old leachate in Bursa MSWL-T Valley. Therefore, after the closure of the landfill, treatment processes should focus on removal of ammonia and refractory organics. Several alternatives for leachate treatment, similar to leachate from Bursa MSWL, were discussed in the following paragraphs.

The leachates having low concentrations of metals do not require a treatment process to decrease the metal content in leachate. In addition to low content of metals in leachate compared to the regulatory target effluent concentrations (e.g. in the Turkish Regulation), significant removals of some of the metals by aerobic and anaerobic treatment can be achieved (Blakey et al., 1992). SS does not also require a separated removal process, becaues biological treatment also reduce SS concentration by sedimentation (McBean et al., 1995).

Considering the fresh leachate composition of Bursa MSWL, young leachate from the Main Valley and pre-closure period of the T Valley containing high BOD, COD, BOD/COD ratio and NH_4-N requires biological treatment. However, biologically treated leachate still has high concentration of organics and should be reduced further (Ehrig and Stegmann, 1992). It is difficult to treat biologically treated old leachate that requies physical/chemical treatment.

Currently operational leachate treatment plant in Bursa MSWL, from which treated leachate is transferred to wastewater treatment plant with sewer system, includes aerated lagoon, facultative lagoon and sequencing batch reactor. Leachate treatment plant does not include any other further treatment method due to the fact that effluent is transferred to Bursa wastewater treatment plant. This processes applied for leachate from Bursa MSWL were suitable for discharging into sewer system of the city.

On-site treatment alternatives, which require extensive treatment, for fresh and old leachates were developed on the basis of leachate characteristics of Bursa MSWL. These alternatives were Alternatives for on-site treatment of fresh and old leachates similar to leachates from Bursa MSWL were presented as follows. These alternatives were suggestions that based on generalizations, thus a treatability study must be conducted.

Fresh Leachate:

Alternative 1:

- Equalization pond
- Anaerobic treatment process (Upflow anaerobic sludge blanket reactor , UASB)
- Biological nitrification/denitrification process or air stripping
- Physical/chemical treatment (Carbon adsorption or chemical oxidation)

Since leachate quality and quantity are highly fluctuated, an equalization pond is beneficial to balance leachate quality and quantity fluctuations. Anaerobic treatment should be applied in order to reduce high organic strength. UASB is an effective method in removal of high strength organics in leachate and can be used for fresh leachate from Bursa MSWL. Nitrification/denitrification or air stripping should follow anaerobic treatment in order to remove ammonia, which is in high concentration in old leachate and not removed during anaerobic treatment. Finally, in order to remove remaining refractory organics, physical/chemical process should be applied. Carbon adsorption can be applied to remove poorly biodegradable organics in pre-treated leachate, color and refractory organics (McBean et al., 1995). Chemical oxidation can also be used to remove ammonia, residual organics and bacterial and viral content of leachate after biological treatment (Tchobanoglous and Burton, 1991).

Alternative 2:

- Equalization pond
- Aerobic treatment (Aerated lagoon, sequencing batch reactor, SBR)
- Denitrification
- Physical/chemical treatment (Carbon adsorption or chemical oxidation)

Aerobic treatment is an effective method for treatment of high organic load in fresh leachate. Aerated lagoon can be applied in removal of organics and ammonia in leachate. SBR is also suitable particularly for the higher organic strength and concentrations of ammonia-N in leachates. It has the ability to vary the time sequence, as opposed to the inflexibility of specific volumes of separate tanks, providing a flexible leachate treatment system (Environmental Agency, 2005). Aerobic treatment should be followed by denitrification step in order to convert nitrate nitrogen, produced during nitrification, to nitrogen gas. Carbon adsorption and chemical oxidation are also recommended for the leachate treated aerobically.

<u>Old Leachate:</u>

Old leachate requires different treatment processes than fresh leachate due to the variation of leachate quality and quantity. Due to small leachate flow generation rate and nearly stabilized concentrations of leachate pollutants in the closed landfill, equalization tank is not needed. Since readily degradable organic compounds diminish with waste stabilization over the years and efficiency of biological processes decreases, physical/chemical processes are more suitable in treatment of old leachate having refractory organics. Ammonia-N was also high in old leachate from Bursa MSWL-T Valley. Therefore, as also mentioned before, leachate treatment should focus on removal of ammonia and refractory organics in old leachate. The biological treatment alternatives recommended for fresh leachate are not needed for old leachate. However, physical and chemical processes should continue to operate for old leachate. The treatment alternatives for old leachate, the features of which were given before, are as follows.

Alternative 1: Physical/chemical treatment (Air stripping and carbon adsorption)

Alternative 2: Physical/chemical treatment (Chemical oxidation)

CHAPTER 5

SUMMARY AND CONCLUSION

In this study, chemical composition, quality and quantity variations in the leachate of Bursa MSWL were investigated using landfill data, collected weekly and in some instances monthly, during the last 7 years from 1998 to 2004. A simple water balance method was applied for the closed T and open Main Valleys in 2003 using monthly precipitation and temperature data from Bursa Meteorological Station. Then, a conventional statistical analysis of leachate quality and quantity data was carried out to characterize pollution parameters of “fresh” and “old” leachates. Next, a time series analysis was carried out and data characteristics such as randomness and seasonality were examined. The crosscorrelations between leachate parameters and autocorrelations within parameters were also analyzed using time series analysis. In addition, factor analysis was performed in order to determine the correlations between several leachate parameters simultaneously.

The annual leachate amount determined using WBM was 19 % and 60 % of the annual precipitation in the closed T and open Main Valleys, respectively. Since the Main Valley was open, the amount of leachate generation was very high compared to the closed T Valley. The annual measured leachate amount corresponded to 36 % of leachate amount determined using WBM in the T Valley due to the fact that WBM does not take into account time period required for waste to reach its field capacity. The annual measured leachate amount in the Main Valley, corresponded to 163 % of leachate amount determined by WBM for the Main Valley. The estimation of leachate flow rate by WBM was found to be lower than the measured value in the open Main Valley due to the water content of waste and other water inputs to the landfill, which are not taken into account in WBM method. The measured annual leachate generation rate in the closed T and open Main Valley was about 7 % and 98 % of the annual total rainfall amount in 2003, respectively. This situation implies significant moisture supply by the waste itself in the Main Valley.

Leachate from Bursa MSWL contained a variety of organics, inorganics and metals at much higher concentrations than the typical wastewater. The leachate quality and quantity for Bursa MSWL showed large fluctuations for both closed T and open Main Valleys. Leachate parameters showing normal distribution in the post-closure period of the T Valley were pH, total alkalinity, NH_4-N, total P, EC, Pb, Cu, Cl and S. In the T Valley, leachate quality parameters having high variability were BOD, EC, Fe, Zn, Pb, CN^- and F. In the closed T Valley, leachate quality parameters having high variability were BOD, $Cr^{6+}$and total CrO_4. Leachate quality parameters, including COD, pH, total alkalinity, NH_4-N, total N, EC, Zn, Cu, Cr^{6+}, total CrO_4, CN^-, Cl, SO_4, S and SS were in the normal distribution range and only Fe and F had high variability in the Main Valley. The T Valley had final cover and older than the Main Valley and therefore the wastes in this valley were more stabilized. Pre- and post-closure periods for the T Valley also demonstrated variations. During pre-closure period, leachate generally had higher pollutant concentrations due to fresh waste disposal. Organic, inorganic components and metal concentrations decreased after the closure of the valley. However, after closure, due to unexpected emergency disposal of fresh waste in the T Valley in June 2002, leachate strength increased for a short period again. This showed the high pollutant load of fresh leachate. BOD, COD and other inorganics were lower, while pH value was higher in the T Valley. The Main Valley was an open valley and had been operating since October 2000. Therefore, in the Main Valley leachate was generally characterized by higher pollutant concentrations and lower pH values. Average BOD/COD ratio was 0.33 in the T Valley and 0.60 in the Main Valley. This ratio is an indicator for the decomposition stages in the landfill. Although metal concentrations did not show a clear trend, they generally decreased with the age of the landfill in both closed T and open Main Valley. Fe is the metal with the highest concentration in the leachate as in the other landfills reported in the literature. The waste composition is a significant factor affecting metal content in leachate. Pollutant concentrations in leachate were generally decreased with waste age in both valleys and they were in the range of typical values reported in the literature.

It was observed that leachate generally contains higher concentrations of pollutants during dry seasons. In addition, the food remains were higher during dry season and could increase microbial activity with increasing temperature, resulting an increase in leachate strength due to enhanced decomposition rate of solid waste. On the other hand, it contained lower concentrations during wet seasons due to dilution of leachate.

The 8 years-old closed T Valley was in the advanced state of biodegradation and close to methanogenic conditions due to high pH and relatively lower pollutant concentrations. On the other hand, the 4 years-old open Main Valley was in the acetogenic stage due to higher pollutant concentrations and lower pH values. The acetogenic phase lasted about 4 years in the T Valley due to nearly constant BOD/COD ratio of about 0.1 after December 2000. While, BOD/COD ratio in the Main Valley was still high in August 2004 with a value of about 0.5-0.6 due to acidic conditions .

It was found through time series analysis that leachate flow rate is more critical in the open Main Valley and should be measured once a week. There were not many statistically significant relationships found between flow rate and leachate quality parameters in Bursa MSWL. BOD, COD concentrations had statistically significant correlation with each other and had inversely statistically significant correlation with pH values in both valleys. The all possible combinations of crosscorrelations between couples of leachate parameters were determined in order to develop sampling strategies for the leachate monitoring program of closed T and open Main Valleys.

Optimum landfill leachate monitoring programs should include a minimum number of measured parameters in order to reduce the labor and cost of monitoring.

Because, it may not always be feasible to measure a large number of leachate parameters for a landfill. Using standardized skewness coefficients, coefficient of variation, auto- and cross- correlation coefficients within and between leachate parameters determined by time series analysis, and factor analysis, sampling strategies for leachate monitoring programs were developed for landfills similar to the closed T and open Main Valleys of Bursa MSWL. The lag periods, at which leachate parameters had statistically significant correlation, statistically correlated leachate parameters, and distribution and variability of leachate parameters were the basis of the recommendations for sampling strategies. In addition to conventional statistical and time series analyses, critical parameters for leachate composition were also considered when recommending sampling strategies. The recommendations based on the results of this study were listed in Sections 4.2.4.1 and 4.2.4.2.

