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AN ASSESSMENT OF HEALTH ASPECTS OF THE IMPACT OF DOMESTIC AND INDUSTRIAL WASTE DISPOSAL ACTIVITIES ON GROUNDWATER RESOURCES

➢ A LITERATURE REVIEW ≺

Report to the
WATER RESEARCH COMMISSION
by the
GROUNDWATER PROGRAMME
DIVISION OF WATER TECHNOLOGY
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WRC Project No: 371/1/93
ISBN 1 86845 028 7
CSIR Project No: 670 26070

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Introduction

Although groundwater only contributes about 15% to South Africa's water supply at present, it is of great importance when one considers that more than 280 towns and villages use groundwater for water supply. This represents towns and settlements spread over about 65% of the area of South Africa. One of the great benefits of groundwater is that it can frequently be obtained close to the point of use. Treatment of drinking water, on the other hand, is not cost effective for scattered rural communities. Consequently the approach should be to prevent contamination in the first place.

The transmission of hazardous chemical substances and infectious diseases through contaminated drinking water has been a frequent and well-documented occurrence in the past. Any disease caused by drinking contaminated water can be transmitted through groundwater if the disease causing agent reaches the water source in infective doses to cause the specific illness. Some contaminants are more likely than others to be present in groundwater with the result that some waterborne diseases occur more frequently. The degree to which groundwater is developed for drinking water supplies, geological and hydrological conditions, waste disposal practices, and general technological development all influence the role of groundwater in the transmission of a particular disease in any country.

Study Objectives

The contamination of groundwater by industrial, domestic and agricultural activities and the associated health implications are receiving wide-spread attention and this literature review is aimed at gaining knowledge about the impact of domestic and industrial waste disposal practices on groundwater supplies and the associated health implications. The aims of the project are (i) to conduct a comprehensive literature survey which outlines health aspects of the impact of domestic and industrial waste disposal to land on groundwater resources and (ii) to review current domestic and industrial waste disposal practices to land in South Africa and thereby establish the relevance of the overseas experience, as determined in (i), to South Africa.

Waste Disposal

Groundwater is constantly being effected to a greater or lesser extent by the application of fertilizers and pesticides, urban development, disposal of domestic refuse to land, sewage sludge disposal, mining activities and in particular, the disposal to land of effluents containing high concentrations of chemicals and sludges produced by industry. However, groundwater contamination by leachates from the above presents the real problem and will increase if not managed properly.

Landfilling has long been the major disposal method for both domestic and industrial wastes. Legislation affecting the control and prevention of water pollution in South Africa is found in the Water Act of 1956; the Health Act of 1977; the Environment Conservation Act of 1989 and the Environmental Conservation Amendment Act of 1992. The Department of Water Affairs and Forestry (DWA&F) has been assigned with the responsibility of executing these Acts. Much research effort is being carried out in South Africa relating to groundwater contamination and aquifer protection. These studies relate to policy development, suitable investigative techniques and methods and the setting of minimum requirements. Such efforts can only lead to improved standards in the waste disposal field, but unfortunately, time will be required to achieve this.

The DWA&F has been actively involved in developing and implementing legislation in an attempt to prevent the loss of valuable water resources. The promulgation of the Environment Conservation Act No. 73 of 1989 and the Environment Conservation Ammendment Act No. 79 of 1992 are just two examples of this. The permitting of waste sites has however been slower than anticipated and only 7 per cent of the country's waste sites have been investigated or reported on. About 15 per cent of the identified waste disposal sites have been issued with permits or are in the process of obtaining permits. At present processing rates, it is estimated that this will take approximately 50 years to achieve. However the process is moving in the right direction and the problem of issuing of permits is being addressed. Even though South Africa is not on the same level of standard with regard to waste disposal requirements and practices as other more developed countries, the lessons learned during the ongoing research work remain applicable. It must be remembered that the standards employed in the USA, for example, have received attention since the mid-1970's while our efforts are still really in the infancy stage. The fact that in the USA they have detected so much groundwater contamination is related to the specific monitoring performed. The few cases of documented groundwater contamination in South Africa should not be seen as an indicator that similar problems do not exist in this country. Rather the view should be that we have just not located them as yet.

Leachate

The unstable and dispersed movement of liquids through the mass of a landfill site results in the leaching of soluble compounds, which were originally present in the waste or were formed in chemical and biochemical processes, together with transferable organic and inorganic materials, and micro-organisms like bacteria, protozoa, helminths and viruses.

As municipal landfills are covered by a low permeability layer only when dumping is terminated, rainfall furthers the process of decomposition and leaching. The rainwater percolates through a landfill and the leachate penetrates the soil and feeds the groundwater. The penetration can be controlled by various means but it is practically impossible to completely prevent infiltration of precipitation.

The pollution threat of leachate, real or potential, to surface and groundwater has long been realized and has been the key consideration in landfill site design to prevent serious and costly problems. However, in many recent cases, the protection of groundwater has become the leading objective for licensing landfill sites. In recent years, the number of documented sites in which landfill leachate is known to contaminate the underlying aquifer has been on the increase, but only a few cases have been studied in detail with regard to geochemical processes, the attenuation of contaminants and the occurrence of potentially hazardous organic chemicals in leachates from municipal landfills.

Health Aspects

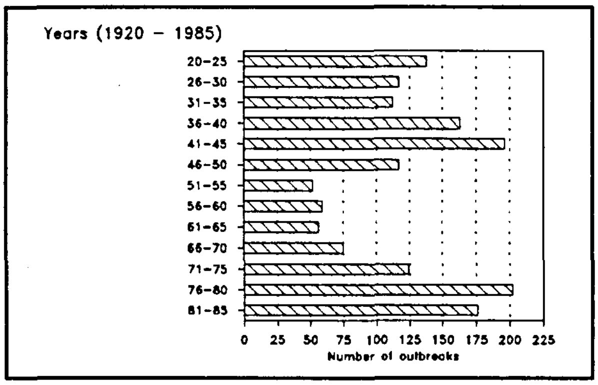
The most important source of groundwater contamination in the United States is believed to be the disposal of industrial wastes in impoundments and landfills. There are approximately 76 000 active industrial landfills in the United States; some 50 000 active and inactive sites are estimated to contain potentially hazardous chemical wastes. Groundwater contaminants such as benzene, polychlorinated biphenyl, chlorinated phenols, organic solvents, heavy metals, selenium, and arsenic have originated from industrial landfills and in many instances have migrated some distance from the original contamination site.

From 1971 until 1979 in fourty five U.S states and Puerto Rico, 267 outbreaks of waterborne diseases affecting 57 974 people were reported. Fifty four per cent of the **outbreaks** occurred where noncommunity water systems exist of which there are approximately 150 000 in the USA and 96 per cent of these use groundwater resources. Sixty nine per cent of the **illnesses** occurred in community water systems, which number 64 000 and serve 200 million people. About 82 per cent of the community water systems and 30 per cent of the population served thereby, use groundwater. Twelve per cent of the **outbreaks** and one per cent of the **illnesses** occurred in individual water systems, which primarily depend on untreated groundwater.

Another literature review in 1984 stated that from 1946 to 1977 in the United States, there were 264 outbreaks and 62 273 reported cases of waterborne diseases due to contaminated groundwater. This accounted for about 50 per cent of all the waterborne illnesses.

A review in 1990 reported outbreaks of waterborne diseases and the causes of waterborne outbreaks from 1971 until 1985. There were 502 outbreaks and 111 228 reported cases of waterborne diseases due to contaminated groundwater. This data does not differ significantly from the data as presented in the previous review. In the cases of illness, groundwater still accounted for about 50 per cent of all the illnesses, but there was an increase in cases where the causes of the illnesses were related to surface water. It is also interesting to note that although the period between 1971 to 1985 is half (14 years) the time of the period 1946 to 1977 (31 years), the waterborne outbreaks (502 against 264) and the cases of illness (111 228 against 62 273) are nearly double. This is a clear indication that the contamination of groundwater had grown or that the extent/awareness of the problem is spreading. However, in the 1990 review it is stated that although more outbreaks were reported during 1971-1985 than any previous 15-year period since 1920 (see adjacent Figure), the number of reported waterborne outbreaks has declined since 1981. It was also said that it is difficult to determine whether the decline in the reported number of waterborne outbreaks during 1981-1985 is due to the occurrence of fewer outbreaks or less active surveillance and reporting.

The exact relationship between groundwater pollution by waste disposal sites and outbreaks of waterborne diseases is however unknown.



Waterborne disease outbreaks in the U.S. between 1920 and 1985

Groundwater moves very slowly and geohydrological conditions vary from site to site. The velocity is often not more than 10 m/year and pollution can therefore take place over a long period of time before being detected. Pollution of an aquifer in Germany was detected 1,5 km downstream of a landfill site 25 years after startup and 9 years after closure and it took another 18 years for the contaminant levels to drop to background levels.

Another example, and probably the best known, is the Love Canal saga. The landfill site started as a section of canal that was never completed and eventually received approximately 22 000 tons of chemical waste between 1942 and 1953. The earliest problems were recorded in 1976 and included the following:

- landfill surface decline expose disposal drums,
- contaminated surface water ponding in neighbouring backyards,
- unpleasant odours,
- migration of chemicals to adjacent basements,
- chemical migration into and through the sewer network.

"Subsequent health studies that indicated a predisposition towards spontaneous abortion and low birth-weight in infants prompted an emergency to be declared at the site. This measure resulted in the evacuation of 236 families from the site".

A second state of emergency was declared in 1980 when additional testing of residents revealed chromosomal abnormalities.

Inorganic contaminants

The following Table is a partial list of inorganic constituents, selected on their historical significance and widespread occurrence in groundwater.

Parameter	Crisis limit	Impact
Nitrate mg/ℓ N	20	Infant methaemoglobinaemia
Sodium mg/ℓ Na	800	Chronic, long-term toxicity
Magnesium mg/ℓ Mg	200	May cause diarrhoea in new users
Sulphate mg/ℓ SO_4	1200	Taste, odours, cathartic effect - Na- & Mg- SO_4
Fluoride mg/ℓ F	3	Dental & skeletal fluorosis
Arsenic mg/ℓ As	0.6	Toxic in excess e.g. bronchial diseases
Selenium mg/ℓ Se	0.1	Toxic in excess
Aluminium mg/ℓ Al	1	Soluble aluminium salts exhibit neurotoxicity
Iron mg/ℓ Fe	2	High concentrtions potentially toxic to children

Organic contaminants

It is not known which of the organic contaminants are the most prevalent and need identification. The data found in the literature is merely compiled from groundwater surveys and monitoring of contaminated boreholes. These samples were also only analysed for specific chemicals and the data therefore may not be repesentative of the actual problem. Some selected organic compounds have been tested for carcinogenicity while others detected in groundwater have not been tested. There are nine organic compounds that, according to the available literature, seem to be important groundwater contaminants and are listed below.

Compound	Effect
Vinyl chloride	Potential human carcinogen
Carbon tetrachloride (Carbona)	IDLH = 300 ppm
1,2-Dichloroethane	Potential human carcinogen
1,1-Dichloroethane	IDLH = 4 000 ppm
Tetrachloroethylene	IDLH = 500 ppm (Carcinogenic)
Trichloroethylene (Trichoran)	IDLH = 500 ppm (Carcinogenic)
Trichloroethane (Methyl chloroform)	IDLH = 1 000 ppm
Dichloroethylenes	IDLH = 4 000 ppm
Methylene chloride (Chloroform)	IDLH = 5 000 ppm (Carcinogenic)

IDLH = Immediate Danger to Life and Health

Biological contaminants

Less is known about the microbiology of groundwater than about any other part of the biosphere. Groundwater has long been considered to be of unquestionable excellent quality because the soil barrier is mostly effective in providing isolation of this high quality source water from surface pollutants. However, both inorganic and organic chemicals that enter the groundwater environment can be transformed by microbiological processes. Besides transforming chemical compounds directly, the growth of bacteria can cause clogging and change the permeability of the aquifer material and also affect the chemical environment resulting in a pH change and affecting the oxidation-reduction potential of the system. This can lead to precipitation or dissolution of phosphates and heavy metals, oxidation or reduction of iron and sulfur salts. Micro-organisms could therefore be directly or indirectly responsible for groundwater pollution.

Various studies have shown the existence and survival in leachate from landfills as shown in the following Table.

	Densities per 100 mℓ	
Days after placement	Faecal coliforms	Faecal streptococci
42	2 600 000	240 000 000
43	4 900 000	790 000
56	2 000	79 000
63	9 000	33 000
70	33 000	170 000

It is clear, as seen in the literature, that large numbers of bacteria are "dumped" into the environment daily and that they also survive for some time outside their hosts. What is not shown however, is the bacterial spores, parasites, their cysts and ova which may to an even greater extent contribute to the groundwater pollution potential. The presence of nutrients together with moisture (water), heat and other necessary factors for sustaining bacterial growth in waste disposal sites may even produce larger bacterial populations.

Some of the most relevant infectious diseases that may be transmitted by drinking contaminated groundwater are listed below.

Disease	Micro-organism
Amoebiasis	*Entamoeba histolytica*
Giardiasis	*Giardia lamblia*
Balantidiasis	*Balantidium coli*
Cryptosporidiosis	*Cryptosporidium*
Cholera	*Vibro cholera,*
Hepatitis	Hepatis A virus
Paratyphoid Fever	*Salmonella paratyphi*
Typhoid Fever	*Salmonella typhi*
Salmonellosis	*Salmonellae*
Shigellosis	*Shigellae*
Gastroenteritis	Various micro-organisms e.g. *Escherichia coli, Campylobacter, Yersinia enterocolitica,* norwalk-, rota-, adeno- viruses

Conclusions

Groundwater pollution from waste disposal activities is a fact of life. Overseas it has already created serious environmental problems and the cleanup of contaminated groundwaters may ultimately cost billions of rands to rectify, if ever. In South Africa indications are that the problem also exists but publised data is scarce. The solution to groundwater pollution is best described by the aphorism *"Prevention is better than cure"*.