The sampling recommendations may be applicable for closed and open landfills similar to closed T and open Main Valleys, respectively, in age, leachate composition, landfill operation and climatological condition. The leachate parameters in the open landfills should be measured more frequently than in the closed landfills. In the closed landfills, one of BOD or COD, one of which would help estimate unmeasured one, should be measured once in every 4 months. pH also should be measured once in every 4 months. Since total CrO_4 and Cr^{6+} had relatively strong relationship, one of these parameters is enough to be included in the leachate monitoring program and should be measured once in every 2 months in the closed landfill. SO_4 had not any crosscorrelation with other leachate parameters and statistically correlated at lag 1, thus it should be measured each month. In the open landfills similar to the Main Valley, BOD or COD, total CrO_4, Cr^{6+}, total P and pH one of should be measured once in every 2 months. CN^- should be measured once in a month. Total alkalinity should be measured at least one or twice each month due to the lack of statistically significant correlations at any lags in the open landfill. NH_4-N or total N should be measured each month.

Several leachate treatment alternatives were recommended based on the leachate composition and site conditions of Bursa MSWL. Leachate is first fresh and it becomes old; so, suggested on-site treatment alternatives should be flexible enough to account for transition from fresh to old leachate. Considering the fresh leachate composition of Bursa MSWL, young leachate from the Main Valley and pre-closure period of the T Valley containing high BOD, COD, BOD/COD ratio and NH_4-N requires biological treatment. After the closure of the landfill BOD, COD and metal concentrations generally showed significant decreasing trends with waste age, while NH_4-N concentration was still high for the old leachate in Bursa MSWL. Therefore, after the closure of the landfill, treatment processes should focus on focus on removal of ammonia and refractory organics.

The leachates having low concentrations of metals do not require a treatment process to decrease the metal content in leachate, because their concentrations were relatively low when compared to the effluent values in the regulations and significant metal removals can be achieved by aerobic or anaerobic treatment. Biological treatment also reduce SS concentration by sedimentation. Since leachate quality and quantity are highly fluctuated, an equalization pond is beneficial to balance leachate quality and quantity fluctuations. First alternative for fresh leachate treatment was anaerobic treatment (UASB), nitrification/denitrification or air stripping, and physical/chemical treatment steps (chemical oxidation and carbon adsorption). Second alternative includes aerobic treatment (aerated lagoon or SBR), denitrification, and physical/chemical treatment steps. Old leachate does not require biological treatment applied for fresh leachate. The treatment alternatives for old leachate, which requires physical/chemical treatment in order to remove ammonia, were air stripping, carbon adsorption and chemical oxidation.

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APPENDIX A: Solid Waste Amounts in Bursa MSWL between 1995 and 2003

Table A.1. Solid Waste Amount Disposed of in Bursa Landfill in 2000 (Ton)

SOURCE / MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
Osmangazi Municipality	15763	16353	16801	12983	16917	14001	14031	13594	15068	15215	14416	15384	180529
Yıldırım Municipality	10168	10754	11670	8845	9249	9456	9622	9197	10088	10099	9864	10620	119631
Nilüfer Municipality	2223	2408	2629	2399	2699	2564	2588	2548	2928	2820	2635	2705	31146
Central Municipalities MSW	**28154**	**29514**	**31101**	**24227**	**28867**	**26020**	**26241**	**25339**	**28084**	**28134**	**26915**	**28709**	**331305**
Mudanya Municipality	521	530	572	502	643	600	742	705	684	630	543	571	7243
Güzelyalı Municipality	179	206	223	190	281	323	549	492	332	221	194	237	3428
Demirtaş Municipality	207	223	238	89	232	175	194	172	212	192	203	238	2375
Görükle Municipality	168	179	281	174	299	245	244	222	109	150	278	264	2611
Emek Municipality	514	521	548	219	530	409	422	370	452	495	490	556	5525
Çalı Municipality	102	125	101	402	141	96	70	104	138	101	80	62	1522
Ovaakça Municipality	0	76	79	63	101	77	80	57	101	106	104	117	962
Zeytinbağı Municipality	0	0	0	0	8	58	58	65	71	62	52	47	422
Other Municipalities MSW	**1692**	**1859**	**2043**	**1639**	**2235**	**1984**	**2359**	**2187**	**2097**	**1957**	**1945**	**2094**	**24089**
Commercial and Industrial MSW	975	1516	1457	1848	1759	1496	1610	s1406.96	1548	1864	1755	1199	18434
Yard. Street Wastes	127	210	195	282	216	220	113	99	240	115	250	113	2180
Institutional MSW	**1102**	**1726**	**1653**	**2130**	**1975**	**1715**	**1723**	**1505**	**1788**	**1979**	**2005**	**1312**	**20614**
TOTAL MSW	***30949***	***33099***	***34796***	***27996***	***33077***	***29720***	***30323***	***29031***	***31969***	***32070***	***30865***	***32114***	***376008***
Non-hazardous Process Wastes	986	1168	1375	1580	2136	1694	1631	1517	1971	1926	1980	1255	19218
Slaughterhouse Waste	174	148	179	240	138	220	113	99	112	115	104	83	1724
Sludge	112	429	591	439	232	216	407	224	378	187	343	224	3783
TOTAL INDSUTRIAL S.W	***1271***	***1745***	***2145***	***2258***	***2507***	***2129***	***2152***	***1839***	***2461***	***2228***	***2427***	***1562***	***24725***
MEDICAL WASTE	***59***	***65***	***63***	***66***	***77***	***70***	***69***	***60***	***70***	***74***	***75***	***62***	***810***
TOTAL	**32279**	**34910**	**37004**	**30320**	**35661**	**31919**	**32544**	**30930**	**34500**	**34372**	**33367**	**33738**	**401543**

Table A.2. Solid Waste Amount Disposed of in Bursa Landfill in 2001 (Ton)

SOURCE / MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
Osmangazi Municipality	15325	13713	14143	12714	12974	12800	13507	14494	13568	13251	14210	15780	166479
Yıldırım Municipality	10105	9046	9974	8597	8938	10143	9435	10100	9526	9362	10071	10870	116167
Nilüfer Municipality	2573	2251	2522	2350	2458	2475	2566	2735	2706	2630	2543	2428	30238
Central Municipalities MSW	**28003**	**25011**	**26639**	**23661**	**24369**	**25418**	**25508**	**27330**	**25800**	**25243**	**26824**	**29078**	**312884**
Mudanya Municipality	548	513	550	513	538	568	742	773	636	547	508	534	6970
Güzelyalı Municipality	198	177	210	196	227	338	576	596	612	195	160	214	3697
Demirtaş Municipality	217	210	187	180	169	167	173	195	171	183	190	250	2293
Görükle Municipality	251	235	261	248	227	241	272	294	259	269	257	275	3088
Emek Municipality	580	546	521	451	434	371	401	429	390	436	517	597	5674
Çalı Municipality	89	82	86	104	67	85	107	121	134	103	111	115	1205
Ovaakça Municipality	122	110	191	101	100	97	105	104	112	104	108	113	1366
Zeytinbağı Municipality	51	47	56	49	54	49	63	75	70	51	50	57	672
Gürsu Municipality	0	0	0	0	0	0	895	484	519	471	594	675	3638
Kestel Municipality	0	0	0	0	0	0	0	23	525	590	571	783	2493
Other Municipalities MSW	**2057**	**1920**	**2062**	**1843**	**1816**	**1915**	**3335**	**3093**	**3428**	**2950**	**3065**	**3612**	**31096**
Commercial and Industrial MSW	1380	1419	1217	1873	1927	1606	1635	1591	1638	1456	1375	1505	18621
Yard. Street Wastes	154	138	210	167	160	211	276	244	201	139	154	97	2151
Institutional MSW	**1534**	**1557**	**1428**	**2040**	**2088**	**1818**	**1911**	**1834**	**1839**	**1596**	**1528**	**1601**	**20772**
TOTAL MSW	***31594***	***28488***	***30129***	***27543***	***28273***	***29151***	***30755***	***32257***	***31066***	***29789***	***31417***	***34291***	***364753***
Non-hazardous Process Wastes	1392	1262	1294	1354	1354	1145	1316	1524	1530	1530	1193	1000	15894
Slaughterhouse Waste	155	72	128	100	115	91	74	84	77	103	91	93	1182
Sludge	338	244	285	214	513	267	359	426	92	811	1061	358	4970
TOTAL INDSUTRIAL S.W	***1885***	***1578***	***1707***	***1668***	***1982***	***1504***	***1750***	***2034***	***1699***	***2444***	***2344***	***1451***	***22045***
MEDICAL WASTE	***76***	***71***	***73***	***73***	***78***	***76***	***79***	***81***	***71***	***81***	***76***	***69***	***903***
TOTAL	***33555***	***30137***	***31909***	***29284***	***30333***	***30731***	***32584***	***34372***	***32836***	***32314***	***33837***	***35811***	***387703***

Table A.3. Solid Waste Amount Disposed of in Bursa Landfill in 2002 (Ton)