Special care must be taken in identifying polluters and the pollutants involved since mobilisation of naturally occurring "contaminants" in the aquifer may also occur. For example when drinking water is recharged into an alluvial waterbody it frequently becomes gradually polluted by dissolved manganese and iron. The manganese and iron originate from the aquifer due to the decrease of dissolved oxygen in the groundwater. Under these conditions, Mn(IV) is reduced both chemically and bacterially into the Mn(II) soluble form.

The data supporting different views of researchers in different investigations should be taken into account when calling a chemical compound a "contaminant". *TCE*, for example, has been used in the United States for many years as an excellent degreasing agent, a popular dry cleaning solvent, an extraction agent in decaffeinating coffee, a general anaesthetic in medicine and dentistry, and in numerous other ways. Its uses were severely curtailed in 1976 when a study by the National Cancer Institute provided evidence that *TCE*, in very high experimental dosages, caused tumour growths in a sensitive mouse species. Subsequent studies by other researchers have failed to reproduce the carcinogenic response to *TCE* from any species of test animal while recent epidemiological studies have failed to implicate *TCE* as a cause of cancer in humans.

Although chemical pollution was identified previously, it is now also generally recognised that groundwater systems are as prone to microbial infestations as are surface waters. The presence of micro-orgamisms in municipal and biological waste may be significant because of its potential health impact. It appears that the potential hazard to man from the pathogenic agents reaching the groundwater depend upon (i) the number and nature of the pathogens initially placed in the landfill, (ii) their ability to survive or to maintain their infectious features and (iii) their ability to move through the landfill into the surrounding environment. Environmental conditions such as temperature, pH, time and the presence of chemical and biological antagonists may control and have a meaningful effect on the die-off and survival of micro-organisms. It is clear that the leachate may have a definite antibacterial impact with regard to the inactivation of micro-organisms, such that the microbiological health risks associated with the leachate from waste disposal landfills may be minimal. It is important, however, to remember that the inactivation capacity of different leachates may vary considerably depending on various factors and if pathogenic bacteria, viruses, protozoa or helminths survive in the leachate, they will consequently reach the groundwater. The health risk then becomes a function of their survival and movement through the aquifer.

The prevention of illegal dumping practices (e.g. toxic materials) would save considerable amounts of money. This holds both for industrial and domestic waste disposal. For example, the toxic content of domestic waste can be reduced by obtaining the co-operation of the public. This requires training in environmental awareness to encourage the public to sort their domestic waste and the provision of an intensive network of collection points which are regularly serviced. The number of waste sites must also be minimised and sites that have been closed must continue to be monitored for groundwater pollution.

Much research effort is being carried out in South Africa relating to groundwater contamination and aquifer protection. These studies relate to policy development, suitable investigative techniques and methods, and the setting of minimum requirements. Such efforts can only lead to improved standards in the waste disposal field. The DWA&F has been developing and implementing legislation in an attempt to prevent the loss of valuable water resources. Permitting of waste sites has been slower than anticipated and only 7 per cent of the country's waste sites have been investigated or reported on and about 15 per cent of the identified waste disposal sites have been issued with permits or are in the process of obtaining permits.

Recommendation

The basic legal framework already exists in South Africa, and the emphasis, in order to reduce the irresponsible disposal of industrial waste, should be placed on increased inspection and implementation of the environmental protection laws. Television and newspapers could play a vital role in improving environmental awareness education of the public. Government could encourage and facilitate the collection of sorted municipal waste and promote environmental training at schools.

FOREWORD

1. Acknowledgements

This report resulted from a project funded by the Water Research Commission entitled:

An Assessment of Health Aspects of the Impact of domestic and industrial Waste disposal activities on groundwater resources

The Steering Committee responsible for this project consisted of the following persons:

Mr AG Reynders	Water Research Commission (Chairman)
Mr HM du Plessis	Water Research Commission
Dr PL Kempster	Hydrological Research Institute, DWA&F
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Dr G Tredoux	Division of Water Technology, CSIR
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The financing of the project by the Water Research Commission and the contributions of the members of the Steering Committee are gratefully acknowledged.

The inputs by members of the Groundwater and Health Programmes, Alan Wright, John Weaver, Kerry Murphy and Bettina Genthe, of WATERTEK, CSIR are also greatly appreciated.

Drs R. Kfir and E. Meintjies, the previous project leaders, are sincerely thanked for giving me the opportunity for carrying out such an interesting and heartwarming project.

2. Purview of Report

The intention of this report is to present the findings of a literature review and outlines the health aspects of the impact of domestic and industrial waste disposal activities on groundwater resources. The report is structured as follows.

Chapter One entails a general introduction on groundwater contamination and states the objectives of the study. It also describes the importance of groundwater as a drinking water resource together with the contamination thereof.

Chapter Two provides a general introduction on industrial waste disposal. It addresses leachate generation and types of contamination from different industries. A few case studies are included to present a perspective of the extent of the problem.

Chapter Three includes an introduction on municipal waste disposal and leachate generation. Some information on chemical and microbiological contamination are reviewed.

Chapter Four deals with the health aspects of groundwater contamination, with a general introduction on health aspects of groundwater contamination. Detailed information on the sources of groundwater contamination, the importance of some inorganic, organic, biological contaminants and infectious diseases is presented.

Chapter Five entails a short discussion on Legislation with a general introduction, some international measures and the SA waste disposal situation.

Chapter Six outlines the conclusions of the study.

Chapter Seven provides a general recommendation and outlines further research that may still be needed.

CHAPTER 1 INTRODUCTION

1.1 Preamble

The transmission of hazardous chemical substances and infectious diseases through contaminated drinking water has been a frequent and well-documented occurrence in the past (Craun, 1984). Contamination of water sources and connections in water distribution systems have also occurred. With improvements in water protection, treatment, and distribution of drinking water, the occurrence of outbreaks of waterborne disease has been minimized. Any disease caused by drinking contaminated water can be transmitted through groundwater if the aetiologic agent reaches the water source in infective doses to cause the specific illness. Some contaminants are more likely than others to be present in groundwater with the result that some waterborne diseases occur more frequently. The degree to which groundwater is developed for drinking water supplies, geological and hydrological conditions, waste disposal practices, and general technological development all influence the importance of groundwater in the transmission of a particular disease in any country.

The list of possible chemical contaminants of groundwater is very large. Chemical contaminants originating from natural geological deposits or as a result of man's activities can contaminate entire aquifers as well as local areas. Groundwater contaminants such as arsenic, barium, fluoride, selenium, and radionuclides can be related to the natural composition of soils and rock. Contamination with synthetic organic chemicals and heavy metals such as cadmium, chromium, and lead is generally associated with the manufacture, disposal, and transportation of chemicals. Once groundwaters are contaminated with chemicals, they tend to remain contaminated because of insufficient dilution, the slow movement of groundwater in most aquifers, the technical inability to restore polluted aquifers and lack of any natural cleaning capabilities in most aquifers (Travis and Doty, 1990; Craun, 1984). Contamination generally occurs in local areas by seepage of waste into aquifers and improperly developed wells, or the entry of sewage-contaminated surface water into poorly protected wells.

Groundwater occurs below the surface of the earth and such terrestrial subsurface environments are invisible, inaccessible, and remote. The disposal of "waste" occurs world-wide and until recently, most people had never thought seriously about its impact on groundwater (Ghiorse & Wilson, 1988). Indeed, the aphorism "*Out of sight, out of mind*" aptly describes a traditional view of the terrestrial subsurface held by many. Unfortunately, the lack of interest implicit in this view has created serious environmental problems which ultimately may cost millions of rands to rectify, if at all.

1.2 Study Objectives

The contamination of groundwater and the associated health implications are now receiving wide-spread attention. In South Africa, studies are at present being conducted in order to assess the impact of mining (gold and coal) and agricultural activities on the quality of groundwater resources.

This study is aimed at filling the gap which exists in knowledge about the impact of domestic and industrial waste disposal practices on groundwater supplies and the associated health implications. The aims of the project are:

(i) to conduct a comprehensive literature survey which outlines health aspects of the impact of domestic and industrial waste disposal to land on groundwater resources.
(ii) to review current domestic and industrial waste disposal practices to land in South Africa and thereby establish the relevance of the overseas experience, as determined in (i), to South Africa.

1.3 Groundwater Importance

Although groundwater only contributes about 15% to South Africa's water supply at present, it is of great importance when one considers that more than 280 towns and villages use groundwater for water supply. This represents towns and settlements spread over about 65% of the area of South Africa (Kok & Simonis, 1989). One of the great benefits of groundwater is that it can be obtained at the point of need. This advantage is lost however should the water require treatment. Such treatment is not cost effective for scattered rural communities. Consequently the approach should be to prevent contamination in the first place.

In the United States (Craun, 1984) groundwater makes up nearly 25% of all water used and about 50% of the population depend on groundwater as their main source of drinking water. For many small communities groundwater is the main water supply source and rural water supplies are obtained from wells or springs. Many states use more groundwater than surface water. For example, the groundwater use (as percentage of the total water use) is in Kansas 86%, Nebraska 68% and Arizona 61%. Table 1 shows surface and groundwater use as percentage of potable water use in different countries:

Table 1: Potable groundwater use in different countries

Country	Groundwater (%)	Surface water (%)
Italy	93	7
Federal Republic of Germany	71	29
Belgium	70	30
Netherlands	65	35
France	50	50
Sweden	46	54
America	25	75
England and Wales	10	90
South Africa	15	85

Rimmer and Theron, 1990

Groundwater also has an important role in the aquatic environment by providing baseflow which keeps the rivers flowing, supports wetlands and dilutes effluents. Urban groundwater is potentially as valuable as any other water source, both as an environmental agent and as a water source (Lerner & Tellam, 1992).

1.4 Groundwater Contamination

Groundwater is constantly being threatened by the application of fertilizers and pesticides, urban development, disposal of domestic refuse to land, mining activities and in particular, the disposal to land of effluents containing high concentrations of industrial chemicals and sludges. However, groundwater contamination by leachates from the above presents the real problem and will increase if not managed properly. It was reported by Senior and Shibini in 1990) that 29% of groundwater supplies to 942 U.S. cities were contaminated. Many chemicals have been detected in landfill leachates from domestic, industrial and co-disposal sites as illustrated in Table 2 (see page 4).

The mobilisation of naturally occurring "contaminants" in a aquifer may also occur. For example when water is recharged into an alluvial aquifer for water supply, levels of dissolved manganese and iron gradually increase. The manganese and iron originate from the aquifer due to the decrease of dissolved oxygen in the groundwater. Under these conditions, Mn(IV) is reduced both chemically and bacterially into the Mn(II) soluble form. Under these conditions it is essential that in addition to classical hydrological studies, manganese speciation and bacteriological experiments are also needed to determine the origin of the manganese and the processes that lead to the groundwater pollution (Jaudon, *et al.*, 1989).

The protection of groundwater is therefore very important as surface water supplies will be insufficient to meet all South Africa's drinking water needs in the near future. It has been estimated that domestic water demand for most major metropolitan areas will continue to grow at a rate of 5% p.a. (DWA&F, 1986). In these areas, water demand will exceed supply by the year 2010. In Cape Town and the Durban-Pietermaritzburg areas for example, this will occur in 2008 and 1999 respectively (Parsons, 1992). An increasing number of reports have indicated that groundwater sources may be polluted by chemicals of industrial origin at places where contamination was previously unsuspected. The mobile, persistent low molecular weight halogenated hydrocarbons seem to be, as a group, one of the most prevailing categories of pollutants in groundwater. In the Netherlands this type of pollution has received much attention after an accidental discovery in 1976 by the National Institute of Drinking Water Supply of the presence of trichloroethylene in the drinking water obtained from a groundwater source previously thought to be unpolluted (Trouwborst, 1981). In the context of groundwater pollution, a convenient distinction can be drawn between five potential pollution sources i.e.:

(i) industrial waste (accidental / non-accidental spills),
(ii) domestic waste and sewage sludge treatment / disposal,
(iii) agriculture practices,
(iv) mining and
(v) nuclear waste

Table 2: Chemicals detected in Leachates from Domestic, Industrial and Co-disposal Landfill sites

Elements		
Aluminium	Cobalt	Nickel
Arsenic	Copper	Potassium
Barium	Iron	Selenium
Beryllium	Lead	Silicon
Boron	Magnesium	Silver
Cadmium	Manganese	Sodium
Calcium	Mercury	Strontium
Chromium	Molybdenum	Zinc
Inorganic radicals		
Ammonium	Fluoride	Phosphate
Bicarbonate	Nitrate	Sulfate
Chloride	Nitrite	Sulfide
Cyanide		
Aliphatics		
Acetic acid	Heptanoic acid	Methyl hexyl ketone
Acetic acid, ester	Heptanol	2-Methyl pantanoic acid
Butanol	Hexane	4-Methyl pantanoic acid
2-Butyl alcohol	Hexanoic acid	2-Methyl propanoic acid
iso-Butylamine	Hexanoic acid, butyl ester	Myristic acid
sec-Butylamine	Hexanoic acid, heptyl ester	γ-Nonalaction
t-Butylamine	Hexanoic acid, hexyl ester	Octane
Butyric acid	Hexanoic acid, methyl ester	Octanoic acid
iso-Butyric acid	Hexanoic acid, octyl ester	1-Octanol
Butyric acid, ester	Hexanoic acid, pentyl ester	Oleic acid
Butyric acid, propyl ester	Hexanoic acid, propyl ester	Palmitic acid
Carbon tetrachloride	1-Hexanol	Pentanoic acid
Caproic acid	Hexanone	*iso*-Pentanoic acid
iso-Caproic acid	Hexene	Pentanoic acid, ethyl ester
Chloroform	Ketones	Propionic acid
Dialkoxydimethoxy propane	Lauric acid	*iso*-Propyl alcohol
Dichloroethane	Methanol	Squalene
Dichloromethane	Methyl acetate	Stearic acid
Diethyl ether	Methylamine	Tetrachloroethylene
Disulfides	Methylene chloride	Trialkyl phosphate
Ethanol	2-Methyl butanoic acid	Trichloroethylene
Ethyl acetate	3-Methyl butanoic acid	Trimethylamine
Ethyl butyl ether	2-Methyl butyric acid	3,5,5-Trimethyl hexanoic acid
Ethyl ester	Dimethyl ketone	Valeric acid
Ethyl hexanol	Methyl ethyl ketone	iso-Valeric acid
Heptane	Methyl *iso*-butyl ketone	Vinyl chloride
Aromatics		
2-(4-Acetyl phenyl) propan-2-ol	Di-t-butyl cresol	Lignin
Alkyl benzenes	2,6-Di-t-butyl-4-methyl phenol	3-Methyl indole
C6 allylphenol	Diethyl phthalate	Methyl naphthalene
Benzaldehyde	Dimethyl benzoic acid	Napthalene
Benzene	Dimethyl t-butyl phenol	Phenol
Benzoic acid	Dioctyl phthalate	Phenyl acetic acid
Benzyl alcohol	Dipropyl phthalate	2-Phenyl ethanol
Butyl benzene sulfonamide	Disulfides	Phenyl propanol
t-Butyl cresol	Ethyl benzene	Phenyl propionic acid
t-Butyl methoxy phenol	Ethyl methyl benzene	Phthalates
t-Butyl phenol	Ethyl methyl thioindone	Styrene
Chlorotriisopropyl	p-Ethyl phenol	Tannin
Cresols	Fulvic acid	Toluene
p-Cresol	Humic acid	Xylene
Acyclics	**Terpenes**	
t-Butyl cyclohexane	α-Bicyclic sesquiterpene	Camphene
Cyclohexane	Camphor	Fenchone
Cyclohexane hexanoic acid	Terpineol	
Cyclohexanol	α-Terpineol	
Cyclohexanone	Thujone	

Senior and Shibini (1990)

Many kinds of environmental threats result from the disposal of waste by landfilling, but the pollution of groundwater at waste disposal sites is arguably the most important. The production of leachate, even at properly designed and operated landfills, is not limited to excess water regions alone, but it also develops in areas where the yearly evapotranspiration exceeds the rainfall by a wide margin (Rimmer and Theron, 1990). Consequently, groundwater pollution follows when leachate is able to infiltrate into the aquifers. There is no certainty that even the best designed and engineered landfill will, in time, not leak. The potential health hazard of contaminated groundwater is of extreme importance to groundwater users as most water obtained from boreholes is not treated.

The contamination of groundwater from different sources occurs worldwide. Primarily it is due to the large variety of materials used by industry and households. The disposal of toxic waste, municipal solid waste, sewage sludge, industrial waste and effluents are some examples of groundwater pollution sources. Some pathways for contaminants to reach groundwater are the following (Dragun, Kuffner and Schneiter, 1984):

1: Seepage from unlined effluent lagoons and other surface impoundments
2: Improper landfilling
3: Improper surface and subsurface disposal
4: Leaks in pipes, process equipment and storage tanks
5: Accidental spills.

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CHAPTER 2 INDUSTRIAL WASTE DISPOSAL

2.1 Introduction

Landfilling has long been the major disposal method for both domestic and industrial wastes. Throughout the United States enormous amounts of industrial waste are deposited within the upper layers of the earth's crust at land disposal sites (Dunlap et al., 1976). It is estimated that since the late 1950's 750 million tons of toxic chemicals have been discarded in 30 000 to 50 000 hazardous waste sites (Griffith, Duncan, Riggan and Pellom, 1989). In the UK more than 95% of all industrial solid wastes are disposed of by landfill methods which are still the cheapest disposal option (Robinson and Maris, 1985). In the Netherlands land disposal of waste is also the most common practice (Hoeks, 1976). Major industrial firms recycle their chemical wastes or have them incinerated or stored in selected disposal sites. However, there have been several cases where firms that were hired to dispose of the industrial wastes, have created some of the worst hazardous waste sites, due to insufficient disposal equipment or by simply overlooking the repercussions (Paling, 1991).

Unfortunately, many of the thousands of landfills, active or abandoned, have been operated with little regard for the dangers of groundwater contamination. Among the many substances which might enter the groundwater are potentially hazardous organic and inorganic compounds. Of the organics, chlorinated hydrocarbon solvents (CHS's) are particular common as they are widely-used, mobile and resistant to degradation.

Virtually all industrial sites pollute the soil and groundwater through careless handling of chemicals, inadequately trained staff, equipment which is often not available and safety procedures that are not followed. Much waste is not regulated at present and many practices are entirely uncontrolled. Industrial sites should be treated like municipal landfills. They should be managed and correctly monitored. If industrialists had to use the groundwater from below their own sites, they would suffer the consequences of their own pollution (Lerner and Tellam, 1992). The quantities of industrial waste requiring disposal and the constant problem of keeping water resources as pure as possible in fast growing countries, provide an overriding need to ensure that leachate emanating from landfill sites does not contaminate groundwater.

2.2 Leachate

It was formerly believed that the residual chemicals in the leachate would be removed as the leachate percolates through the upper soil mantle, and enters unsaturated subsurface zones, eventually reaching groundwater in a purified state. Until a little more than 15 years ago, it was believed that groundwater supplies were safe from pollution. Sadly, this belief was proved to be wrong. Thus, until very recently terrestrial dump sites were not perceived as a threat to groundwater supplies. Many examples exist around the world where land application of different wastes are now polluting many groundwater sources. In many areas of the world today aquifers containing vital groundwater supplies are polluted with toxic chemicals and other substances with little hope of reclaiming them in the near future.

Polluted aquifers are still *out of sight*, but they are no longer *out of mind* (Ghiorse & Wilson, 1988).

Assmuth (1992) investigated, in a five year study, the distribution, concentrations in various phases, attenuation and emmissions of hazardous substances in Finnish municipal and industrial mixed-waste landfills. Table 3 (see page 8) shows the statistics of contaminant concentrations in landfill leachate together with concentrations ranges in other landfill studies. From the results it is clear that the leachate quality was typical of runoff from all of Finland's landfills, but was below many of the upper levels reported elsewhere. The peak concentrations exceeded the toxic levels and drinking water norms.

2.3 Types of contamination from different industries

Cases of pollution by the leaching of buried chemicals into groundwaters from old landfills and industrial waste disposal sites have been reported. Several chlorocarbons have been identified in leachates obtained from within and around a chemical waste disposal site (DeLeon, *et al.*, 1980).

Contamination of groundwater and soil by leaking underground petroleum storage tanks (six important volatile aromatics, *viz.*, benzene, toluene, ethylbenzene and three xylene isomers) is an increasingly common environmental problem (Roe, *et al.*, 1989).

Sawhney and Kozloski (1984) identified different volatile compounds, varying over a wide concentration range, in leachates from four landfill sites. The high concentrations of a number of industrial solvents (acetone, isopropyl alcohol, methyl ethyl ketone, 2-butyl alcohol, benzene and methyl isobutyl ketone) in the leachate show appreciable industrial waste contamination. Their results show that large concentrations of many organic compounds, both volatile and nonvolatile, can leach from landfills into the groundwater.

Aquifers in Region Lagunera in northern Mexico are heavily contaminated with arsenic which has caused adverse health effects (Del Razo, 1990). The database suggest that As concentrations have been steadily increasing during the last ten years. It is not clear from the publication where the As contamination originates from.

Tetrachloroethylene (*TCE*), an established animal carcinogen, has been widely used for the cleaning of cloth for many years. Its uses were severely curtailed in 1976 when a study by the National Cancer Institute in the USA provided evidence that *TCE*, in very high experimental dosages, caused tumour growths in a sensitive mouse species. It is interesting to note that subsequent studies by other researchers have failed to reproduce the carcinogenic response to *TCE* from any species of test animal. Recent epidemio-logical studies have failed to implicate *TCE* as a cause of cancer in humans (Schaumburg, 1990). Currently, this chemical together with *Trichloroethylene* appears to be the most prevailing pollutant of groundwater in various countries (Zoeteman, *et al.*, 1980; US Council on Environmental Quality, 1981; Japan's Environment Agency, 1983; Trouwborst, 1981). While the biological monitoring of *TCE* exposure is popular in occupational health, *TCE* is seldomly analysed in subjects exposed through the general environment.

Table 3: Concentrations ($\mu g/\ell$) of contaminants in landfill leachate

Substance or quality variable	Median	Mean	Maximum	n	Finland Studies	B.R.D., U.S.A U.K., D.K	In sewage	Acceptable in potable water
pH (pH units)	7	-	8.6	208	6.6 - 7.9	6.2 - 8.2	6.6 - 8.7	6 - 9.5
Cl^- (mg/ℓ)	130	220	1800	141	170 - 360	359 - 4130	30 - 60	400
NH_4-N (mg/ℓ)	14	46	340	153	39 - 130	59 - 1380	20 - 40	1.5
COD_{Cr} (mgO_2/ℓ)	200	400	2200	52	280 - 1700	273 - 21260		
As	<6	9.5	760	177	12	56 - 253		40
Cd	<6	0.8	70	248	0.6 - 2.6	2.7 - 18	<1	5
Cu	20	22	190	248	4 - 46	22 - 336	<10 - 470	1000
Ni	12	260	3200	72	37 - 98	48 - 701		50
Pb	3	0.7	63	136	14 - 32	29 - 249	10 - 70	40
Zn	90	1200	110000	255	190 - 150000	150 - 13000	90 - 250	3000
Dichloromethane	19	520	5700	53		64 - 20000		30
$CHCl_3$ (Chloroform)	0.1	0.82	100	53	0.44	15 - 21800	1 - 430	25
1,2-*Dichloroethane*	2.6	55	680	53		5.5 - 20000	1 - 59	
Tetrachloroethane	0.34	3.3	110	30	1.6	26 - 23600	2 - 1100	14
Toluene	0.61	53	1500	66		7.5 - 660000	1 - 13000	
Σ *Xylenes*	0.5	100	2400	66		12 - 48000		
Ethylbenzene	<0.1	48	980	66			1 - 730	
1,2-*Dichlorobenzene*	<0.1	0.31	2.8	54		10 - 32	2 - 440	
Hexachlorobenzene	<0.01	0.51	10	54				0.01
2,4,6-*Trichlorophenol*	0.098	0.82	6.0	29	1.9 - 9.4		1 - 6	0.1
Pentachlorophenol	0.083	0.15	3.0	29	0.1 - 1.52		2 - 94	0.1
Σ *Cresols*	4.2	78	870	47	10 - 2100			
Lindane	<0.05	0.43	15	46			0.02 - 0.5	0.1
Dieldrin	<0.05	0.058	1.1	49			0.03	0.1
Σ DDT isomers	<0.05	0.023	0.23	49				0.1
Σ PCB's	<0.05	0.49	3.8	36	0.04 - 5		2.3 - 50	0.5
Σ AOCls	37	160	3200	111		5000 - 360000		

Assmuth, 1992

Hexavalent chromium pollution problems in groundwater are well known in some areas such as Barcelona and Castelló de la Plana (Spain). They originate from metallurgical, plating and leather factories and their disposal was concealed by disposing of them into excavations near or inside the factories. Most of these old factories have closed down years ago. The owners are gone and no responsible party can be located. The consequences have been the closing of important supply wells, many in areas short of water, and reduction of or damage to the emergency water supply capacity for important urban areas (Custodio, 1992).

2.4 Case Studies

In order to present a perspective of the magnitude of the problem, case studies of industrial contamination of groundwater, as cited in the literature in different countries, are presented below:

USA

A study was conducted to identify specific organic pollutants in groundwater contributed by a landfill (Norman landfill). This study identified 52 organic complexes (many of these being potentially undesirable) at low levels which were contributing to the groundwater pollution within and immediately under the landfill. A few of the compounds identified could be the result of leaching of natural products, including foods, or the possible end products of microbial metabolism. In assessing the results, it should clearly be noted that most of the compounds identified included only substances readily amenable to gas chromatography and consequently represent probably less that 10% of the compounds present. Most of the missing material is probably composed of compounds too polar and/or too high in molecular weight to be identified by gas chromatographic procedures. Characterization of this material would undoubtedly have yielded much additional information concerning the organic pollutants contributed to groundwater by landfills, but the necessary analytical facilities were not always readily available at the time (Dunlap, *et al.*, 1976).

Canada

Reinhard, *et al.*, (1984) established the spatial distribution of trace organic compounds in leachate plumes of two sanitary landfills. The majority of the compounds originated from decomposing plant material and included aliphatic and aromatic acids, phenols, and terpene compounds. Minor constituents, including chlorinated and non-chlorinated hydrocarbons, nitrogen-containing compounds, alkylphenol polyethyoxylates, and alkyl phosphates, were determined to be of industrial and commercial origin.

Russia

Shelest, *et al.*, (1990) in their investigation found that groundwater contained nitro and amino compounds and phenols in amounts exceeding the maximum permissible concentration for drinking water sources. The quality of the groundwater had deteriorated with the growth of industrial production and the associated accumulation, migration and transformation of pollutants from the surface, leakage from recirculation water systems and sewage, accidents in workshops and poor industrial standards.

Australia

Gerritse, *et al.*, (1990) reported on the impact of residential urban areas on groundwater quality on the Swan Coastal Plain, W. Australia. Concentrations of all major ions in groundwater (total dissolved salts) were found to increase with intensity of development in urban areas, with salts of chloride and sulphate accounting for most of the increase. The percentage of sulphate increases strongly in groundwater from unsewered urban areas. The existence of high levels of fluoride in the Bayswater Main Drain was found to be as a result of disposal of industrial waste. Levels of borate (origin: laundry detergents) in the groundwater in unsewered areas was found to be significantly higher than in the sewered urban areas.

Japan

Kido, et al., (1989) found *Tetrachloroethylene* (*TCE*) concentrations of up to 5 $\mu g/\ell$ in blood samples of inhabitants using groundwater in an area downstream of a drycleaning plant. No *TCE* was found in blood samples of people, in the same area, who used municipal water. The municipal water contained no *TCE*. The inhabitants complained that their well water had a "chemical" smell particularly when boiled. The blood samples of the users of groundwater with the highest concentration of *TCE* (27 000 $\mu g/\ell$) also showed the highest concentrations of *TCE* ($5 \mu g/\ell$).

Holland

An investigation in the Netherlands showed tri- and perchloroethylene to be the most prevailing pollutants in groundwater, with the exception of one single case of serious tribromoethene pollution in the vicinity of a former brominated products production site. In some cases the analyses showed that tri- and perchloroethylene were detected at levels higher than 10 $\mu g/\ell$ and could be traced to past point discharges to the ground (Trouwborst, 1981).