SOURCE / MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
Osmangazi Municipality	15388	13704	13195	13577	13075	12582	15933	15780	15484	15240	14692	15858	174508
Yıldırım Municipality	10980	10039	9354	9747	9369	9891	11489	11386	11013	10940	10551	11357	126116
Nilüfer Municipality	2575	2378	2445	2643	2627	2859	3330	3367	3390	3247	2895	2877	34634
Central Municipalities MSW	**28943**	**26121**	**24995**	**25968**	**25072**	**25332**	**30752**	**30532**	**29887**	**29427**	**28138**	**30091**	**335258**
Mudanya Municipality	484	451	486	510	558	631	842	867	739	604	545	570	7288
Güzelyalı Municipality	189	177	189	204	240	381	667	649	403	249	187	226	3761
Demirtaş Municipality	190	210	189	180	190	173	221	247	241	208	243	257	2547
Görükle Municipality	262	223	221	248	225	252	313	323	328	304	287	304	3289
Emek Municipality	375	506	462	495	433	397	818	498	493	527	554	645	6205
Çalı Municipality	95	90	110	127	41	25	36	16	27	38	78	80	763
Ovaakça Municipality	120	113	101	106	100	91	116	116	126	121	113	137	1359
Zeytinbağı Municipality	52	48	44	47	55	61	71	77	75	64	59	60	713
Gürsu Municipality	621	522	526	573	482	441	561	61	386	392	360	488	5414
Kestel Municipality	632	215	0	0	0	0	0	0	0	0	0	0	847
Other Municipalities MSW	**3021**	**2554**	**2329**	**2490**	**2324**	**2452**	**3645**	**2853**	**2817**	**2507**	**2426**	**2766**	**32184**
Commercial and Industrial MSW	1187	1055	1415	1620	1851	1685	1898	1875	1724	1951	1461	1355	19076
Yard. Street Wastes	134	139	166	186	207	224	387	252	256	304	176	209	2641
Institutional MSW	**1321**	**1194**	**1582**	**1805**	**2058**	**1909**	**2285**	**2127**	**1980**	**2255**	**1637**	**1564**	**21716**
TOTAL MSW	***33285***	***29869***	***28905***	***30263***	***29454***	***29693***	***36682***	***35512***	***34684***	***34189***	***32201***	***34422***	***389159***
Non-hazardous Process Wastes	1104	1024	1314	1407	1273	1201	1538	1321	1562	1576	1278	1229	15827
Slaughterhouse Waste	132	81	133	107	53	88	88	57	99	70	63	68	1041
Sludge	378	152	323	359	278	874	537	261	395	1058	1389	636	6639
TOTAL INDSUTRIAL S.W	***1615***	***1257***	***1770***	***1874***	***1604***	***2162***	***2164***	***1638***	***2057***	***2704***	***2731***	***1933***	***23508***
MEDICAL WASTE	***68***	***64***	***79***	***78***	***83***	***79***	***88***	***80***	***81***	***84***	***81***	***80***	***945***
TOTAL	**34967**	**31191**	**30755**	**32214**	**31142**	**31934**	**38933**	**37230**	**36822**	**36976**	**35012**	**36435**	**413612**

Table A.4. Solid Waste Amount Disposed of in Bursa Landfill in 2003 (Ton)

SOURCE / MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	TOTAL
Osmangazi Municipality	15940	15404	16160	14425	13806	13793	15054	14853	15732	16357	151525
Yıldırım Municipality	11023	11082	11734	10335	9886	9819	10972	10491	10995	11551	107889
Nilüfer Municipality	2967	2668	2934	3029	3116	3170	3455	3370	3719	3628	32056
Central Mun. MSW	**29930**	**29154**	**30827**	**27789**	**26809**	**26782**	**29481**	**28714**	**30447**	**31536**	291469
Mudanya Municipality	576	519	552	537	575	657	803	823	717	631	6390
Güzelyalı Municipality	222	207	227	219	244	364	616	659	428	268	3454
Demirtaş Municipality	229	260	283	231	195	187	231	221	214	239	2289
Görükle Municipality	308	261	314	291	264	253	305	296	307	303	2901
Emek Municipality	642	608	640	561	500	451	505	501	552	614	5575
Çalı Municipality	122	103	104	109	67	43	71	49	61	31	759
Ovaakça Municipality	138	119	148	120	107	102	119	114	134	111	1212
Zeytinbağı Municipality	53	49	54	56	58	58	67	71	74	65	605
Gürsu Municipality	368	389	393	333	333	331	395	571	651	643	4407
Kestel Municipality	0	0	0	0	0	0	0	103	490	476	1068
Other Municipalities MSW	**2658**	**2514**	**2715**	**2458**	**2342**	**2445**	**3113**	**3407**	**3628**	**3381**	28661
Commercial and Industrial MSW	1547	1343	1495	1629	2128	1819	1923	1746	2051	2037	17719
Yard. Street Wastes	271	177	221	224	269	247	326	245	231	303	2514
Institutional MSW	**1819**	**1520**	**1716**	**1853**	**2397**	**2065**	**2249**	**1991**	**2282**	**2340**	20233
TOTAL MSW	***34407***	***33188***	***35258***	***32100***	***31549***	***31292***	***34843***	***34112***	***36357***	***37257***	340364
Non-hazardous Process Wastes	1310	1073	1416	1736	1519	1471	2271	2259	2086	2195	17336
Slaughterhouse Waste	187	98	145	495	248	82	50	99	107	122	1632
Sludge	131	56	44	14	106	223	226	199	279	115	1393
TOTAL INDSUTRIAL S.W	***1627***	***1227***	***1605***	***2245***	***1872***	***1776***	***2546***	***2557***	***2472***	***2433***	20360
MEDICAL WASTE	***92***	***67***	***87***	***86***	***89***	***86***	***92***	***81***	***88***	***89***	857
TOTAL	**36127**	**34481**	**36950**	**34431**	**33510**	**33154**	**37482**	**36750**	**38917**	**39778**	**361582**

Table A.5. Solid Waste Amount Disposed of in Bursa Landfill Between 1995-2003 (Ton)

SOURCE / YEAR	1995	1996	1997	1998	1999	2000	2001	2002	2003	TOTAL
Osmangazi Municipality	19142	126529	151649	160474	169778	180529	166479	174508	151525	1300612
Yıldırım Municipality	318	53629	89289	100847	114070	119631	116167	126116	10788909	827956
Nilüfer Municipality	5374	15785	19886	24812	28289	31146	30238	34634	32056	222220
Central Municipalities MSW	**24834**	**195942**	**260824**	**286133**	**312137**	**331305**	**312.884.06**	**335258**	**291469**	**2350787**
Mudanya Municipality	0	0	3992	6657	6950	7243	6970	7288	6390	45491
Güzelyalı Municipality	0	0	2102	3300	3551	3428	3697	376086	3454	23293
Demirtaş Municipality	0	1587	1612	1852	1863	2375	2293	2547	2289	16418
Görükle Municipality	345	2365	3521	191914	2042	2611	3088	3289	2901	22081
Emek Municipality	1067	3056	3301	4136	4985	5525	5674	6205	5575	39524
Çalı Municipality	0	294	432	989	1169	1522	1205	763	759	7132
Ovaakça Municipality	0	0	0	0	0	962	1366	1359	1212	4900
Zeytinbağı Municipality	0	0	0	0	0	422	672	713	605	2411
Gürsu Municipality	0	0	0	0	0	0	3638	5414	4407	13458
Kestel Municipality	0	0	0	0	0	0	2493	847	1068	4409
Gemlik Municipality	0	63	0	0	0	0	0	0	0	63
Kurşunlu Municipality	0	0	0	751	506	0	0	0	0	1258
Other Municipalities MSW	**1412**	**7364**	**14959**	**19604**	**21066**	**24089**	**31096**	**32184**	**28661**	**180436**
Commercial and Industrial MSW	1292	8109	9418	12284	11821	18434	18621	19076	17719	116775
Yard. Street Wastes	5	1682	2455	2729	2742	2180	2151	2641	2514	19099
Institutional MSW	**1297**	**9791**	**11874**	**15013**	**14563**	**20614**	**20772**	**21716**	**20.233.25**	**135874**
TOTAL MSW	**27543**	**213097**	**287657**	**320750**	**347766**	**376008**	**364753**	**389159**	**340364**	**2667097**
Non-hazardous Process Wastes	0	10559	15300	18226	13185	19218	15894	15827	17336	125544
Slaughterhouse Waste	0	0	5411	4421	1883	1724	1182	1041	1632	17295
Sludge	0	0	0	2938	3542	3783	4970	6639	1393	23264
TOTAL INDSUTRIAL S.W	**0**	**10559**	**20711**	**25585**	**18610**	**24725**	**22045**	**2350807**	**20360**	**166103**
MEDICAL WASTE	0	277	484	610	738	810	903	945	857	5625
TOTAL	**27543**	**223934**	**308852**	**346946**	**367114**	**401543**	**387701**	**413612**	**361582**	**2838825**

TableA.6. Average Daily Solid Waste Amounts Between 1995 and 2002 (Ton)

MONTHS	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
1996	330	385	499	380	619	663	754	692	747	736	777	761	7343
1997	781	860	832	828	721	757	817	815	926	904	888	1028	10156
1998	929	955	935	893	806	919	913	950	977	959	1042	1112	11389
1999	997	1073	1076	933	884	1006	1092	1015	1058	937	995	1011	12075
2000	1041	1247	1194	1011	1150	1064	1.050	998	1150	1109	1112	1088	13214
2001	1082	1076	1062	976	978	1024	1051	1109	1073	1042	1123	1155	12753
2002	1128	1114	992	1074	1005	1064	1298	1241	1227	1233	1167	1214	13757

Table A.7. Average Monthly Solid Waste Amounts Between 1995 and 2003 (Ton)

MONTHS	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
1995								2042	4373	5752	7910	74658	27543
1996	10234	10788	1547783	11391	19187	19905	23306	21467	22416	22802	23302	23657	22393
1997	24218	24067	25777	24847	22347	22703	25315	25264	27792	28032	26628	31862	308852
1998	28812	26736	28976	26900	24979	27567	29290	29452	29306	28769	31260	34999	346946
1999	30921	30005	33349	27978	27403	30192	33857	31453	31732	29044	29835	31345	367114
2000	32279	34910	37004	30320	35661	31919	32544	30930	34500	34372	33367	33738	401543
2001	33555	30136	31910	29284	30333	30731	32583	34372	32836	32314	33838	35811	387701
2002	34967	31191	30755	32214	31142	31934	38933	37230	3682218	36976	35012	36435	413612
2003	36127	34481	36950	34431	33510	33154	37482	36750	38917	39778	0	0	361582

APPENDIX B: Leachate Qualİty Data From Bursa MSWL

Tablo B.1. Leachate Quality Data for T Valley (1997-2004)