Mexico

Chromium (VI) contamination in an area north of Mexico City was caused by a factory that produced chromate salts from 1958 until 1978 (Gutierrez-Ruiz, 1989). The production process was very inefficient since the raw material was inexpensive and the environmental protection issue was not considered to be important. The process was carried out in the open air and no care was taken about dust emissions, process water and solid waste disposal. Solid residues were deposited in several places, as these were used as filling material at the construction sites. The factory closed in 1978 because of health problems (increased number of respiratory diseases) and in 1982 an "industrial grave" was built to dispose of the solid residues which could be recollected. A hole with a depth of 3,5 m was excavated surrounded by 25 cm thick reinforced concrete walls. 75000 tons of waste material was deposited in the grave, directly on the soil, with no insulating material between the residues and the ground. Chromium (VI) is leaching and contaminating the aquifers.

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CHAPTER 3 MUNICIPAL WASTE DISPOSAL

3.1 Introduction

The use of landfill sites for direct tipping of domestic refuse continues to be the major disposal route for such wastes in many parts of the world. In the UK, for instance, more than 90% of all domestic and commercial solid wastes are disposed of by landfill methods (Robinson and Maris, 1985), while in North Carolina, USA, sanitary landfills are the primary method (95%) of solid waste disposal (Borden and Yanoschak, 1990). In the Netherlands land disposal of waste is the most common practice (Hoeks, 1976). Waste is dumped in the so-called "sanitary landfill", i.e. an engineering method of disposal of refuse on land, creating a minimum of nuisance from an environmental and sanitary point of view. Landfilling is also the principal method of solid waste disposal in the Kingdom of Saudi Arabia (Husain, *et al.*, 1989).

The most commonly used landfill disposal sites are pits, abandoned quarries, or natural land surface depressions. The quantities of solid waste requiring disposal and the constant problem of keeping water resources as pure as possible in rapidly developing countries result in an overriding need to ensure that leachate emanating from landfill sites does not contaminate groundwater.

Originally, household garbage consisted primarily of biodegradable materials but the refinement of our lifestyle has brought with it an unlimited output of less degradable products. For example, used batteries (specifically watch batteries), used and half empty cans of various solvents, oven cleaner, paints, poison, hairsprays, etc, are frequently disposed of as domestic waste into landfills (Paling, 1991). It is speculated that every household in the U.S. contributes more than 4.5 ℓ/year of hazardous waste towards contamination of municipal sanitary landfills. Numerous cases of illegal dumping of industrial wastes at municipal sanitary landfills has also been recorded. Co-disposal of industrial waste was identified as the primary cause of groundwater contamination at 130 of the 138 landfills on the Superfund National Priorities List (Franklin, 1986). In time, all the above may decompose and have their contents leached down to the groundwater. The pollution potential of leachate can therefore be compared to domestic sewage or settled sewage sludge and in addition to the chemical toxicity problem, the possibility of landfill pathogenic species moving into aquifers must also be recognised.

3.2 Leachate

The pollution threat of leachate, real or potential, to surface and groundwater has long been realized and has been the key consideration in landfill site design to prevent serious and costly problems. However, in many recent circumstances the protection of groundwater is now the leading objective for licensing landfill sites (Senior and Shibini, 1990). In recent years, the number of sites at which landfill leachate is known to contaminate the underlying aquifer has been increasing, but only a few cases have been studied in detail with regard to geochemical processes, the attenuation of contaminants and the occurrence of potentially hazardous organic chemicals in leachates from municipal landfills. To assess the impact on water quality at a given site, several questions which need to be addressed were identified (Reinhard, *et al.*, 1984).

(i) What are the potentially harmful constituents in the leachate?
(ii) What are the local hydrogeologic conditions?
(iii) What is the significance of attenuating factors such as biological and/or chemical degradation, adsorption, ion exchange, precipitation, and hydrodynamic dispersion?

These questions are difficult to answer, mainly because of the cost and complications involved in obtaining geohydrological data and representative samples of groundwater, as well as a lack of data on degradation and sorption constants.

The unstable and dispersed movement of liquids through the mass of a landfill site results in the leaching of soluble compounds, which were originally present in the waste or were formed in chemical and biochemical processes, together with transferable organic and inorganic materials, and micro-organisms like bacteria, protozoa, helminths and viruses. As municipal landfills are covered by a low permeability layer only when dumping is terminated, rainfall furthers the decomposition and leaching process. The rainwater percolates through a landfill and the leachate penetrates the topsoil and feeds the groundwater. The penetration can be controlled by various means but it is practically impossible to completely prevent infiltration of precipitation (Hoeks, 1976).

Leachate arising from domestic waste landfills may contain high concentrations of organic and inorganic substances, and has the potential to pollute both surface and groundwaters. Monitoring the quality of groundwater in the vicinity of municipal landfills has proved that water quality deterioration occurs at many sites (Paling, 1991).

3.3 Chemical Contamination

The composition of leachate from municipal wastes has been widely studied. The chemical composition of leachate from a landfill at a particular time depends on many factors, including the type of waste, the disposal method and the degree to which it has been stabilised by processes within the landfill. The character and composition of the refuse, the age of the landfill, the percolation rate and the contact time between percolate and refuse are important factors in determining the ultimate leachate contamination.

It is not possible to predict with any accuracy the "potency" of leachate from any one site, because of the wide range or conditions (moisture content of wastes, seasonal variations in infiltration of water, composition of wastes, landfill microbiology, depth of fill, compaction, use and composition of cover). In the literature, large differences in the composition of leachate are found which are partly due to the factors mentioned above, but also to the different ways of collecting and analysing the leachate samples. However, most authors report a rapid decrease in the concentration of pollutants within rather short distances from the waste disposal site (Hoeks, 1976; DeWalle and Chian, 1981; Sykes, *et al.*, 1982; Engelbrecht and Amirhor, 1975).

Table 4 shows the chemical composition of leachate from newly dumped refuse while typical ranges are shown in Table 5.

Table 4: Chemical composition of leachate from freshly dumped refuse

Component (mg/ℓ)	1972	1973	1974
COD	-	-	63 000
BOD	32 400	33 100	-
Cl	2 240	1 810	3 950
SO_4	630	560	1 740
HCO_3	-	-	14 430
Organic N	550	320	390
Inorganic NH_4-N	845	790	1 410
NO_3-N	-	-	-
Total PO_4	-	9.6	25.5
Ortho PO_4	-	-	6.8
Total Fe	305	270	1 590
Ca	-	2 190	2 625
Mg	-	340	450
Na	1 805	1 470	2 990
K	1 860	1 115	1 800
pH (pH units)	5.6	-	5.7
EC (25 °C) mS/m	-	-	324 000

Hoeks, 1976

Table 5: Range of chemical composition of leachate from sanitary landfills

Constituent (mg/ℓ)	Range of values
COD	40 - 89 520
BOD	81 - 33 360
TOC	256 - 28 000
TS	0 - 59 200
TDS	584 - 44 900
Cl	4.7 - 2 467
SO_4	1 - 1 558
NH_4-N	0 - 1 106
NO_3 + NO_2-N	0.2 - 10.3
Total PO_4	0 - 130
Ortho PO_4	6.5 - 85
Fe	0 - 2 820
Ca	50 - 7 200
Mg	17 - 15 600
Na	0.09 - 125
K	28 - 3 770
Pb	$<$0.10 - 2
Cd	$<$0.03 - 17
pH (pH units)	3.7 - 8.5
EC (25 °C) mS/m	281 - 1 680

Engelbrecht & Amirhor, 1975

The data indicates that the leachate contains a large number of contaminants.

The contaminants of the greatest concern as shown in the two Tables, are:

- dissolved organic compounds - they may affect taste and odours,

- nitrogen compounds - eutrophication problems in surface waters and poisonous effects of high NO_3-contents in drinking water,

- heavy metals - toxic effects - industrial wastes from *e.g.*, galvanic industries are sources of heavy metal pollution if dumped at waste disposal sites.

- sodium, potassium, chloride, calcium and magnesium - harmless to humans at normal concentrations, but ecologically harmful and may pose problems when groundwater is used for industrial purposes.

Leachate from domestic solid wastes usually contains high concentrations of both soluble organic matter and of inorganic ions such as chloride, sulphate and metals (mainly iron, sodium, potassium, calcium, manganese and zinc) (Robinson and Maris, 1979). The major cations found in the UK leachates are sodium, calcium, potassium and magnesium in order of decreasing concentration.

Iron concentrations found varied from 0,09-380 mg/ℓ and may reflect the degree of aeration of the leachate prior to sampling. Iron concentrations in the U.S. are reported as frequently exceeding 1000 mg/ℓ (Engelbrecht and Amirhor, 1975). In all samples the concentrations of toxic metals (*e.g.*, chromium, nickel, copper, cadmium and lead) were not markedly higher than those found in domestic sewage. The highest concentration of soluble phosphorus which was determined was 0,41 mg/ℓ but concentrations below 0,1 mg/ℓ were common (Robinson and Maris, 1979).

The composition of leachate from samples taken at UK landfills showed that these are similar in composition to leachate from domestic wastes in USA, Canada and other countries. A general characteristic of these leachates is their low phosphorus concentration, which may inhibit biological treatment processes unless additions are made.

The composition of organic matter in leachate varies as wastes decompose within a landfill. The organic composition of leachates from various landfill sites in the UK showed TOC values ranging from 21-4440 mg/ℓ as well as a range of short-chain carboxylic acids (Robinson and Maris, 1979). In the U.S. the data (Table 4) indicates that the leachate is generally high in organic matter. The BOD, COD and TOC values are as high as 89 000, 33 000 and 28 000 mg/ℓ respectively (Engelbrecht and Amirhor, 1975).

Table 6 (see page 15) shows the composition of leachate in the Kingdom of Saudi Arabia (Husain, *et al.*, 1989) and the extreme variability in the concentration of its constituents which may be influenced by a number of waste- and site-specific factors.

Table 6: Variability of Leachate composition in the Kingdom of Saudi Arabia

Constituent	Minimum, mg ℓ^{-1} (except pH)	Maximum, mg ℓ^{-1} (except pH)
Chloride (Cl)	34	2800
Fe	0.2	5500
Mn	0.06	1400
Zn	0	1344
Ca	5	4080
Mg	16.5	15600
K	2.8	3770
Na	0	7700
Phosphate (PO_4)	0	154
Cu	0	9.9
Pb	0	5.0
Sulphate (SO_4)	1	1826
Total-N	0	1416
TDS	0	42276
TSS	6	2685
pH (pH units)	3.7	8.5
Alkalinity as $CaCO_3$	0	20850
Total hardness	9	22800
BOD	9	54610
COD	0	89520

Husain, *et al.*, 1989

Analyses of water samples from boreholes at two waste disposal sites, Dhahran and Juaymah, as shown in Table 7 (see page 16) and Table 8 (see page 17), indicate that there was, in spite of the arid nature of the climate, a definite increase in the concentration of pollutants in downgradient groundwater over that observed in upgradient boreholes. The presence of BOD and COD in groundwater is generally considered as a clear indication of contamination.

At Dhahran the average concentrations of BOD, COD and TOC in the samples obtained from the downgradient borehole were found to be 6.5, 23.5 and 34.3 mg ℓ^{-1} respectively. On the other hand, the mean concentration of the same parameters in upgradient monitoring wells was found to be less than 2.4, 11.5 and 10.0 mg ℓ^{-1}, respectively. The ammonia-N and organic-N in the downgradient wells were 0.37 and 0.29 mg ℓ^{-1} whereas in upgradient wells they were 0.11 and 0.15 mg ℓ^{-1}, respectively.

At Juaymah the average concentration of BOD and TOC in groundwater samples obtained from upgradient boreholes was less than 3.0 and 7.2 mg ℓ^{-1}, respectively, while the concentration of the same parameters in downgradient well samples was above 5.0 and 35.0 mg ℓ^{-1}, respectively. A similar trend for ammonia-N, organic N, phosphate, sulphate, and metals in downgradient samples was observed. Due to the shallow water table near the Juaymah landfill site, there was very little possibility of natural attenuation of leachate by the soil. Therefore, most of the leachate pollutants could only have been reduced through a process of dilution with groundwater. The water from these shallow aquifers at both places is not at the moment being used for human consumption or for any other commercial purpose. The slight increase of pollutants on the downgradient side was therefore considered not to be very critical. However, the findings of the study were considered to be helpful in selecting the site and in operating the future landfills in the region.

Table 7: Average concentrations of analysed parameters at Dharan waste disposal site

PARAMETERS (mg/ℓ)	Downstream	Upstream	Upstream
Temperature (°C)	30.2	29.5	29.7
pH (pH units)	7.34	7.49	7.55
Suspended solids	11	40	23
Total solids	5200	4618	2779
BOD	6.5	2.4	2.2
COD	23.5	11.5	7.5
TOC	34.3	9.4	9.9
Ammonia-N	0.37	0.11	0.10
Organic-N	0.29	0.15	0.08
Phosphate			0
Chloride	0.00251	0.00183	957
Sulphate	2109	1929	997
Ca	1388	1400	78
Mg	112	106	68
Na	111	111	428
Fe	945	850	0.03
Zn	0.18	0.16	0.09
Ni	0.15	0.12	0.03
Cu	0.05	0.03	0.10
	0.10	0.10	

Husain, *et al.*, 1989

Monitoring data on 71 sanitary landfills located throughout N. Carolina indicated 71% of the landfills surveyed had groundwater quality violations for organic and/or inorganic pollutants in one or more monitoring wells. Statistically significant increases were detected in the average concentrations of inorganic pollutants in groundwater and downstream surface water samples when compared to upstream surface water samples. The largest percentage increases were observed for zinc, turbidity, total organic carbon, conductivity, total dissolved solids and lead. Violations of N. Carolina Groundwater Quality standards for heavy metals and hazardous organic compounds were detected at 53% of the landfills studied. The most common heavy metal violations were for lead (18%), chromium (18%), zinc (6%), cadmium (6%) and arsenic (6%). The organic compounds of greatest threat to ground-water were the chlorinated solvents (8%), petroleum-derived hydrocarbons (8%) and pesticides (5%). The distribution of the organic chemical concentrations was strongly asymmetrical with a few landfills containing high levels of synthetic organics while at the majority of landfills, organic chemicals in groundwater were at or below the analytical detection limit. High levels of anaerobic degradation products such as propionic, butyric and valeric fatty acids were also found at some sites, although synthetic organics were not detected at these same sites. These anaerobic degradation products are not highly toxic but, because of their offensive odour, would render water supplies unfit for other uses (Borden and Yanoschak, 1990).

Table 8: Average concentrations of analysed parameters at Juaymah waste disposal site

PARAMETERS (mg/ℓ)	Downstream	Upstream	Downstream	Upstream
Temperature (°C)	27.5	27.9	30.2	29.3
pH (pH units)	7.16	7.13	6.77	6.70
Suspended solids	9	26	37	72
Total solids	4097	6739	52833	55132
BOD	2.4	3.0	5.1	9.3
COD	9.9	15.2		
TOC	3.9	7.2	35.1	37.0
Ammonia-N	0.10	0.07	0.62	7.97
Organic-N	0.04	0.05	0.28	0.66
Phosphate	0.00349	0.00353	0.00822	0.0159
Chloride	2046	3234	29950	33466
Sulphate	806	1069	3494	2840
Ca	120	155	634	814
Mg	121	166	532	778
Na	712	1401	11024	13827
Fe	0.12	0.18	0.41	0.74
Zn	0.10	0.10	0.22	0.20
Ni	0.03	0.05	0.45	0.48
Cu	0.10	0.10	0.11	0.11

Husain, et al., 1989

The quality of groundwater near North Carolina sanitary landfills appears to be similar to wastewater receiving secondary treatment. The detection frequency for organic pollutants in groundwater is much lower than the detection frequency in wastewater effluent. The frequency of water quality violations for heavy metals was slightly higher for landfills than for wastewater effluent when a common standard was applied. The results of this study indicated that landfills are having measurable impacts on ground- and surface water quality, but that these impacts may not be as severe as is commonly assumed.

3.4 Microbiological Contamination

Considering the heterogeneous nature of the waste, it is clear that the biological populations must also be just as heterogeneous. Food waste, human and pet waste that are discarded in municipal landfills could contribute a large number of different micro-organisms. However, it is virtually impossible to obtain a representative sample of a size that can be analysed. If a reliable sample could be obtained, then a further problem exists of how to extract and enumerate the micro-organisms present. These problems have resulted in a lack of information on the biological aspects of solid waste disposal and the available information should probably be accepted with caution.

Waste deposited at a landfill site contains both high numbers and a great variety of micro-organisms. Health care and pharmaceutical industry, academic and industrial research laboratories, veterinary facilities and the food, drug and cosmetic industries are the major contributors of infectious waste in the United States (Fedorak and Rogers, 1991). Furthermore, household refuse that may contribute are facial tissues, pet faeces, used disposable diapers and foodstuffs. Pahren (1987) found that the numbers of total coliforms in municipal waste are similar to the numbers in undigested sewage sludge and hospital waste and were 7,7 x 10^8, 2,8 x 10^9 and 9,0 x 10^8 /g respectively. Pahren (1987) also found that environmental conditions in a landfill (elevated temperature and antagonistic characteristics of the leachate) have detrimental effects on the survival of the micro-organisms. Therefore, although micro-organisms have been found in leachate their numbers are often quite low. Blammon and Pieterson (1974) found that the numbers of faecal coliforms during the initial 2-month leaching period averaged 1,5 x 10^4 /mℓ and during the third month the numbers decreased sharply and remained at low values from 0,3 to 1,8 /mℓ. Similar studies (Sobsey, 1978, Donnelly and Scarpino, 1984) arrived at the same conclusions and stated that leachate for properly operated landfills did not constitute an environmental or public health hazard from enteric viruses.

Engelbrecht and Amirhor (1975), stated that the major pathogens present in waste may be classified as bacteria, viruses, protozoa and helminths, but very little definitive information is available on the biological properties of municipal solid waste. Their potential hazard is a function of three factors:

(i) the number and nature of the pathogens in the landfill,
(ii) their ability to survive or to maintain their pathogenic aspects and
(iii) their ability to move through the landfill into the aquifer

In the published reports that Engelbrecht and Amirhor (1975) have reviewed on refuse species, they found that the densities, per gram of dry municipal refuse of faecal coliforms and faecal streptococci, were 5 x 10^3 and 2,8 x 10^3 respectively. In the decomposed material of a three year old landfill the density of faecal coliforms ranged from less than 1 to 100 /g dry weight and faecal streptococci were less than 60 /g. *Staphylococcus aureus*, *Diplococcus pneumoniae*, *Klebsiella pneumoniae*, haemolytic streptococci (*Streptococcus pyogenes*) and various other streptococci species, *Proteus* species, *Salmonella typhimurium* and other serotypes were also reported to occur in municipal solid waste.

It was found that the survival of micro-organisms (enteric bacteria and viruses) in landfills or leachates is controlled by various factors such as temperature, pH, time, water activity and the presence of chemical and biological antagonists. It was also found that the numbers of total coliform, faecal coliform, faecal streptococci and total plate counts varied substantially with the age of the leachate. The rate of virus inactivation is also linked to the age of the landfill that generates the leachate. With lysimeter studies it was discovered that polio virus type 1 was not significantly inactivated by leachate collected during a period of 26 to 47 days of operation. However, reovirus type 1 was inactivated within 10 minutes by the 47 day leachate. With polio virus, inactivation increased with operation time and it was found that pH control plays a major role in the inactivation. At pH 5.3 and 22 °C, inactivation was convincingly better than at pH 7.0. Bacterial inactivation showed the same relationship with pH and the stability order in different environments is demonstrated by the following results:

22 °C / pH 5.3: *Salmonella typhimurium* > faecal streptococci >> faecal coliforms,
22 °C / pH 7.0: faecal streptococci > *Salmonella typhimurium* >> faecal coliforms,
55 °C all pH's: *Salmonella typhimurium* > faecal streptococci >> faecal coliforms.

From these results it is clear that the leachate may have a definite cleaning impact with regard to the inactivation of micro-organisms, such that the microbiological health risks associated with the leachate from waste disposal landfills may be minimal. It is however important to remember that the inactivation capacity of different leachates may vary considerably depending on various factors and if pathogenic bacteria, viruses, protozoa or helminths survive in the leachate they will consequently reach the groundwater. The health risk then becomes a function of their survival and movement through the aquifer.

CHAPTER 4 GROUNDWATER POLLUTION HEALTH ASPECTS

4.1 Introduction

The information in Chapter 4 is mostly from American literature since the bulk of the available literature originated from that country. It does therefore not cover all information relevant to this subject although some references from other countries have also been included.

From 1971 until 1979 in 45 U.S. States and Puerto Rico, 267 outbreaks of waterborne diseases affecting 57 974 people were reported. Fifty four per cent of the **outbreaks** occurred where noncommunity water systems exist. There are approximately 150 000 noncommunity water systems in the United States of which 96% use groundwater resources. Sixty nine per cent of the **illnesses** occurred in community water systems, which number 64 000 and serve 200 million people. About 82% of the community water systems and 30% of the population served thereby, use groundwater. Twelve per cent of the **outbreaks** and 1% of the **illnesses** occurred in individual water systems, which primarily depend on untreated groundwater (Craun, 1984).

Another literature review (Keswick, 1984) stated that from 1946 to 1977, there were 264 outbreaks and 62 273 reported cases of waterborne diseases due to contaminated groundwater in the United States. This accounted for about 50% of all the waterborne illnesses (see Fig. 1).

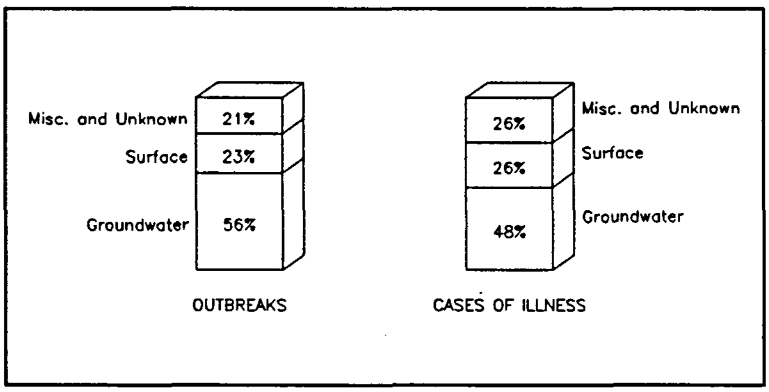

Fig. 1: Waterborne disease outbreaks in the U.S. (1946 - 1977, Keswick, 1984)

Craun (1990) again reviewed the reported outbreaks of waterborne diseases and the causes of waterborne outbreaks from 1971 until 1985. There were 502 outbreaks and 111 228 reported cases of waterborne diseases due to contaminated groundwater. Fig. 2 (see page 21) presents his data graphically. As can be seen in Fig. 2 the data does not differ significantly from the data as presented in Fig. 1. In the cases of illness, groundwater still accounted for about 50% of all the illnesses, but there was an increase in cases where the causes of the illneses was surface water. It is also interesting to note that although the period between 1971 to 1985 is half (14 years) the time of the period 1946 to 1977 (31 years), the waterborne outbreaks (502 against 264) and the cases of illness (111 228 against 62 273) are nearly double. This is a clear indication that the contamination of groundwater had grown or that the extent of the problem is spreading. However, Craun (1990) stated that although more outbreaks were reported during 1971-1985 than any previous 15-year period since 1920 (see Fig. 3), the number of reported waterborne outbreaks has declined since 1981. Craun also said that it is difficult to determine whether the decline in the reported number of waterborne outbreaks during 1981-1985 is due to the occurrence of fewer outbreaks or less active surveillance and reporting.

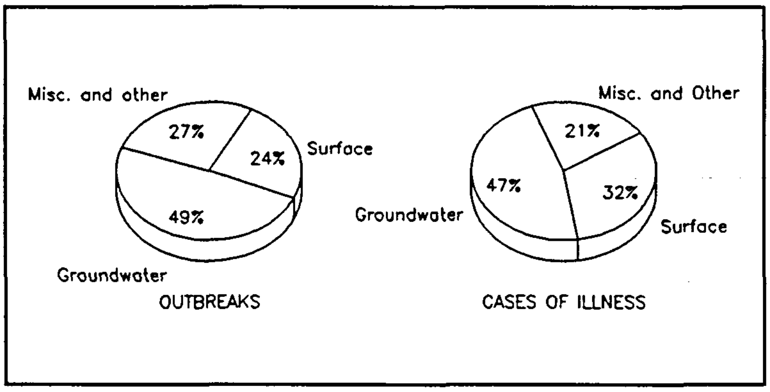

Fig. 2: Waterborne disease outbreaks in the U.S. (1971 - 1985, Craun, 1990)

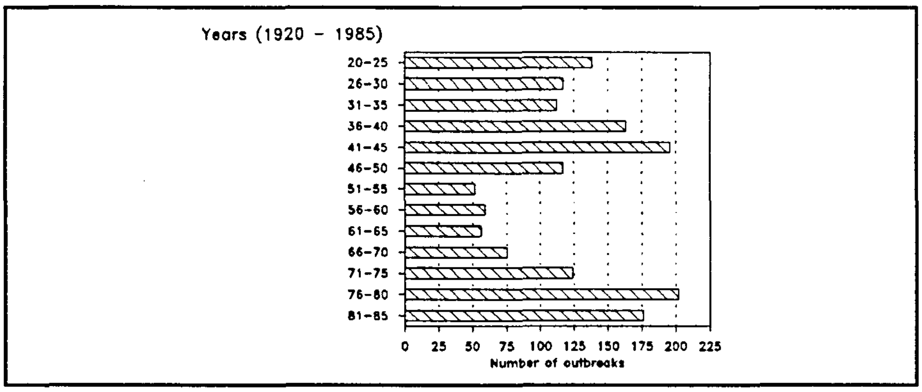

Fig. 3: Number of waterborne disease outbreaks, 1920 - 1985 (Craun, 1990)

The exact relationship between groundwater pollution by waste disposal sites and outbreaks of waterborne diseases is however unknown.

Groundwater moves very slowly and, as already mentioned, geohydrological conditions vary from site to site. The velocity is often not more than 10 m/year and pollution can therefore take place over a long period of time before being detected. Pollution of an aquifer in Germany was detected 1,5 km downstream of a landfill site 25 years after startup and 9 years after closure and it took another 18 years for the contaminant levels to drop to background levels (Rimmer and Theron, 1990). Another example, and probably the best known, is the Love Canal saga. The landfill site started as a section of canal that was never completed and eventually received approximately 22 000 tons of chemical waste between 1942 and 1953

(Schwartz, 1988).

The earliest problems were recorded in 1976 and included the following:

- landfill surface decline expose disposal drums,
- contaminated surface water ponding in neighbouring backyards,
- unpleasant odours,
- migration of chemicals to adjacent basements,
- chemical migration into and through the sewer network.

"Subsequent health studies that indicated a predisposition towards spontaneous abortion and low birth-weight in infants prompted an emergency to be declared at the site. This measure resulted in the evacuation of 236 families from the site" (Schwartz, 1988).

A second state of emergency was declared in 1980 when additional testing of residents revealed chromosomal abnormalities.

4.2 Contamination Sources

The most important source of groundwater contamination in the United States is believed to be the disposal of industrial wastes in impoundments and landfills. There are approximately 76 000 active industrial landfills in the United States; some 50 000 active and inactive sites are estimated to contain potentially hazardous chemical wastes.
Groundwater contaminants such as benzene, polychlorinated biphenyl, chlorinated phenols, organic solvents, heavy metals, selenium, and arsenic have originated from industrial landfills and in many instances have migrated some distance from the original contamination site. Industrial-waste landfills are therefore considered to be the most common source of serious groundwater pollution. The U.S.EPA defines hazardous wastes as those that are toxic, corrosive, ignitable or chemically reactive. The potential for contamination from landfill sites is greatest in areas with shallow groundwater tables and high rainfall.