							1997					
Parameter	January	February	March	April	May	June	July	August	September	October	November	December
COD		46082	39828	40613	48500	42680	39984	43840	55513	55891	42627	39222
							1998					
BOD	32750	32167	16675	11580	14316	17634	25800	20517	26792	21500	27250	26575
COD	42588	41333	24178	18210	21712	31377	39357	30894	41390	26933	37400	38600
BOD/COD	0.77	0.78	0.69	0.64	0.66	0.56	0.66	0.66	0.65	0.80	0.73	0.69
pH	7.31	7.48	7.12	7.30	7.10	7.15	6.83	7.14	6.92	7.14		
SS										18250		
EC	4.77											
Total CrO_4					6.26	6.69		6.49	13.15	12.25	9.30	11.15
Cr^{6+}	11.55	6.97	5.25	6.85	4.61	5.14	6.25	5.83	11.75	9.20	6.55	9.80
Fe	61.68	48.47	28.87	19.21	31.00	63.48	238.72	149.02	174.00	97.35	145.50	204.70
Cd			1.52	2.62	1.44	3.07	2.19	1.80	0.65	11.24	0.00	0.00
Cu	19.30	13.62	10.43	10.92	14.66	14.42	18.10	19.42	29.00	10.82	15.00	5.74
CN^-	1.63	1.87	2.15	0.52	0.91	1.32	1.35	2.76			13.55	7.25
Cl	2224.00	2482.00	3284.00									
F			0.40	0.20	7.81	12.11	15.98	20.90	27.50	14.70	24.95	0.16
Zn			47.63	24.50	35.36	25.54	26.38	74.40	56.05	73.00	96.70	121.20
Pb			10.70	20.16	49.25	54.46	80.03	106.40	93.20	45.54	35.80	15.10
Total PO_4			60.00		40.92	21.38	49.60	46.61	67.50	14.80	25.40	32.45
Mg	1375	1250										
NH_4-N	54	40								343		
Phenol			89									
Hardness						750						
Grease										1429		

Table B.1. Continued

	1999											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
BOD	24866	11738	8810	13015	5750	15000	15550	13000	13638	9613	3189	3279
COD	37320	20175	14380	19600	10113	23763	24580	21200	21200	14150	7573	7410
BOD/COD	0.67	0.58	0.61	0.66	0.57	0.63	0.63	0.61	0.64	0.68	0.42	0.44
pH	6.94	7.11	7.25	7.00	7.50	7.83	7.66	7.59	7.63	7.93	8.07	7.96
SS									1780	1505	1253	1310
Total CrO_4	11.24	10.05	6.30	6.03	5.95	4.80	8.27	8.05	9.60	8.07	5.35	3.15
Cr^{6+}	9.50	8.50	11.30	5.48	5.33	4.00	6.37	6.65	8.55	6.37	4.80	2.80
Fe	110.36	35.00	22.25	47.55	26.40	43.35	30.30	33.70	32.80	27.23	28.30	23.00
Cd	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu	14.32	14.60	6.70	15.90	6.75	8.30	12.60	7.25	16.30	12.40	15.30	7.75
CN	3.56	2.15	9.70	1.90	5.50	6.38	2.73	9.50	3.25	4.17	5.30	1.90
F	13.34	0.00	2.80	5.33	3.58	3.80	3.23	4.15	4.50	2.23	0.90	0.50
Zn	180.00	64.30	19.15	18.05	17.00	104.20	18.40	21.90	20.40	35.40	17.85	12.55
Pb	25.28	11.65	6.70	5.90	1.15	1.75	8.33	1.80	1.70	2.00	0.80	0.30
Total PO_4	20.56	13.55	12.35	15.18	16.25	19.40	18.57	14.32	24.00	21.77	16.55	18.65

Table B.1. Continued

	2000											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
BOD	5668	8420	10578	17180	15772	20853	20364	26215	13335	20892	11428	1865
COD	10623	13795	18026	25775	22750	31767	33480	41200	21633	31900	16609	5246
BOD/COD	0.53	0.61	0.59	0.67	0.69	0.66	0.61	0.64	0.62	0.65	0.69	0.36
pH	7.65	7.48	7.34	7.36	7.41	7.23	7.29	7.17	7.36	7.49	7.96	8.28
SS	1135	1294	1644	2170	1746	2558	2516	2709	2768	1801	1990	1500
EC					655.25	500.00	493	55.52	38.67	43.75	43.34	37.92
Total CrO_4	7.10	3.90	4.80	4.35	6.50	11.60	13.43	13.45	13.40	21.90	16.75	14.45
Cr^{6+}	5.15	2.85	4.50	3.60	5.27	11.30	12.03	11.65	10.57	20.60	15.85	11.25
Fe	14.60	20.60	13.75	29.15	26.30	68.00	50.03	56.20	35.00	63.10	25.90	13.50
Cd	0.00	0.00	0.05	0.10	0.00	0.00	0.00	0.00	1.03	0.00	0.29	0.24
Cu	8.00	16.35	10.00	8.40	11.70	16.00	25.47	18.00	21.87	19.10	10.90	7.18
CN	2.05	2.15	2.30	1.85	1.87	2.10	3.50	6.45	4.20	1.20	0.92	0.94
F	0.10	3.00	2.20	7.70	10.93	15.40	15.20	11.85	5.07	9.45	2.00	0.36
Zn	13.90	21.35	18.00	30.95	39.57	47.20	35.23	30.55	14.40	33.70	5.04	6.44
Pb	15.80	5.70	8.15	12.60	7.37	10.00	10.40	7.15	4.83	5.50	1.82	0.55
Total PO_4	16.00	20.45	19.40	16.55	23.80	25.60	26.50	28.50	45.13	17.20	22.90	20.10
NH_4-N											306.00	59.85
Total N											2610	2523
SO_4											184	349
S^{2-}											0.82	0.53
Total Alk.											13325.00	12250.00

Table B.1. Continued

	2001											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
BOD	758	344	354	198	395	404	224	234	226	217	218	202
COD	4260	4880	3960	1970	2865	4390	4632	5240	4690	4770	4540	2550
BOD/COD	0.18	0.07	0.09	0.10	0.14	0.09	0.05	0.04	0.05	0.05	0.05	0.08
pH	8.39	8.33	7.89	7.77	7.75	7.93	7.79	8.06	8.26	8.29	8.4	7.87
SS	1500	1217	1320	420	838	650	544	600	1062	838	930	600
EC	44.20	43.40	41.20	23.54	29.24	39.60	48.90	46.10	44.10	46.20	35.60	18.30
Total CrO_4	4.90	3.70	3.34	2.62	3.30	2.94	5.16	4.90	3.60	3.70	3.64	2.80
Cr^{6+}	2.50	2.60	2.36	2.16	2.40	2.66	3.70	3.40	2.97	3.07	2.80	2.60
Fe	7.30	6.58	7.02	7.18	9.78	8.26	8.57	7.96	6.90	7.27	14.50	12.00
Cd	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu	3.70	3.80	6.28	2.56	3.44	4.16	5.13	4.78	2.93	3.87	5.08	3.00
CN	0.60	1.06	0.70	0.40	0.70	0.56	0.40	0.50	0.40	0.70	0.50	0.30
F	0.50	0.82	0.10	0.86	0.00	1.82	1.67	1.75	1.40	3.50	3.38	1.60
Zn	5.40	6.56	2.84	3.64	2.20	4.00	7.70	6.50	5.65	4.86	5.44	6.90
Pb	0.20	0.04	0.16	0.20	0.50	0.08	0.60	0.44	0.60	0.60	0.52	1.10
Total PO_4	23.30	25.40	26.00	12.30	22.70	27.40	33.00	36.00	32.60	34.40	27.30	17.30
NH_4-N	44	33	32	83	93	940	192	1820	2430	1493	2388	1390
Total N	26	3440	3100	1660	2240	2790	1840	3580	3760	3285	4020	2900
SO_4	266	160	200	480	300	180	120	170	300	240	440	460
S^{2-}	0.58	0.60	0.80	0.30	0.40	0.80	0.60	0.70	1.00	0.80	0.60	0.40
Total Alk.	15300	14400	14300	6200	9300	14600	14700	14500	14800	15800	14100	6900

Table B.1. Continued

	2002											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
BOD	192	283	262	218	230	200	27567	8462	684	252	158	222
COD	1860	3540	3950	2540	2510	2850	45533	17550	4860	3330	1940	3740
BOD/COD	0.10	0.08	0.07	0.09	0.09	0.07	0.61	0.48	0.14	0.08	0.08	0.06
pH	7.73	8.03	7.99	7.91	7.89	8.10	6.32	7.54	8.02	8.28	8.12	8.43
SS	520	940	660	443	462	587	2890	1505	1340	680	420	406
EC	18.80	33.40	33.40	25.80	28.10	37.50	44.87	37.50	37.70	29.90	20.40	34.00
Total CrO_4	2.08	4.40	3.80	2.36	2.83	3.76	16.10	8.40	4.63	4.85	2.50	3.30
Cr^{6+}	1.90	3.53	2.73	1.96	2.40	3.40	10.95	7.60	3.67	4.73	2.05	2.87
Fe	8.66	7.50	8.70	9.80	8.20	6.13	122.50	19.70	13.90	8.80	7.23	10.70
Cd	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.10
Cu	3.32	4.47	6.40	2.32	2.87	2.40	10.60	7.80	3.47	5.20	4.40	5.10
CN	0.20	0.30	0.60	0.80	0.50	0.70	2.15	1.10	1.03	2.50	1.83	1.50
F	1.10	3.93	1.80	1.54	0.00	1.20	22.15	2.44	1.47	1.73	0.97	0.00
Zn	6.50	13.10	15.10	19.80	14.50	17.00	97.20	25.00	32.50	17.10	13.10	14.70
Pb	0.72	1.13	0.73	0.24	0.70	1.80	4.03	4.40	1.27	1.60	1.50	1.80
Total PO_4	17.40	29.30	27.90	19.60	22.00	23.60	50.10	31.70	30.40	26.30	14.40	26.70
NH_4-N	1582	2225	2105	1910	1614	1397	1564	1120	1570	2715	1646	2574
Total N	2970	3520	4600	4140	4800	5100	6435	5200	5660	4670	3390	3930
SO_4	360	280	260	340	320	340	1150	580	400	280	280	200
S^{2-}	0.20	0.60	0.60	0.40	0.40	0.40	0.40	0.60	0.80	0.60	0.20	0.60
Total Alk.	5800	13000	12700	8100	10200	10700	8150	8900	12500	11300	6500	11700

Table B.1. Continued

	2003											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**Octoner**	**November**	**December**
BOD	293	262	229	206	298	235	277	142	82	105	101	112
COD	3900	2950	1730	2035	3175	3530	3340	3460	3810	3770	2950	3680
BOD/COD	0.08	0.09	0.13	0.10	0.09	0.07	0.08	0.04	0.02	0.03	0.03	0.03
pH	7.74	8.27	7.66	7.52	7.70	7.93	7.86	8.07	8.55	8.51	8.30	8.39
SS	433	573	110	405	885	660	720	652	500	477	220	373
EC	19.70	29.00	10.90	18.60	32.90	34.80	33.50	40.20	40.80	35.00	32.50	34.40
Total CrO_4	2.47	2.82	1.60	2.60	2.24	2.08	2.60	2.10	2.60	0.46	0.63	0.58
Cr^{6+}	1.46	1.30	1.34	1.38	1.86	1.44	1.57	1.50	1.80	0.34	0.52	0.45
Fe	14.60	8.80	6.04	9.40	6.14	5.92	6.63	7.00	8.00	5.16	4.98	6.36
Cd	0.00	0.00	0.00	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Cu	5.30	3.16	1.92	4.70	2.36	2.72	2.42	3.00	2.00	0.12	0.11	0.09
CN	0.96	0.80	0.34	0.85	1.10	0.88	0.94	0.88	0.92	0.40	0.25	0.70
Cl	3257.00	3216.00	1616.00	3240.00	3796.00	4220.00	4190.00	3900.00	3120.00	3220.00	3485.00	2990.00
F	0.06	1.14	0.84	0.95	1.30	1.48	1.43	1.20	0.80	1.03	0.78	1.04
Zn	12.80	11.70	9.20	10.90	15.70	17.50	16.10	14.20	15.60	12.65	10.52	9.94
Pb	0.87	0.68	1.52	0.77	1.60	0.94	1.30	1.20	0.75	0.62	0.79	0.56
Total PO_4	15.20	25.40	10.90	18.80	22.10	24.70	23.90	22.40	19.60	14.10	12.10	11.60
NH_4-N	1666	1860	1202	1770	2500	2475	2450	2300	2600	1400	1538	989
Total N	3750	4300	2805	3960	4310	5100	4500	4400	5000	3560	3670	4230
SO_4	540	360	300	450	460	400	430	260	260	660	920	870
S^{2-}	0.20	0.40	0.20	0.40	0.40	0.40	0.40	0.50	0.40	0.40	0.30	0.40
Total Alk.	6900	8600	4200	6300	11500	11200	11400	12700	12500	12800	8890	11700

Table B.1. Continued

	2004							
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**
BOD	78.9	207	58	140	370	283	258	182
COD	1150	1693	590	2656	3330	3395	3180	3980
BOD/COD	0.07	0.12	0.10	0.05	0.11	0.08	0.08	0.05
pH	7.59	7.63	7.62	8.25	8.13	8.13	8.74	8.31
SS	189.00	140.00	106.70	193.30	280.00	245.00	240.00	247.00
EC	62.80	20.60	8.13	26.60	32.10	33.80	35.20	38.10
Total CrO_4	0.48	0.37	0.28	0.27	0.31	0.66	0.42	0.46
Cr^{6+}	0.32	0.26	0.18	0.21	0.22	0.43	0.36	0.27
Fe	3.92	4.17	1.93	3.88	4.34	4.80	5.98	7.70
Cd	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Cu	0.07	0.11	0.06	0.09	0.10	0.22	0.13	0.26
CN^-	0.16	0.40	0.13	0.21	0.33	0.24	0.33	0.35
Cl	1360	2047	8160	5450	4460	4650	5200	5450
F	0.69	0.38	0.18	0.30	0.36	0.61	1.04	1.23
Zn	5.18	4.83	1.17	2.78	4.46	3.80	3.14	4.02
Pb	0.28	0.19	0.13	0.08	0.17	0.10	0.08	0.13
Total P	5.04	5.03	5.26	5.98	6.15	5.57	7.20	8.60
NH_4-N	810	762	447	162	630	840	780	720
Total N	2280	2270	795	4730	3700	4060	3900	4120
SO_4	510	225	152	170	190	180	191	150
S^{2-}	0.20	0.20	0.08	0.30	0.20	0.20	0.40	0.40
Total Alk.	3500	6800	3020	9960	10700	14020	11800	13500

Table B.2. Leachate Quality Data for Main Valley (2000 to 2004)

	2000		
Parameter	**October**	**November**	**December**
BOD	27318	41751	31264
COD	40450	56375	43475
BOD/COD	0.68	0.74	0.72
pH	6.47	6.49	6.59
SS	2320	3394	2463
EC	37.45	53.40	42.05
Total CrO_4	9.20	20.45	22.90
Cr^{6+}	8.80	19.55	18.90
Fe	190.40	200.50	77.75
Cd	0.00	0.00	0.00
Cu	8.40	6.50	7.40
CN^-	2.90	2.15	1.05
F	12.20	17.95	15.25
Zn	43.60	47.90	44.70
Pb	48.00	31.55	17.00
Total P	23.90	25.15	19.35
NH_4-N			178
Total N		1501	1683
SO_4		1320	868
S^{2-}		0.45	0.23
Total Alk.		10475	6400

Table B.2. Continued

	2001											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
BOD	50150	26705	31163	31654	42638	38910	39267	37550	31746	34067	34675	16625
COD	63325	37333	45175	46713	60150	57840	59767	56900	50496	58433	53138	28100
BOD/COD	0.79	0.72	0.69	0.68	0.71	0.67	0.66	0.66	0.63	0.58	0.65	0.59
pH	6.47	6.52	6.37	6.36	6.24	6.29	6.18	6.17	6.46	6.45	6.57	6.76
SS	3031	1770	2008	2316	2931	2811	2858	3113	2832	3267	2528	1263
EC	46.68	34.62	49.63	45.00	58.23	57.06	51.60	55.30	44.58	52.87	46.70	25.80
Total CrO_4	22.23	12.43	13.55	6.73	9.75	10.00	10.95	13.15	12.80	11.60	10.30	8.88
Cr^{6+}	18.90	10.79	9.70	5.13	8.35	9.30	8.30	11.25	9.57	10.60	8.00	5.48
Fe	302.67	147.30	237.00	188.60	279.10	304.40	301.30	307.80	274.60	273.00	263.50	98.60
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu	4.00	1.93	3.70	4.75	8.10	7.60	6.90	9.30	9.13	12.00	10.60	4.03
Total CN^-	1.30	1.55	1.20	1.20	1.20	1.20	0.60	0.90	1.00	0.70	0.70	0.43
F	23.07	12.08	20.50	23.08	51.45	59.40	45.95	59.30	41.87	39.40	37.60	11.10
Zn	81.20	52.90	53.50	37.55	60.00	55.50	62.60	70.20	51.60	52.20	60.40	41.30
Pb	35.93	37.18	36.40	43.75	28.00	20.10	16.30	16.50	13.47	6.40	16.40	15.20
Total PO_4	18.03	12.90	22.45	15.85	30.70	25.85	23.85	32.65	38.17	40.40	40.70	12.20
NH_4-N	878	520	764	468	435	1043	731	842	1598	1903	2010	947
TOT-N	1763	933	697	1497	1968	2250	3023	3281	3832	3950	3695	2398
SO_4	1512	1081	1300	1250	1595	1580	1320	1410	1307	1360	1473	663
S^{2-}	0.23	0.24	0.40	0.15	0.30	0.40	0.40	0.50	0.47	0.60	0.40	0.35
Total Alk.	12100	7550	8200	6350	9125	10900	10500	10250	11567	12300	10875	5675

Table B.2. Continued

	2002											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
BOD	18256	18700	18768	15328	17032	16069	17356	17888	20758	18563	21140	20988
COD	26990	27828	29439	25528	27067	29300	28150	34800	37650	32243	35150	35425
BOD/COD	0.68	0.67	0.64	0.60	0.63	0.55	0.62	0.51	0.55	0.58	0.60	0.59
pH	7.29	7.75	7.53	7.34	7.50	7.21	7.09	6.62	6.72	6.70	6.72	7.04
SS	1345	1408	1810	1189	1742	2269	2395	2488	2500	2315	2600	2513
EC	35.68	36.23	39.58	30.22	40.97	39.63	44.40	37.20	39.38	33.32	37.78	45.65
Total CrO_4	12.65	9.95	10.25	11.70	11.15	10.95	14.03	14.10	12.90	8.80	12.10	10.90
Cr^{6+}	10.45	8.45	9.40	8.30	7.90	7.90	9.83	11.85	7.75	7.10	9.50	9.03
Fe	45.10	32.20	28.00	29.00	30.25	31.85	49.50	40.45	47.45	39.45	94.50	83.80
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
Cu	12.00	9.70	11.60	12.13	16.10	9.70	9.03	13.70	10.10	9.30	10.00	10.43
Total CN^-	0.90	0.85	0.90	2.57	2.60	1.20	1.43	2.30	2.50	2.40	1.80	1.87
F	8.90	8.80	4.85	1.37	2.80	3.70	9.60	7.85	10.00	6.75	14.15	7.27
Zn	83.40	56.00	73.40	75.53	77.90	66.70	67.73	80.50	91.90	84.40	85.80	76.93
Pb	12.30	2.95	3.05	12.17	8.00	5.25	4.00	3.35	9.15	5.20	8.95	7.37
Total PO_4	15.00	12.65	19.30	20.07	17.45	167.60	42.37	55.15	66.15	36.70	35.55	24.23
NH_4-N	1805	2908	1868	1564	1286	1022	1178	1129	1160	1078	1860	2173
Total N	3420	4975	3750	3742	4445	4450	4407	5705	5780	3868	6090	3803
SO_4	380	390	590	800	920	1030	807	655	730	660	1100	1013
S^{2-}	0.40	0.50	0.60	0.47	0.50	0.40	0.67	0.60	0.60	0.30	0.80	0.47
Total Alk.	9460	12100	11550	8283	10000	6950	8973	6800	8700	5750	7450	8500