Table 9 (see page 23) shows the chemicals found in landfill sites; Table 10 (see page 23) shows the change in the chemical characteristics of leachate with time in a landfill simulation; and Table 11 (see page 24) the micro-organisms identified. As seen in Table 9 the milieu of domestic and industrial chemicals received for disposal makes the tasks of sorting, identifying and controlling pollutants enormous. This needs to be done since landfill from ancient times still produce leachates and the waste disposed of today may not present itself for many years.

The data in Table 10 indicated that the age of a landfill site not only significantly effects the type, but also the concentration of the chemical constituents. As seen in the Table the maximum concentrations of most of the parameters occurred after approximately 90 days of operation. It remained reasonably constant until about 500 to 550 days at which point there was a decrease in the concentration of most of the parameters (Engelbrecht and Amirhor, 1975).

Table 9: Some chemicals found in landfill sites

Classified		Miscellaneous
Acetic acid	Heptane	Acids
Acetone	Heptachlor	Alkaline waste
Aldrin	Hexachlorobenzene	Aromatic hydrocarbons
Alkyl benzene sulfonate	Hexachlorobutadiene	Chlorinated organics
Alkyl ether	Hexachlorocyclopentadiene	Coal tars
Asbestos	Hexane	Explosives
Benzene hexachloride	Hydrogen sulfide	Fly ash
Chloroanilic acid	Kepone	Herbicides
Chloroform	Lindane	Nitrates
Chromic acid	Lithium	Pesticides
Cumene	Methacrylic acid	Petrochemicals
Cyanide	Methane gas	Polynuclear organics
Cyclohexamine	Methyl ethyl ketone	Solvents
Dibromochloropropane	Methylene chloride	Toxic metals
DDT	Mirex	Uranium radiation
DEF	*o*-Nitoaniline	Volitile organics
Dichlorobenzene	Parathion	Waste oil
Dieldrin	Polybrominated biphenyls	
Dichloroethane	Polychlorinated biphenyls	
Dichloroethylene	pentachlorophenol	
Dimethyl sulfide	Phenol	
Dioxane	Sodium	
Dioxin	Stryrene	
Endosulfan	Tetrachlorobenzene	
Endrin	Tetrachloroethylene	
Ethanol	Trichloroethane	
Ethylbenzene	Trichloroethylene	
Ethyl asetate	Trimethylsilanol	
Ethylene dibromide	Tromethamine (Tris)	
Ethylene glycol	Vynyl chloride	
Freon	Zinc chloride	

U.S.EPA, 1980

Table 10: Change in the chemical characteristics of leachate with time in a landfill simulation

	Days of Operation							
	36	48	69	83	110	215	277	550
pH (pH units)	5.40	5.63	5.46	5.30	5.42	5.50	5.35	5.40
EC (mS/m)	-	1370	1590	1690	1740	1910	2000	-
ORP (mV)	-	-60	-68	-30	-100	+14	-50	-
TOC (mg/ℓ)	2890	17900	16700	18600	22050	19400	19400	9500
COD (mg/ℓ)	-	49300	57600	62800	68300	61000	57900	28400
COD/TOC	-	2.88	3.36	3.43	3.10	3.05	2.99	2.99
TS (mg/ℓ)	5100	33989	38095	42247	42515	41430	43680	18600
Fixed solids (mg/ℓ)	2460	15586	18044	21189	20141	19850	20030	9920
% Volatile S.	51.8	54.2	52.6	49.8	52.6	52.1	51.8	46.7
Ca (mg/ℓ)	420	3500	3600	3900	4350	3750	3650	850
Mg (mg/ℓ)	63	620	640	655	620	600	525	170
Fatty acids (mg/ℓ)		16190	19100	19400	24700	22900	21400	11700
FA(C)/TOC		0.475	0.56	0.53	0.56	0.50	0.50	-

Engelbrecht & Amirhor, 1975

Table 11 shows that landfill leachate may contain primary pathogens as well as opportunistic pathogens. Many factors control and influence the persistence of micro-organisms in landfill leachate such as the chemistry of the solid waste, heat generated by waste decomposition, moisture content and the antagonistic action of numerous organisms in the microflora (Geldreich, 1990).

Table 11: Micro-organisms identified in commercial landfill leachates

Organism	Coliform	Coliform antagonist	Pigmented organism	Opportunistic pathogen	Primary pathogen
Bacteria				X	
Acinobacter sp.				X	
Alcaligenes sp.		X		X	
Bacillus sp.		X		X	
Clostridium perfringens				X	
Corynebacterium sp.				X	
Enterobacter agglomerous	X			X	
Enterobacter cloacae	X			X	
Listeria monocytogenes				X	
Micrococcus sp.			X	X	
Moraxella sp.		X		X	
Mycobacterium				X	
Proteus sp.		X		X	
Providencia alcalifaciens				X	
Pseudomonas fluorecens		X	X	X	
Pseudomonas sp.		X	±	X	
Salmonella sp.					X
Staphylococcus sp.			±	X	X
Streptococcus faecalis				X	
Streptococcus durans				X	
Fungi					
Aspergillus niger					X
Cephalosporium sp.					X
Fusarium sp.					X
Neuropora					
Penicillium sp.				X	
Pseudallescheria boydii				X	

Donnelly & Scarpino, 1984

Secondary sources of chemical contamination of groundwater in the United States are septic tanks, mining, and petroleum exploration. Approximately 20 million homes in the United States use septic tank- and cesspool disposal systems, discharging more than one trillion gallons (3.78×10^{10} m^3) of waste into the ground each year. Homeowners can buy septic tank cleaning fluids that contain trichloroethylene, benzene, or methylene chloride, which may cause significant chemical contamination. On Long Island alone some 400 000 gallons (1512 m^3) of septic tank cleaners are used by homeowners.

Mining causes groundwater contamination primarily through waste disposal practices such as slurry and tailings ponds, slag piles, and the failure to reclaim mined land. Petroleum production activities have caused groundwater contamination in 17 south-central and western states in the USA and contamination from brine pits to dispose of saline byproducts of drilling has caused groundwater to become unusable in many areas.

Agricultural practices, use of chemicals, leaks and spills, disposal of chemicals in surface impoundments, underground injection wells, and disposal of wastewater on land and through septic tanks, all contribute to the contamination of groundwater. Pesticides such as *DBCP*, *Aldicarb*, and *Carbonfuran* and nitrates have been found in farm wells. In many instances, the contamination was related to current agricultural practices (Craun, 1984).

In addition to industrial waste disposal practices, inorganic contamination of groundwater can be the result of mining, manufacturing and natural processes such as chemical weathering, soil leaching, and decaying vegetation. Depending on factors such as solubility, pH, adsorption characteristics and formation of complexes, the penetration and movement of rainwater through the soil results in the release of various trace and bulk inorganic constituents into the groundwater.

The greatest impact of water pollution on human health comes through drinking water and over two billion people (Drinking Water Microbiology, 1990) have suffered from deseases due to drinking polluted water. Waterborne illness can be contracted in a number of ways:

(i) ingestion of contaminated water or ice,
(ii) direct contact (bathing, swimming or wading),
(iii) inhalation of aerosols, gases or vapours from contaminated water or wastewater.

As shown above (see Fig. 1 & 2, page 20 & 21) contaminated groundwater, was responsible for over 50% of the waterborne outbreaks during the period 1940 - 1985 (Keswick, 1984).

4.3 Inorganic contaminants

The concentrations of inorganic constituents found in groundwater varies in areas and over time. The following Table 12 (see page 26) is a partial list of constituents, based on their historical significance and widespread occurrence in groundwater. The significance of the parameters listed are briefly discussed.

Nitrate: drinking water containing more than 22 mg/ℓ NO_3-N causes infantile methemoglobinaemia, but cases have occurred at concentrations below 10 mg/ℓ NO_3-N. There is also a small adult population that may develop methemoglobinemia and many cases have been associated with individual, bacterially contaminated wells, which may be the source of nitrate-reducing bacteria (Varley's Practical Clinical Biochemistry, 1969).

Sodium concentrations in the 2100 water systems that supply about 50% of the U.S. population range from 0,4 - 1900 mg/ℓ (NRC, 1977). The suggested safe intake ranges from 1100 - 3300 mg/day for normal adults and 115 - 750 mg/day for infants. Sodium intake with food is generally the major contributor to sodium concentrations, but drinking water with high sodium concentrations can contribute a significant portion of the total intake. High and excessive intake of sodium may be associated with adult hypertension and sodium restricted diets are required in the treatment of congestive cardiac failure, renal disease, cirrhosis of the liver, toxemia of pregnancy and Meniere's disease (NRC, 1979 & 1980).

Table 12: Inorganic contaminants and their effect on human health

Parameter	Crisis limit	Impact
Nitrate mg/ℓ N	20	Infant methaemoglobinaemia
Sodium mg/ℓ Na	800	Chronic, long-term toxicity
Magnesium mg/ℓ Mg	200	May cause diarrhoea in new users
Sulphate mg/ℓ SO_4	1200	Taste, odours, cathartic effect - Na- & Mg- SO_4
Fluoride mg/ℓ F	3.0	Dental & skeletal fluorosis
Arsenic mg/ℓ As	0.6	Toxic in excess e.g. bronchial diseases
Selenium mg/ℓ Se	0.1	Toxic in excess
Aluminium mg/ℓ Al	1.0	Soluble aluminium salts exhibit neurotoxicity
Iron mg/ℓ Fe	2.0	High concentrtions potentially toxic to children

Kempster and Smith, 1985

Magnesium is a common constituent of natural water and gives water an unpleasant taste when the concentration exceeds 100 mg/ℓ. It can have a cathartic and diuretic effect when the concentration is greater than 125 mg/ℓ. It is an important contibutor to water hardness and the magnesium salts break down when heated to form scaling in boilers.

Sulphate may be present in natural waters in concentrations ranging from a few to several thousand milligrams per litre. Sulphate at concentrations above 600 mg/ℓ has a laxative effect on the majority of users.

Fluoride is widely found in water supplies and high concentrations have been reported in areas of every continent. Two chronic effects that are caused by high concentrations of fluoride are being recognised namely (i) mottling of tooth enamel or dental fluorosis and (ii) skeletal fluorosis. Dental fluorosis may occur with fluoride concentrations of 0,8 - 1,6 mg/ℓ and skeletal fluorosis has been seen with the consumption of water containing more than 3 mg/ℓ fluoride. The National Research Centre, Washington, (NRC, 1980) recommendations for safe intakes to protect against dental caries and osteoporosis are represented in Table 13.

Table 13: Recommended Fluoride intake

Age	Fluoride (mg)	Age	Fluoride (mg)
<6 months	0,1 - 0,5	4 - 6 years	1,0 - 2,5
6 - 12 months	0,2 - 1,0	7 - adulthood	1,5 - 2,5
1 - 3 years	0,5 - 1,0	adult	1,5 - 3,0

National Research Centre, Washington (1980)

However, in South Africa, it is recommended that no fluoride supplementation should be prescribed when the drinking water fluoride level is higher than 0,7 mg/ℓ with a maximum daily intake of 1,6 mg (Grobler, 1992).

There are reported concentrations of up to 35 mg/ℓ fluoride in groundwater and most of the communities in Arizona , Colorado, Illinois, Iowa, New Mexico, Ohio, Oklahoma, South Dakota and Texas use groundwater with a natural fluoride concentration of more than 0,7 mg/ℓ (Craun, 1984).

Arsenic is a geochemical contaminant and natural sources amount for much of the arsenic found in surface and groundwaters. It affects tissues that are rich in oxidative systems, primary the alimentary tract, kidneys, liver, lungs and epidermis. People of Antofagasta, Chile, where the drinking water contained 0,8 mg/ℓ arsenic, showed an increase of bronchial and pulmonary disease, cardiovascular pathology, hyperpigmen-tation of the skin and cutaneous lesions like leukoderma, melanoderma and hyperkeratosis. After water treatment that reduced the arsenic levels to 0,08 mg/ℓ, the incidence of cutaneous lesions decreased from 313 to 19 per 100 000 people per year (Craun, 1984).

Selenium is found in water primarily as a result of leaching from rocks and soils that are high in selenium. In seleniferous areas of Wyoming, wells contain enough selenium to be poisonous to man and livestock (NRC, 1979).

Aluminium is the third most abundant element of the earth crust, occurring in minerals, rocks and clays. This accounts for the presence in nearly all natural water as a soluble salt, a colloid or an insoluble compound. Soluble salts may result in neurotoxicity.

Iron in high concentrations is potentially toxic for infants but, its aesthetic undesirability become obvious well below the potentially toxic levels. At concentrations above 300 μg/ℓ it gives rise to discolouration and staining plus taste problems occur.

4.4 Organic contaminants

Contamination of community and individual drinking water wells in the USA (Craun, 1984) with anthropogenic organic products, industrial and agricultural pollutants which are often present in concentrations much higher than found in any surface water sources. Table 14 (see page 28) shows some of these organic compounds with the highest concentration reported. There are no established drinking water standards for most of these products and consumers cannot rely on unusual tastes and odours to identify contaminated boreholes.

It is not known which of the organic contaminants are the most prevalent and these need identification. The data found in the literature is merely compiled from groundwater surveys and monitoring of contaminated boreholes. Analysis was also only done for specific chemicals and the data therefore may not be repesentative of the actual problem.

Some of the selected organic compounds have been tested for carcinogenicity while others detected in groundwater have not been tested. Some of the most important are listed in Table 15 (see page 29). There are nine organic compounds that, according to the available literature, seem to be important groundwater contaminants. Their importance is briefly discussed below.