Table B.2. Continued

	2003											
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
BOD	21718	14455	15138	17340	24060	23350	22220	23988	20925	17775	15288	14283
COD	35064	26565	26775	29038	41220	46800	47640	50350	44600	36775	29375	29133
BOD/COD	0.62	0.54	0.57	0.60	0.58	0.50	0.47	0.48	0.47	0.48	0.52	0.49
pH	6.91	6.92	7.02	6.68	6.72	6.53	6.39	6.21	6.57	6.95	6.92	7.24
SS	2175	1373	1825	1919	2570	2806	3094	3213	2325	2531	1825	1717
EC	40.80	35.78	38.33	37.50	51.12	50.28	53.45	41.98	48.33	48.80	39.30	54.50
Total CrO_4	9.50	9.40	7.55	8.80	9.93	9.35	9.10	10.00	11.90	0.52	0.56	
Cr^{6+}	8.50	8.10	6.60	7.50	8.47	8.10	7.00	8.00	9.70	0.38	0.48	0.47
Fe	104.90	59.50	16.15	24.50	29.77	47.35	50.00	55.00	62.00	17.38	16.62	18.32
Cd	0.00	0.00	0.00	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.12
Cu	13.20	7.60	7.30	9.70	10.80	9.75	10.50	10.00	7.90	0.30	0.31	0.17
Total CN^-	2.00	1.65	1.55	1.85	2.17	1.85	1.60	1.40	1.95	0.26	0.46	0.96
Cl	5635	4018	3365	4440	5597	5065	4675	3800	3630	3150	3183	3540
F	13.20	10.45	4.20	7.45	10.83	14.80	15.05	12.20	12.05	0.69	0.62	0.76
Zn	82.85	62.00	35.55	57.70	65.73	60.25	45.00	53.00	50.50	21.40	23.05	15.20
Pb	10.80	6.20	5.30	7.25	8.73	9.85	10.00	12.00	9.50	9.35	7.35	6.60
Total PO_4	26.65	21.45	16.10	23.30	30.93	37.50	47.67	52.00	44.55	11.63	12.85	20.20
NH_4-N	1732	1490	1496	1404	2175	2510	2667	2800	2420	1128	869	773
Total N	3275	3720	3590	3460	3933	4460	3867	4100	4250	3463	2590	3480
SO_4	1010	1060	750	1330	1087	1140	1260	1100	1005	755	650	580
S^{2-}	0.50	0.50	0.50	0.50	0.43	0.60	0.50	0.60	0.34	0.40	0.30	0.30
Total Alk.	6500	6050	5650	7050	11233	10950	9200	7900	7800	11650	9070	12400

Table B.2. Continued

	2004							
Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**
BOD	9802	7633	6950	7723	10560	11828	12925	7470
COD	17088	12708	12548	13863	19060	23413	24863	13825
BOD/COD	0.57	0.60	0.55	0.56	0.55	0.51	0.52	0.54
pH	7.07	7.05	7.18	7.32	7.36	7.29	7.35	7.55
SS	1423	762	870	1281	1805	2100	1906	1706
EC	34.82	24.48	27.30	36.90	43.68	47.90	45.25	34.53
Total CrO_4	0.24	0.30	0.39	0.42	0.59	0.61	0.57	0.60
Cr^{6+}	0.20	0.22	0.27	0.33	0.45	0.41	0.44	0.33
Fe	3.40	3.89	1.20	1.55	1.91	2.16	1.90	3.05
Cd	0.05	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Cu	0.04	0.07	0.11	0.11	0.12	0.22	0.15	0.16
CN^-	0.53	0.27	0.78	1.70	1.75	1.68	1.65	0.98
Cl	1552	1959	2809	5050	4550	5350	4600	5850
F	0.35	0.22	0.48	0.47	0.43	0.58	0.51	0.40
Zn	12.95	8.08	6.68	9.73	8.87	9.17	9.27	9.15
Pb	3.61	3.99	3.17	4.03	3.59	2.09	1.94	1.13
Total P	9.89	7.88	10.60	19.53	23.73	26.40	18.85	24.28
NH_4-N	643	317	115	216	1729	2075	1794	1925
Total N	4100	1415	1408	2900	3820	4115	4450	3150
SO_4	245	357	333	295	493	435	340	350
S^{2-}	0.15	0.10	0.10	0.25	0.17	0.30	0.30	0.40
Total Alk.	5120	5565	6355	10425	11530	10560	9155	12950

APPENDIX C: Leachate Flow Rate From Bursa MSWL And Rainfall Data

Table C.1. Flow Rate Measurements (2002)

Month	Date	T Valley (l/s)	Main Valley (l/s)
January	21.01.2002	0.24	2.25
	23.01.2002	0.24	2.00
	25.01.2002	0.24	2.00
	28.01.2002	0.24	2.00
	30.01.2002	0.24	2.00
	Avg.	**0.24**	**2.05**
February	01.02.2002	0.24	2.00
	04.02.2002	0.24	1.64
	06.02.2002	0.24	2.00
	08.02.2002	0.17	1.50
	11.02.2002	0.13	1.50
	13.02.2002	0.18	2.00
	15.02.2002	0.24	2.00
	18.02.2002	0.24	2.50
	20.02.2002	0.24	2.50
	27.02.2002	0.24	2.50
	Avg.	**0.22**	**2.01**
March	01.03.2002	0.20	2.30
	04.02.2002	0.20	2.25
	06.03.2002	0.23	2.30
	08.03.2002	0.23	2.30
	11.03.2002	0.25	2.50
	13.03.2002	0.24	2.50
	15.03.2002	0.24	2.30
	18.03.2002	0.24	2.30
	27.03.2002	0.25	2.50
	29.03.2002	0.25	2.50
	Avg.	**0.23**	**2.38**

Table C.1. Continued

Month	Date	T Valley (l/s)	Main Valley (l/s)
April	01.04.2002	0.24	2.30
	03.04.2002	0.24	2.30
	05.04.2002	0.24	2.50
	08.04.2002	0.17	2.40
	10.04.2002	0.13	2.70
	12.04.2002	0.18	3.00
	15.04.2002	0.24	3.00
	17.04.2002	0.24	2.80
	19.04.2002.	0.24	2.80
	22.02.2002	0.22	2.70
	24.04.2002	0.22	2.50
	26.04.2002	0.20	2.50
	29.04.2002	0.17	2.50
	Avg.	0.21	2.62
May	01.05.2002	0.12	2.54
	03.05.2002	0.12	2.41
	06.05.2002	0.10	2.25
	08.05.2002	0.12	2.30
	10.05.2002	0.12	2.30
	13.05.2002	No measurement	
	15.05.2002	No measurement	
	17.05.2002	No measurement	
	20.05.2002	No measurement	
	22.05.2002	0.10	2.00
	24.05.2002	0.10	2.00
	27.05.2002	0.08	1.80
	29.05.2002	0.08	1.64
	31.05.2002	0.10	1.80
	Avg.	0.10	2.10

Table C.2. Flow Rate Measurements (2003)

Month	Date	T Valley (l/s)	Main Valley (l/s)
Jan.	01.01.2003	0.12	2.50
	03.01.2003	0.25	3.00
	06.01.2003	0.25	3.00
	08.01.2003	0.25	3.00
	10.01.2003	0.18	3.20
	13.01.2003	0.14	3.60
	15.01.2003	0.20	2.25
	17.01.2003	0.16	2.20
	19.01.2003	0.18	2.70
	22.01.2003	0.20	3.60
	24.01.2003	0.18	2.70
	27.01.2003	0.18	2.50
	29.01.2003	0.15	2.25
	31.01.2003	0.13	2.20
	Avg.	**0.18**	**2.76**
Feb.	03.02.2003	0.15	3.50
	05.02.2003	0.17	4.10
	07.02.2003	0.17	3.50
	10.02.2003	0.15	2.70
	17.02.2003	0.25	2.57
	19.02.2003	0.27	2.60
	21.02.2003	0.40	4.70
	24.02.2003	0.30	4.50
	26.02.2003	1.00	6.50
	28.02.2003	0.75	5.00
	Avg.	**0.36**	**3.97**
Mar.	03.03.2003	0.62	3.00
	05.03.2003	0.50	4.50
	07.03.2003	0.32	4.10
	10.03.2003	0.28	3.00
	12.03.2003	0.26	2.25
	14.03.2003	0.26	2.00
	17.03.2003	0.22	2.00
	19.03.2003	0.23	1.80
	21.03.2003	0.21	2.00
	24.03.2003	0.16	1.50
	26.03.2003	0.18	1.50
	28.03.2003	0.20	1.50
	31.03.2003	0.20	1.55
	Avg.	**0.28**	**2.36**

Table C.2. Continued

Month	Date	T Valley (l/s)	Main Valley (l/s)
Apr.	02.04.2003	0.20	1.64
	04.04.2003	0.18	2.00
	07.04.2003	0.21	2.58
	09.04.2003	0.25	2.62
	11.04.2003	0.25	3.00
	14.04.2003	0.32	3.00
	16.04.2003	0.50	3.00
	18.04.2003	0.30	3.30
	21.04.2003	0.17	3.50
	23.04.2003	0.10	3.50
	25.04.2003	0.13	3.30
	28.04.2003	0.13	3.30
	30.04.2003	0.15	3.00
	Avg.	**0.22**	**2.90**
May	02.05.2003	0.16	3.00
	05.05.2003	0.15	3.00
	07.05.2003	0.13	2.95
	09.05.2003	0.15	3.00
	12.05.2003	0.13	3.00
	14.05.2003	0.15	2.77
	16.05.2003	0.12	2.75
	19.05.2003	0.12	3.00
	21.05.2003	0.12	2.25
	23.05.2003	0.10	2.00
	26.05.2003	0.10	1.64
	28.05.2003	0.12	2.00
	30.05.2003	0.14	2.30
	Avg.	**0.13**	**2.53**
Jun.	02.06.2003	0.12	1.90
	04.06.2003	0.13	1.89
	06.06.2003	0.12	2.00
	09.06.2003	0.12	2.20
	11.06.2003	0.13	2.50
	13.06.2003	0.13	2.00
	20.06.2003	0.12	2.00
	23.06.2003	0.12	2.50
	25.06.2003	0.12	2.50
	27.06.2003	0.11	2.25
	30.06.2003	0.11	2.37
	Avg.	**0.12**	**2.19**