Table 14: Some organic compounds detected in drinking water wells

Compound	Detected µg/ℓ	Compound	Detected µg/ℓ
Trichloroethylene	27 300	1,1-Dichloroethylene	280
Toluene	6 400	1,2-Dichloroethane	250
1,1,1-Trichloroethane	5 440	Bis (2-ethylhexyl) phthalate	170
Acetone	3 000	Dibromochloropropane	137
Methylene chloride	3 000	Trifluorotrichloroethane	135
Dioxane	2 100	Dibromochloromethane	55
Ethyl benzene	2 000	Vinyl chloride	50
Tetrachloroethylene	1 500	Chloromethane	44
Cyclohexane	540	Butyl-benzyl-phthalate	38
Chloroform	490	Lindane	22
Di-*n*-butyl-phthalate	470	1,1,2-Trichloroethane	20
Carbon tetrachloride	400	Bromoform	20
Benzene	330	1,1-Dichloroethane	7
1,2-Dichloroethylene	323	α-BHC	6
Ethylene dibromide	300	Parathion	4.6
Xylene	300	δ-BHC	3.8
Isopropyl benzene	290		

Craun, 1984

Trichloroethylene (TCE) has been reported in groundwater from 14 States. TCE can be formed during chlorination of groundwater, it is an industrial solvent and is used for degreasing metals, in dry-cleaning operations, organic systhesis, refrigerants and fumigants. Most septic tank cleaning fluids also contain TCE (Council on Environmental Quality, 1980).

Carbon Tetrachloride has been found in chlorinated and untreated groundwater in many States. It is present due to impurities in chlorine used as a disinfectant, it is also used in the manufacturing of chlorofluoromethanes, grain fumigants, cleaning agents, fire extinguishers and solvents. Chronic exposure results in nausea, vomiting, headache, drowsiness and excessive fatigue. Acute effects include renal dysfunction, hepatic nodular hyperplasia and cirrhosis (EPA, 1980; Council on Environmental Quality, 1980; National Research Council, 1977).

Tetrachloroethylene was found in eight community groundwater supplies in the EPA surveys. It is a solvent used in dry-cleaning and degreasing operations. It was formerly used as an intestinal antihelminthic compound. It is a potent depressant of the central nervous system and accumulates in the body (EPA, 1980).

Methyl chloroform was found in five community groundwater supplies in the EPA surveys. It is used as an industrial cleaner, degreaser, spot remover, adhesive and vapour pressure depressant. Although the pharmacokinetics of inhaled methyl chloroform have been extensively studied, little information is available on ingested methyl chloroform (National Research Council, 1977; EPA, 1980).

Table 15: Some carcinogenic organic compounds

Compound	Effect
Benzene	IDLH = 2000 ppm (Carcinogenic)
Vinyl chloride	Potential human carcinogen
Carbon tetrachloride	IDLH = 300 ppm
Chloroform	IDLH = 3000 ppm (Carcinogenic)
Dibromochloropropane	Potential human carcinogen
1,2-Dichloroethane	Potential human carcinogen
Dioxane	Potential human carcinogen
Ethylene dibromide	Potential human carcinogen
Lindane	IDLH = 1000 mg/m^3
Tetrachloroethylene	IDLH = 500 ppm (Carcinogenic)
1,1,2-Trichloroethane	Potential human carcinogen
Trichloroethylene	IDLH = 500 ppm (Carcinogenic)
Bis (2-ethylhexyl) phthalate	Potential human carcinogen
Butyl-benzyl-phthalate	No data
Chloromethane	IDLH = 10000 ppm (Carcinogenic)
Cyclohexane	IDLH = 10000 ppm
Dibromochloromethane	No data
Dichloroethylenes	IDLH = 4000 ppm
Di-*n*-butyl-phthalate	IDLH = 9300 mg/m^3
Methylene chloride	IDLH = 5000 ppm (Carcinogenic)
Toluene	IDLH = 2000 ppm
Trifluorotrichloroethane	IDLH = 4500 ppm
Xylene	IDLH = 1000 $\mu g/\ell$ (isomeric mixture)

IDLH = Immediate Danger to Life and Health — Montgomery & Welkom, 1989

1,1-Dichloroethane is used as a solvent and cleaning agent. Although very little information is available on the toxicity of 1,1-Dichloroethane (potential human carcinogen), the EPA (1980) reported that it is present in groundwater of seven States.

Dichloroethylenes are a group of three isomers. 1,1-Dichloroethylene is widely used in industry in the production of methyl chloroform, coating resins, synthytic fibers and adhesives. It has adverse effects on the kidney and liver and is a potential human carcinogen (Montgomery & Welkom, 1989; EPA, 1980).

Methylene chloride is used in the manufacturing of paint and varnish removers, insecticides, solvents, pressurised spray products and Christmas tree bubble lights. Exposure to high levels produces an elevation of , and impairment of the central nervous system and is a human carcinogen. It was found in three percent of the wells surveyed by the USEPA (EPA, 1980; Council on Environmental Quality, 1980).

Vinyl chloride is used in the manufacturing of polyvinyl chloride and copolymers, adhesives for plastics, refrigerant, extraction solvent and organic synthesis. It has been detected in treated and untreated groundwaters. Is a potential human carcinogen and acute exposure has been shown to produce central nervous system dysfunction, sympathetic-sensory polyneuritis and organic disorders of the brain. Lesions of the skin, bones, liver, spleen and lungs have been reported after chronic exposure (Montgomery & Welkom, 1989; EPA, 1980; Council on Environmental Quality, 1980; National Research Council, 1977).

4.5 Biological contaminants

Less is known about the microbiology of groundwater than about any other part of the biosphere. Groundwater has long been considered to be of excellent quality because of the soil barrier providing effective isolation of this high quality source water from surface pollutants. However, both inorganic and organic chemicals that enter the subsurface environment can be transformed by microbiological processes. Besides transforming chemical compounds directly, the growth of bacteria can cause clogging and change the permeability of the aquifer material and can also affect the chemical environment resulting in a pH change and affecting the oxidation-reduction potential of the system (McCarty, *et al.*, 1984). This can lead to precipitation or dissolution of phosphates and heavy metals, oxidation or reduction of iron and sulphur salts. Micro-organisms could therefore be directly or indirectly responsible for groundwater pollution. The following Tables 16, 17, 18, 19 and 20 show the microbial densities in different sources with a potential to pollute groundwater.

Table 16 shows the average count of certain indicators, some pathogenic bacteria, intestinal parasites and viruses in the raw sewage of two towns in South Africa. It is also important to note that under certain conditions the quality of storm water also match that of raw sewage (Wright, 1991).

Table 16: Microbial densities in municipal raw sewage

Parameter	Average count per 100 mℓ	
	Town A sewage	Town B sewage
Aerobic plate count (37 °C / 48 hr)	1 110 000 000	1 370 000 000
Total coliforms	10 000 000	
Escherichia coli	930 000	1 470 000
Faecal streptococci	2 080 000	
Clostridium perfringens	89 000	
Staphylococcus aureus	41 000	28 100
Pseudomonas aeruginosa	800 000	400 000
Salmonellae	31	32
Acid-fast bacteria	410	530
Ascaris ova	16	12
Taenia ova	2	9
Trichuris ova	2	1
Enteroviruses and reoviruses ($TCID_{50}$)	2 890	9 500

Grabow & Nupen, 1972

Table 17 (see page 31) illustrates the microbial characteristics of solid waste from various cities. With the presence of such high counts of indicator bacteria it is apparent that the count for pathogens will also be high.

Table 17: Microbial characterisation of solid wastes from various cities

	Organisms per g wet wt (41% moisture)				
Collection site	Number of samples	Total viable bacteria	Bacterial Spores	Total coliforms	Feacal coliforms
A	4	110 000 000	270 000	3 000 000	260 000
B	3	450 000 000	110 000	6 700 000	510 000
C	6	78 000 000	38 000	1 600 000	1 200 000
D	3	480 000 000	31 000	1 100 000	630 000
E	4	680 000 000	1 900 000	51 000 000	8 100 000
F	2	54 000 000	35 000	13 000 000	5 600 000
G	2	4 000 000	25 000	340 000	15 000
H	3	300 000 000	160 000	8 600 000	3 000 000

Peterson, 1971

Table 18 examines the survival of faecal coliform and streptococci in leachate from sanitary landfills. After 70 days the counts are still as high as 3,3 x 10^4 and 1,7 x 10^5 per 100 mℓ respectively.

Table 18: Faecal coliform and faecal streptococci survival in leachate from sanitary landfills

	Densities per 100 mℓ	
Days after placement	**Faecal coliforms**	**Faecal streptococci**
42	2 600 000	240 000 000
43	4 900 000	790 000
56	2 000	79 000
63	9 000	33 000
70	33 000	170 000

Blannon & Peterson, 1974

Table 19 gives the enteric bacterial profiles in certain raw industrial waste. It is obvious that certain types of waste, like food processing wastes, will support the growth and multiplication of bacteria more than others.

Table 19: Enteric bacterial profiles in raw industrial wastes

Micro-organisms	**Wood pulp and paper**	**Beverage**	**Food processing**	**Meat processing**
Percent of various coliform species				
Escherichia coli	0.4	5.6	35.0	56.9
Klebsiella pneumoniae	92.3	68.0	55.0	21.5
Enterobacter spp.	6.7	15.0	3.3	13.8
Pectobacterium	0.6	7.0	6.0	0.5
Salmonellae	0.008	4.4	0.7	7.3
Viable counts/100 mℓ				
Klebsiella	10^5 - 10^6	10^4 - 10^7	10^3 - 10^5	10^5 - 10^8
Faecal coliforms	10^1 - 10^4	10^3 - 10^5	10^2 - 10^4	10^6 - 10^9

Herman, 1972

Table 20 examines the enteric bacterial profiles in treated industrial waste effluents. It must be noted that the bacteria can survive the different treatments used for the different processes.

Table 20: Enteric bacterial profiles in treated industrial waste effluents

Waste Effluent	*Klebsiella*	*Escherichia coli*	*Enterobacter*	*Pecto bacterium*	*Salmonellae*
	%				
Wood pulp & paper	85.0	4.4	9.5	0.8	0.3
Potato	81.1	0.9	9.4	0.9	1.6
Beverage production	68.9	5.6	15.0	7.0	4.4
Food processing	55.0	24.0	3.3	6.0	0.7
Meat processing	21.5	56.9	13.8	0.5	7.3
Municipal sewage	18.0	62.0	14.3	3.6	2.1

Drinking Water Microbiology, 1990

It is obvious, as seen in all the above tables, that large numbers of bacteria are "dumped" into the environment daily and that they also survive for some time outside their hosts. What is however not shown, is the bacterial spores, parasites, their cysts and ova which may contribute even more to the groundwater pollution potential. The presence of nutrients together with moisture (water), heat and other necessary factors for sustaining bacterial growth in waste disposal sites may produce even larger bacterial populations.

4.5.1 Infectious diseases

Some of the most relevant infectious diseases that may be transmitted by drinking contaminated water are listed in Table 21 and their relevence is discussed.

Table 21: Infectious diseases transmitted by contaminated drinking water

Disease	Micro-organism
Amoebiasis	*Entamoeba histolytica*
Giardiasis	*Giardia lamblia*
Balantidiasis	*Balantidium coli*
Cryptosporidiosis	*Cryptosporidium*
Cholera	*Vibro cholera,*
Hepatitis	Hepatis A virus
Paratyphoid Fever	*Salmonella parathypi*
Typhoid Fever	*Salmonella typhi*
Salmonellosis	*Salmonellae*
Shigellosis	*Shigellae*
Gastroenteritis	Various micro-organismes e.g. *Escherichia coli, Campylobacter, Yersinia enterocolitica,* norwalk-, rota-, adeno- viruses

Craun, 1984; Burger, 1992

Giardiasis is caused by *Giardia lamblia*, a parasitic protozoan, which occurs world wide and lives in the duodenum and upper jejunum. Outside the host it exists in a cyst form that is resistant to the usual disinfection provided for the treatment of drinking water. It produces a chronic diarrhoea accompanied by weight loss, epigastric pain and flatulence. It is also an opportunistic pathogen and can cause severe diarrhoea under certain conditions (Burger, 1992). Giardiasis has been frequently caused by waterborne- disease outbreaks in the United States and in travellers in the Soviet Union (Craun, 1979). No reference was found that Giardiasis has been caused by contaminated groundwater.

Amoebiasis and **Balantidiasis** are two additional protozoa that are sometimes transmitted by contaminated drinking water. Their etiologic agents are *Entamoeba histolytica* and *Balantidium coli* respectively. They also exist in cyst forms outside their hosts and are resistant to usual disinfection. Amoebiasis is the term used to denote all conditions in man and animals resulting from the infection and invasion of the tissues by *Entamoeba histolytica*. Dysentery and liver abscess represent only two of its more dramatic manifestations. *Balantidium coli* is the largest intestinal protozoan of man and man appears to be an incidental and highly resistant host. When established in man it becomes a tissue invader, producing destruction of the tissue (Belding's Text Book of Parasitology, 1965). An outbreak of Balantidiasis occurred in Micronesia in 1971 when a typhoon destroyed water catchment facilities and people were forced to use water contaminated by pig faeces (Craun, 1984). No reference was found that Amoebiasis and/or Balantidiasis has been caused by contaminated groundwater.

Cryptosporidium was decribed in 1907, but has been recognised as a cause of disease in humans only since 1980. The first waterborne outbreak was decribed in the United States during 1985 with a major outbreak in Georgia in January 1987. It causes profuse watery diarrhoea (fluid losses may average three litres a day), abdominal pain, nausea, vomiting and fever (Rose, 1990). No reference was found that Cryptosporidiosis has been caused by contaminated groundwater.

Cholera is a classic waterborne disease and *Vibrio cholerae* contaminated, untreated water, especially from shallow wells is the main source of cholera in underdevelop countries where the disease is endemic. In the 1974 cholera epidemic in Portugal, outbreaks of cholera were traced to bottled water, using water from two untreated springs (Craun, 1984).

Typhoid Fever, Salmonellosis & Shigellosis, is transmitted by *Salmonellae* (including *Salmonellae typhi* and *paratyphi B*) and *Shigellae* species. These are enteric diseases commonly transmitted by drinking water. These bacteria causes Typhoid fever, Dysentery and other serotypes cause diarrhoea, abdominal cramps, fever, chills and vomiting. In 1972 a waterborne outbreak caused by *Salmonellae paratyphi B* occurred in Britain in a group of villages at the same time as an outbreak of the same type in cattle and humans at a farm several miles away. The water supply to the villages was obtained from several springs subject to pollution from the septic tank of a cottage occupied by workers at the infected farm (George, *et al.*, 1972).