Table C.2. Continued

Month	Date	T Valley (l/s)	Main Valley (l/s)
July	02.07.2003	0.10	2.20
	04.07.2003	0.10	2.25
	07.07.2003	0.07	2.57
	09.07.2003	0.07	2.80
	11.07.2003	0.05	2.50
	14.07.2003	0.07	2.55
	16.07.2003	0.07	2.62
	18.07.2003	0.10	3.00
	21.07.2003	0.10	3.00
	23.07.2003	0.12	3.20
	25.07.2003	0.08	3.00
	28.07.2003	0.11	3.02
	Avg.	**0.09**	**2.73**
Sep.	01.09.2003	0.07	2.70
	03.09.2003	0.07	2.62
	05.09.2003	0.06	2.65
	08.09.2003	0.05	2.50
	10.09.2003	0.06	2.50
	Avg.	**0.06**	**2.59**
Oct.	12.10.2003	0.06	2.32
	15.10.2003	0.06	2.75
	17.10.2003	0.07	3.00
	19.10.2003	0.07	2.60
	22.10.2003	0.05	2.60
	24.10.2003	0.05	2.45
	26.10.2003	0.04	2.25
	29.10.2003	0.04	2.25
	Avg.	**0.06**	**2.53**
Nov.	03.11.2003	0.05	2.55
	05.11.2003	0.05	2.55
	07.11.2003	0.10	3.00
	10.11.2003	0.10	3.00
	12.11.2003	0.10	3.02
	14.11.2003	0.08	2.72
	17.11.2003	0.08	2.75
	19.11.2003	0.05	2.66
	21.11.2003	0.05	2.57
	24.11.2003	0.06	2.78
	28.11.2003	0.07	2.65
	Avg.	**0.07**	**2.75**

Table C.3. Leachate flow rate and rainfall data for T and Main Valleys (2002-2003)

Years	**2002**			**2003**		
Months	**Flow Rate (l/s)**		**Rainfall**	**Flow Rate (l/s)**		**Rainfall**
	T Val.	**Main Val.**	**(mm)**	**T Val.**	**Main Val.**	**(mm)**
January	0.24	2.05	62.3	0.18	2.76	65.3
February	0.22	2.01	44.7	0.36	3.97	106.2
March	0.23	2.38	87.9	0.28	2.36	33.1
April	0.21	2.62	126.5	0.22	2.90	112.1
May	0.10	2.10	50.5	0.13	2.59	45.7
June	-	-	25.2	0.12	2.19	2.4
July	-	-	49.9	0.09	2.73	0
August	-	-	31.1	-	-	0
September	-	-	67.2	0.06	2.59	66.9
October	-	-	119.3	0.06	2.53	125.1
November	-	-	67.9	0.07	2.75	64.5
December	-	-	28.8	-	-	91.0

APPENDIX D: Autocorrelation Coefficients for Leachate Parameters and Lag Periods, at which there were Moderately Strong Relationships between Couples of Parameters

Table D.1. Autocorrelation coefficients for SS in T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.87*	*-0.25*	*0.25*
1	***Main***	*0.68*	*-0.29*	*0.29*
	T	*0.80*	*-0.40*	*0.40*
2	***Main***	*0.46*	*-0.40*	*0.40*
	T	*0.71*	*-0.49*	*0.49*
3	***Main***	**0.15**	***-0.44***	***0.44***
	T	*0.62*	*-0.55*	*0.55*
4	***Main***	***-0.02***	***-0.44***	***0.44***

Table D.2. Autocorrelation coefficients for EC in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.63*	*-0.27*	*0.27*
1	***Main***	*0.39*	*-0.29*	*0.29*
	T	*0.37*	*-0.36*	*0.36*
2	***Main***	***0.28***	***-0.33***	***0.33***

Table D.3. Autocorrelation coefficients for Total Alkalinity in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.43*	*-0.29*	*0.29*
1	***Main***	***0.22***	***-0.30***	***0.30***

Table D.4. Autocorrelation coefficients for total CrO_4 in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.85*	*-0.22*	*0.22*
1	*Main*	*0.69*	*-0.29*	*0.29*
	T	*0.71*	*-0.35*	*0.35*
2	*Main*	*0.53*	*-0.40*	*0.40*
	T	*0.56*	*-0.42*	*0.42*
3	*Main*	**0.44**	**-0.45**	**-0.45**

Table D.5. Autocorrelation coefficients for Cr^{6+} in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.79*	*-0.22*	*0.22*
1	*Main*	*0.79*	*-0.43*	*0.43*
	T	*0.65*	*-0.33*	*0.33*
2	*Main*	*0.62*	*-0.43*	*0.43*
	T	*0.52*	*-0.39*	*0.39*
3	*Main*	**0.45**	**-0.50**	**0.50**
	T	*0.42*	*-0.42*	*0.42*
4	*Main*	**0.35**	**-0.53**	**0.53**

Table D.6. Autocorrelation coefficients for Fe in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.77*	*-0.22*	*0.22*
1	*Main*	*0.83*	*-0.29*	*0.29*
	T	*0.63*	*-0.32*	*0.32*
2	*Main*	*0.81*	*-0.44*	*0.44*
	T	*0.50*	*-0.38*	*0.38*
3	*Main*	**0.69**	**-0.55**	**0.55**
	T	*0.49*	*-0.41*	*0.41*
4	*Main*	**0.59**	**-0.62**	**0.62**
	T	*0.44*	*-0.43*	*0.43*
5	*Main*	**0.48**	**-0.66**	**0.66**

Table D.7. Autocorrelation coefficients for Pb in T and Main Valleys

Lag (k)	**Valley**	**Autocorrelation Coefficient**	**Lower 95% Probability Limit**	**Upper 95% Probability Limit**
	T	*0.90*	*-0.22*	*0.22*
1	***Main***	*0.75*	*-0.29*	*0.29*
	T	*0.75*	*-0.36*	*0.36*
2	***Main***	*0.61*	*-0.42*	*0.42*
	T	*0.58*	*-0.43*	*0.43*
3	***Main***	*0.62*	*-0.48*	*0.48*

Table D.8. Autocorrelation coefficients for Cu in T and Main Valleys

Lag (k)	**Valley**	**Autocorrelation Coefficient**	**Lower 95% Probability Limit**	**Upper 95% Probability Limit**
	T	*0.75*	*-0.22*	*0.22*
1	***Main***	*0.78*	*-0.29*	*0.29*
	T	*0.71*	*-0.32*	*0.32*
2	***Main***	*0.67*	*-0.43*	*0.43*
	T	*0.61*	*-0.39*	*0.39*
3	***Main***	*0.61*	*-0.51*	*0.51*
	T	*0.53*	*-0.43*	*0.43*
4	***Main***	***0.51***	***-0.56***	***0.56***
	T	*0.53*	*-0.46*	*0.46*
5	***Main***	***0.41***	***-0.60***	***0.60***

Table D.9. Autocorrelation coefficients for Zn in T and Main Valleys

Lag (k)	**Valley**	**Autocorrelation Coefficient**	**Lower 95% Probability Limit**	**Upper 95% Probability Limit**
	T	*0.68*	*-0.22*	*0.22*
1	***Main***	*0.80*	*-0.29*	*0.29*
	T	*0.50*	*-0.31*	*0.31*
2	***Main***	*0.74*	*-0.43*	*0.43*
	T	*0.36*	*-0.35*	*0.35*
3	***Main***	*0.65*	*-0.53*	*0.53*
	T	***0.34***	***-0.36***	***0.36***
4	***Main***	*0.60*	*-0.59*	*0.59*

Table D.10. Autocorrelation coefficients for CN in T and Main Valley

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.64*	*-0.22*	*0.22*
1	***Main***	*0.58*	*-0.29*	*0.29*
	T	*0.52*	*-0.30*	*0.30*
2	***Main***	**0.25**	**-0.37**	**0.37**
	T	*0.44*	*-0.34*	*0.34*
3	***Main***	**0.31**	**-0.38**	**0.38**

Table D.11. Autocorrelation coefficients for F in T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.68*	*-0.22*	*0.22*
1	***Main***	*0.86*	*-0.29*	*0.29*
	T	*0.71*	*-0.31*	*0.31*
2	***Main***	*0.76*	*-0.45*	*0.45*
	T	*0.40*	*-0.38*	*0.38*
3	***Main***	*0.61*	*-0.55*	*0.55*

Table D.12. Autocorrelation coefficients for total P in T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.57*	*-0.22*	*0.22*
1	***Main***	*0.75*	*-0.29*	*0.29*
	T	*0.44*	*-0.28*	*0.28*
2	***Main***	*0.61*	*-0.42*	*0.42*
	T	**0.31**	**-0.32**	**0.32**
3	***Main***	*0.62*	*-0.48*	*0.48*

Table D.13. Autocorrelation coefficients for NH_4-N in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.73*	*-0.29*	*0.29*
1	*Main*	*0.69*	*-0.29*	*0.29*
	T	*0.66*	*-0.42*	*0.42*
2	*Main*	**0.39**	**-0.41**	**0.41**
	T	*0.50*	*-0.49*	*0.49*
3	*Main*	**0.20**	**-0.44**	**0.44**

Table D.14. Autocorrelation coefficients for total N in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.51*	*-0.29*	*0.29*
1	*Main*	*0.68*	*-0.29*	*0.29*
	T	*0.43*	*-0.36*	*0.36*
2	*Main*	*0.49*	*-0.40*	*0.40*
	T	**0.30**	**-0.40**	**0.40**
3	*Main*	*0.49*	*-0.45*	*0.45*

Table D.15. Autocorrelation coefficients for SO_4 in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.62*	*-0.29*	*0.29*
1	*Main*	*0.75*	*-0.29*	*0.29*
	T	**0.18**	**-0.38**	**0.38**
2	*Main*	*0.66*	*-0.42*	*0.42*

Table D.16. Autocorrelation coefficients for S in the T and Main Valleys

Lag (k)	Valley	Autocorrelation Coefficient	Lower 95% Probability Limit	Upper 95% Probability Limit
	T	*0.52*	*-0.29*	*0.29*
1	*Main*	*0.53*	*-0.29*	*0.29*
	T	**0.32**	**-0.36**	**0.36**
2	*Main*	*0.58*	*-0.36*	*0.36*