Hepatitis is a systemic disease primary affecting the liver. It can be caused by hepatitis A virus (HAV), hepatis B, C, D and E viruses. Only HAV and only recently hepatitis E has been assosiated with polluted water and HAV is very persistent in the environment. There have been 68 waterborne cases of viral hepatitis between 1946 and 1984 and contaminated groundwater was responsible for most oubreaks (Craun, 1984; Idema, 1992).

4.5.2 Infectious diseases and groundwater

As stated above, Cholera, Typhoid fever, Salmonellosis & Shigellosis, Gastroenteritis (by various micro-organisms) and Hepatitis outbreaks have been linked to contaminated groundwater. No references were found that Giardiasis, Amoebiasis, Balantidiasis and Cryptosporidiosis has been caused by contaminated groundwater.

However, the contamination of groundwater by the disease causing agents of the above mentioned diseases cannot be excluded. Their cyst forms can exist outside their hosts and the contamination of groundwater by waste water, surface water runoff, etc., infected with these cyst, may occur. As mentioned above, these diseases are transmitted by contaminated surface water. It is therefore important that the water treatment methods of both groundwater and surface water must include prevention actions against all of the above mentioned diseases.

CHAPTER 5 LEGISLATION

5.1 Introduction

Industrial waste contains more toxic and hazardous materials in comparison with municipal waste and much attention has been focused on the safe disposal of toxic and hazardous industrial waste. Nevertheless, municipal waste may be contaminated with toxic compounds like pesticides, plastics and platicizers, pharmaceuticals, solvents, oils, and many refined or synthetic products from household sources (Murray and Beck, 1990). Illegal dumping of industrial materials in municipal landfills further increases the toxicity of the waste. These materials and their degradation products include toxic ammoniated, sulphonated and phenolic compounds and may slowly leach from the municipal landfill. It must therefore be realised that there is the need to develop a management-response cycle which would be able to predict, monitor and evaluate the control strategies applied to such waste sites to minimise contamination of groundwater.

The implementation of legislation should have a number of positive impacts on solving the groundwater pollution problem as well as certain problems with waste disposal in general. The reduction of the number of waste sites would probably be one of the most important impacts. Stone (1991) reported that 14 000 or 70 per cent of active waste sites were closed in the U.S.A. between 1978 and 1988. Today only 6 000 sites still exist of which 3 000 are to be closed by 1995. Of importance however, is the fact that these sites still require attention as the slow movement of the contaminated leachate will continue to pollute the groundwater.

5.2 International measures

Various countries place great reliance on the natural treatment and attenuation capacity of permeable strata beneath landfill sites, both in the unsaturated and saturated zones. On the other hand, in West Germany and the U.S.A. groundwater at all new landfill sites is isolated by use of natural and artificial liner materials (Robinson and Maris, 1985).

The discovery of numerous illegal or unlicensed dumping sites and the increase of public awareness of the possible danger of hazardous waste has motivated various governments into action (Paling, 1991). They have reacted by initiating new legislation in an attempt to obstruct further illegal dumping and to terminate the loopholes created by differences between national and regional regulations. They have further initiated the clean up of existing sites.

In the United States, the responsibility for the clean-up operations has been delegated to the Environmental Protection Agency (EPA). The operations are financially supported by the so-called Superfund, which, after an initial Congress grant, is partly kept afloat by those companies responsible for the hazardous waste output. The policy of *"the polluter pays"* is followed by most countries. It has the additional advantage of encouraging companies to look at alternatives such as recycling. Since illegal dumping sites often contain a wide variety of hazardous waste, recycling is impossible. Detoxification of waste is achieved commonly by biological decomposition, chemical or physical alteration or by incineration. Due to the size of the problem and the cost of the treatment, some of the less toxic wastes are disposed of by deep well injection and storage in landfills with liners (Paling, 1991).

A new survey, "*Environment U.S.A. '91*" (Gass, 1992), shows that Americans believe that environmental protection is more important than economic growth and are willing to sacrifice jobs in their community, pay more for environmentally friendly products and see violaters jailed for noncompliance. Fifty four per cent want government to take serious action against polluters, even if it means closing down some factories and losing jobs. Fifty five per cent even said they would pay 50 per cent more for garbage collection to ensure safe long-term disposal.

Export to countries like the former East Germany and Nigeria, with slack environmental control legislation and huge foreign debts, have formerly rendered a cheap option for the disposal of toxic waste. The inadequate storage of waste in these countries and the resulting risk to the local population has caused the United Nations to intervene. At a UN sponsored conference in Basle, an agreement was proposed to restrain the international shipment of toxic waste, in particular to third world countries (Paling, 1991).

5.3 SA waste disposal situation

In South African cities, local industry is as intense and versatile as in any Western country. The scale of the industrial and domestic waste problem may therefore be expected to be just as serious. Legislation affecting the control and prevention of water pollution in South Africa is found in the Water Act of 1956; the Health Act of 1977, the Environment Conservation Act of 1989 and the Environmental Conservation Amendment Act of 1992. The Department of Water Affairs and Forestry has been given the responsibility of executing of these Acts.

Much research effort is being carried out in South Africa relating to groundwater contamination and aquifer protection (DWAF, 1991; Ball et al., 1992; Braune et al., 1992; Hodgson, 1992; Murphy, 1992; Parsons and Jolly, 1992; Tredoux, 1992; Weaver, 1992a; 1992b and others). These studies relate to policy development, suitable investigative techniques and methods and the setting of minimum requirements. Such efforts can only lead to improved standards in the waste disposal field. Unfortunately, time will be required to achieve this.

The DWAF has been assisting in the development and implementation of legislation in an attempt to prevent the loss of valuable water resources. The promulgation of the Environment Conservation Act No. 73 of 1989 and the Environment Conservation Ammendment Act No. 79 of 1992 are just two examples of this. The permitting of waste sites has however been slower than anticipated. Kok (1992) stated that only 7 % of the country's waste sites had been investigated or reported. Only about 15 % of South Africa;s identified waste disposal sites have been issued with permits or are in the process of obtaining permits (Parsons, 1992). At present processing rates, Parsons (1992) estimates that this will take approximately 50 years to achieve. However the process is moving in the right direction and the problem of issuing of permits is being addressed.

Even though South Africa does not have the standards with regard to waste disposal requirements and practices as other more developed countries, the lessons learned during this research work remain applicable. It must be remembered that the standards employed in the USA, for example, have received attention since the mid-1970's while our efforts are still really in the infancy stage. The fact that they have detected so much groundwater contamination is related to the specific monitoring performed. The few documented cases of groundwater contamination in South Africa should not be seen as an indicator that similar problems do not exist in this country. Rather the view should be that we have just not found them as yet.

5.4 National Groundwater Monitoring Strategy

No national groundwater monitoring network is in place in South Africa. Little information thus exists at this national scale. A strategy to install such a network is presently being developed (Parsons, 1993). The installation of a national network will provide an overview of groundwater quality in the country and will serve as a baseline to evaluate future groundwater quality changes related to diffuse pollution. It is also expected that with increased effective monitoring of waste disposal sites, a more accurate picture of contaminated groundwater will emerge.

CHAPTER 6 CONCLUSIONS

6.1 Preamble

In order to minimise and prevent pollution it is important to have a list of the most important industrial activities in an area, an inventory of the potential sources of pollution, and their relative contribution to pollution of groundwater. It is therefore essential to determine, by active monitoring of the quantity and quality of leachates, whether municipal sanitary landfills and other sources of domestic and/or industrial waste disposal have a major adverse impact on surface and groundwater quality in South Africa. This information can then be used to evaluate the adequacy of S.A.'s past policies for siting municipal sanitary landfills and to determine if more extensively engineered methods of controlling leachate migration are warranted.

6.2 Conclusions

The aims of this study which appear on page 2 (under 1.2 Study Objectives) of the report have by and large been attained. The study achieved its main objective, namely the literature survey outlining the health aspects of the impact of domestic and industrial waste disposal on groundwater resources.

However, no review was done on the current domestic and industrial waste disposal practices in South Africa in view of the detailed studies carried out recently on hazardous and other wastes. It was agreed in discussions with the WRC not to spend time on this objective, but rather to concentrate on objective no. 1.

The main conclusions of this study are:

- Groundwater pollution from waste disposal activities is a fact of life. Overseas it has already created serious environmental problems and the cleanup of contaminated groundwaters may ultimately cost billions of rands to rectify, if ever. In South Africa indications are that the problem also exists but published data are scarce. The solution to groundwater pollution is best described by the aphorism *"Prevention is better than cure"*.

- Special care must be taken in identifying polluters and the pollutants involved since mobilisation of naturally occurring "contaminants" in the aquifer may also occur. For example, when water is recharged into an alluvial aquifer for water supply, it gradually becomes "polluted" by dissolved manganese and iron. The manganese and iron originate from the aquifer due to the decrease of dissolved oxygen in the groundwater. Under these conditions, Mn(IV) is reduced both chemically and bacterially into the Mn(II) soluble form.

- The data supporting different views of researchers in different investigations should be taken into account when calling a chemical compound a "contaminant". *TCE*, as an example, has been used in the United States for many years as an excellent degreasing agent, a popular dry cleaning solvent, an extraction agent in decaffeinating coffee, a general anaesthetic in medicine and dentistry, and in numerous other ways. Its uses were severely curtailed in 1976 when a study by the National Cancer Institute provided evidence that *TCE*, in very high experimental dosages, caused tumour growths in a sensitive mouse species. Subsequent studies by other researchers have failed to reproduce the carcinogenic response to *TCE* from any species of test animal while recent epidemiological studies have failed to implicate *TCE* as a cause of cancer in humans.

⊘ Although chemical pollution was identified previously it is now also generally recognised that groundwater systems are as prone to microbial infestations as are surface waters. The presence of micro-orgamisms in municipal and biological waste may be significant because of its potential health impact. It appears that the potential hazard to man from the pathogenic agents reaching the groundwater depend upon (i) the number and nature of the pathogens initially placed in the landfill, (ii) their ability to survive or to maintain their infectious features and (iii) their ability to move through the landfill into the surrounding environment. Environmental conditions such as temperature, pH, time and the presence of chemical and biological antagonists may control and have a meaningful effect on the die-off and survival of micro-organisms. It is clear that the leachate may have a definite antibacterial impact with regard to the inactivation of micro-organisms, such that the microbiological health risks associated with the leachate from waste disposal landfills may be minimal. It is important, however, to remember that the inactivation capacity of different leachates may vary considerably depending on various factors and if pathogenic bacteria, viruses, protozoa or helminths survive in the leachate, they will consequently reach the groundwater. The health risk then becomes a function of their survival and movement through the aquifer.

⊘ The prevention of illegal dumping practices (e.g. toxic materials) would save considerable amounts of money. This holds both for industrial and domestic waste disposal. For example, the toxic content of domestic waste can be reduced by obtaining the co-operation of the public. This requires training in environmental awareness to encourage the public to sort their domestic waste and the provision of an intensive network of collection points which are regularly serviced. The number of waste sites must also be minimised and sites that have been closed must continue to be monitored for groundwater pollution.

⊘ Much research effort is being carried out in South Africa relating to groundwater contamination and aquifer protection. These studies relate to policy development, suitable investigative techniques and methods and the setting of minimum requirements. Such efforts can only lead to improved standards in the waste disposal field. The DWA&F has been involved in developing and implementing legislation in an attempt to prevent the loss of valuable water resources. Permitting of waste sites has been slower than anticipated and as of December 1992 only 7 per cent of the country's waste sites have been investigated or reported on and about 15 per cent of the identified waste disposal sites have been issued with permits or are in the process of obtaining permits.

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CHAPTER 7 RECOMMENDATIONS

7.1 Public Awareness and Education

The basic legal framework already exists in South Africa, and the emphasis, in order to reduce the irresponsible disposal of industrial waste, should be placed on increased inspection and implementation of the environmental protection laws. Television and newspapers could assist in creating a greater environmental awareness amongst the public. Government could encourage and facilitate the collection of sorted municipal waste and promote environmental education at schools.

7.2 Further Research

As described in this report, much research is being carried out in South Africa relating to groundwater contamination and aquifer protection. These studies relate to policy development, suitable investigative techniques and methods, and the setting of minimum requirements. In order to ensure that viable water resources are not contaminated by waste disposal the following research may still be of value:

(i) *A GIS-database incorporating and overlaying the position of waste sites, the type of waste disposed, surface water sources, the position and type of aquifer, the geomorphology, geology and hydrology, should be developed, particulary in "sensitive" environments where groundwater is used as drinking water.*

(ii) *Monitoring the quality and quantity of leachate at the worst industrial and municipal waste site in order to evaluate if the leachate is contaminating the groundwater and to what extent the pollution is moving into the aquifer to serve as a guideline for other sites.*

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1. Groundwater Chemicals Desk Reference, John H. Montgomery and Linda M. Welkom, Lewis Publishers, Inc. 1989.

2. Groundwater Chemicals Desk Reference, Volume 2, John H. Montgomery, Lewis Publishers, Inc. 1991.

Protection of groundwater requires that professionals from environmental consultanting groups need reliable, accurate and readily accessible data to accomplish this task. Unfortunately, the necessary data are scattered throughout many reference books, papers and journals. The above books are designed to include, in a single reference, all the information needed by those involved in the protection and remediation of the groundwater environment. Their formats are easy to use by a wide spectrum of professionals. The data fields have been selected to fulfil the minimum technical requirements of the user based on the extensive experience of the authors, their colleagues, and others.

These books should be useful to government agencies, environmental scientists, emergency response teams and *cleanup contractors (for physicochemical properties, exposure data, uses category and analytical test methods); environmental personnel from consulting and industrial firms (for exposure data and physicochemical data); chemical engineers, scientists and industrial hygienists (for synonym index, uses category, exposure and physicochemical data); real estate developers, insurance underwriters and environmental attorneys (for uses category and synonym index).*

A unique feature is the listing of competing values for most of the physicochemical properties. For example, all reported solubilities found in the documented literature have been cited for each compound enabling the reader to determine the reliability or uncertainty of these values. This feature enhances the value of all the physicochemical data.

These books are respectively based on 425 and 336 references. They are broad enough, and comprehensive enough to serve its purpose as desk reference, but small enough to be taken out into the field.

J.H. Montgomery and L.M. Welkom