Table D.17. Various lag periods, at which there were moderately strong relationships between couples of parameters in the T Valley

Parameter Couples	Crosscorrelation Coefficients	Lag Periods
SS-BOD	0.86, 0.80, 0.76, 0.67, 0.64	1, 2, 3, 4, 5
SS-COD	0.87, 0.80, 0.75, 0.66, 0.60	1, 2, 3, 4, 5
SS-pH	-0.59, -0.58, -0.58, -0.56	1, 2, 3, 4
SS-EC	0.66, 0.68, 0.62, 0.55	1, 2, 3, 4
SS-Total CrO_4	0.74, 0.62, 0.54	1, 2, 3
SS-Cr^{6+}	0.73, 0.62, 0.54	1, 2, 3
SS-Fe	0.80, 0.73, 0.68, 0.57, 0.53	1, 2, 3, 4, 5
SS-Cu	0.82, 0.77, 0.68, 0.65, 0.60, 0.56	1, 2, 3, 4, 5, 6
SS-CN^-	0.65, 0.55, 053, 0.51, 0.53, 0.52	1, 2, 3, 4, 5, 6
SS-F	0.78, 0.73, 0.65, 0.53	1, 2, 3, 4
SS-Zn	0.66, 0.62, 0.57	1, 2, 3
SS-Pb	0.70, 0.77, 0.77, 0.68, 0.70, 0.57	1, 2, 3, 4, 5, 6
SS-S^{2-}	0.52	1
Total CrO_4-BOD	0.79, 0.82, 0.77, 0.70, 0.57	1, 2, 3, 4, 5
Total CrO_4-COD	0.79, 0.83, 0.78, 0.71, 0.57	1, 2, 3, 4, 5
Total CrO_4-SS	0.84, 0.81, 0.77, 0.70, 0.55	1, 2, 3, 4, 5
Total CrO_4-EC	0.51, 0.65, 0.71, 0.77	2, 3, 4, 5
Tot.CrO_4-Cr^{6+}	0.84, 0.70, 0.55	1, 2, 3
Tot.CrO_4-Fe	0.56, 0.60, 0.52	1, 2, 3
Tot.CrO_4-Cu	0.79, 0.75, 0.76, 0.68, 0.57	1, 2, 3, 4, 5
Tot.CrO_4-CN^-	0.51, 0.54	1, 2
Tot.CrO_4-F	0.64, 0.67, 0.69, 0.64, 0.52	1, 2, 3, 4, 5
Cr^{6+}-BOD	0.72, 0.76, 0.71, 0.63, 0.53	1, 2, 3, 4, 5
Cr^{6+}-COD	0.73,0.78, 0.74, 0.65, 0.53	1, 2, 3, 4, 5
Cr^{6+}-pH	-0.60, -0.63, -0.62, -0.60, -0.55, -0.52	1, 2, 3, 4, 5, 6
Cr^{6+}-SS	0.81, 0.79, 0.75, 0.66, 0.50	1, 2, 3, 4, 5
Cr^{6+}-EC	0.64, 0.71, 0.78	3, 4, 5
Cr^{6+}-Fe	0.53, 0.57, 0.52	1, 2, 3
Cr^{6+}-Zn	0.51	2
Cr^{6+}-CN^-	0.51	2
Cr^{6+}-Total CrO_4	0.83, 0.68, 0.54	1, 2, 3
Cr^{6+}-Cu	0.76, 0.70, 0.68, 0.63, 0.53	1, 2, 3, 4, 5
Cr^{6+}-F	0.59, 0.65, 0.63, 0.67	1, 2, 3, 4
Fe-BOD	0.66, 0.60, 0.52, 0.51, 0.56, 0.54	1, 2, 3, 4, 5, 6
Fe-COD	0.68, 0.60, 0.54, 0.51, 0.55, 0.52	1, 2, 3, 4, 5, 6
Fe-pH	-0.59, -0.60, -0.57, -0.56	1, 2, 3, 4
Fe-SS	0.77, 0.73, 0.58	1, 2, 3
Fe-EC	0.78, 0.61, 0.69, 0.51	1, 2, 3, 4
Fe-Cu	0.56, 0.55, 0.54	1, 2, 3
Fe-Pb	0.79, 0.81, 0.79, 0.71, 0.55	1, 2, 3, 4, 5
Fe-CN^-	0.55	1
Fe-F	0.77, 0.70, 0.58	1, 2, 3
Fe-Total P	0.55, 0.62	3, 4

Table D.17. Continued

Parameter Couples	Crosscorrelation coefficients	Lag Periods
SS-Total CrO_4	0.63	1
SS-S	0.52	1
SS-Cu	0.50	1
Total CrO_4-BOD	0.60	1
Total CrO_4-COD	0.60	1
Total CrO_4-SS	0.53	1
Total CrO_4-Cr^{6+}	0.64	1
Total CrO_4-Fe	0.58	1
Total CrO_4-Cu	0.56	1
Cr^{6+}-BOD	0.52	1
Cr^{6+}-COD	0.52	1
Cr^{6+}-Total CrO_4	0.52	1
Cr^{6+}-Fe	0.51	1
Fe-COD	0.52, 0.53	1, 2
Cu-SS	0.51	1
Cu-Total CrO_4	0.50	1
Cu- Cr^{6+-}	0.50	1
Cu-Total P	0.54	1
Zn-Pb	0.73, 0.69	1, 2
Zn-NH_4-N	0.51	1
Zn-Total N	0.65, 0.57	1, 2
Pb-Zn	0.64, 0.63, 0.64	1, 2, 3
Pb-NH_4-N	0.52	1
Pb-Total N	0.56, 0.53, 0.55	1, 2, 3
CN^--Zn	0.64, 0.71, 0.64	1, 2, 3
CN^--Pb	0.54, 0.55, 0.55	1, 2, 3
NH_4-N-Zn	0.55	1
Total N-Zn	0.58	1
S^{2-}-COD	0.52	1
S^{2-}-SS	0.53	1
S^{2-}-Cr^{6+}	0.51	1
S^{2-}-Total CrO_4	0.53	1
S^{2-}-Total Alkalinity	0.57	1

Table D.18. Various lag periods, at which there were moderately strong relationships between couples of parameters in the Main Valley

Parameter Couples	Crosscorrelation coefficients	Lag Periods
SS-BOD	0.50	1
SS-COD	0.59	1
SS-pH	-0.60	1
SS-EC	0.51	1
SS-Fe	0.58, 0.52	1, 2
SS-SO_4	0.58, 0.51	1, 2
Total CrO_4-BOD	0.57, 0.54	1, 2
Total CrO_4-Cr	0.82, 0.65	1, 2
Total CrO_4-Cu	0.58, 0.53	1, 2
Total CrO_4-Zn	0.59, 0.54	1, 2
Cr^{6+}-BOD	0.58, 0.51	1, 2
Cr^{6+}-Total CrO_4	0.78, 0.61	1, 2
Cr^{6+}-Cu	0.53	1
Cr^{6+}-Zn	0.54	1
Cr^{6+}-Pb	0.51	1
Fe-BOD	0.77, 0.80, 0.68, 0.64, 0.53	1, 2, 3, 4, 5
Fe-COD	0.71, 0.70, 0.56	1, 2, 3
Fe-pH	-0.68, -0.63, -0.59	1, 2, 3
Fe-SS	0.53, 0.53	1,2
Fe-EC	0.51	1
Fe-Pb	0.67,0.62, 0.67, 0.77, 0.71,0.72, 0.67,0.67	1, 2, 3, 4, 5, 6, 7
Fe-F	0.81, 0.75, 0.60	1, 2, 3
Fe-Tot.N	-0.53, -0.54, -0.58, -0.57	4, 5, 6, 7
Fe-SO_4	0.66, 0.67, 0.52	1, 2, 3
Cu-Total CrO_4	0.51	1
Cu-Zn	0.71, 0.69, 0.65, 0.58	1, 2, 3, 4
Cu-S^{2-}	0.71, 0.60	1, 2
Zn-Total CrO_4	0.67, 0.66, 0.53	1, 2, 3
Zn-Cr^{6+}	0.62, 0.61	1, 2
Zn-S	0.58, 0.59	1, 2
Pb-BOD	0.60, 0.58, 0.55	1, 2, 3
Pb-pH	0.51	1
Pb-Total CrO_4	0.52, 0.52	2, 3
Pb-Cr^{6+}	0.56, 0.57	2, 3
Pb-Fe	0.54	1
Pb-Total N	0.61, 0.52	1, 2
Pb-SO_4	0.53	1
CN^--pH	0.53	6
CN^-EC	0.54	4

Table D.18. Continued

Parameter Couples	**Crosscorrelation coefficients**	**Lag Periods**
F-BOD	0.74, 0.70, 0.63, 0.61, 0.55	1, 2, 3, 4, 5
F-COD	0.72, 0.63, 0.52	1, 2, 3
F-EC	0.51	1
F-Cr^{6+}	0.51	6
F-Fe	0.81, 0.77, 0.67, 0.58	1, 2, 3, 4
F-Pb	0.53,0.64,0.70,0.72,0.70, 0.68, 0.74,0.57	1, 2, 3, 4, 5, 6,7, 8
F-Total N	-0.56, -0.58, -0.62, -0.56	4, 5, 6, 7
F-SO_4	0.68, 0.67, 0.57	1, 2, 3
Total N-Pb	-0.60	1
SO_4-BOD	0.68, 0.64, 0.51	1, 2, 3
SO_4-COD	0.69, 0.58	1, 2
SO_4-pH	-0.65, -0.53	1, 2
SO_4-SS	0.60	1
SO_4-Total CrO_4	0.54, 0.58, 0.52	1, 2, 3
SO_4-Cr^{6+}	0.55, 0.58, 0.53	1, 2, 3
SO_4-Fe	0.80, 0.61, 0.56	1, 2, 3
SO_4-Pb	0.54, 0.62, 0.54, 0.53	1, 2, 3, 4
SO_4-F	0.63, 0.52	1, 2
S^{2-}-Cu	0.64, 0.62, 0.61	1, 2, 3
S^{2-}-Zn	0.58, 0.64	1, 2