Groundwater Pollution by Municipal Solid Waste Landfill Leachate: A Case Study of Okhla Landfill Delhi

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The large number of municipal solid waste (MSW) landfills and the many hazardous materials which they contain pose a serious threat to both surrounding environment and human populations. Once waste is deposited at the landfill, pollution can arise from the percolation of leachate to the porous ground surface. Contamination of groundwater by such leachate renders it and the associated aquifer unreliable for domestic water supply and other uses. This study deals with Okhla municipal landfill, Delhi. The leachate samples were subjected to physicochemical and toxicological studies with a view to determining the degree of pollution and contamination in this wastewater, which varied substantially with time of sampling. All parameters examined showed markedly higher values indicating significant risk to public health and environment. The study recommends that immediate steps be taken to stop further contamination of the groundwater.

Keywords: municipal landfills, leachate, groundwater contamination

Introduction

One of the oldest and most common methods of municipal waste disposal is landfilling. This is most likely to remain the ultimate fate of solid waste since it appears to be one of the cheapest ways (Britz et al., 1990). Once disposed of in landfill, solid waste undergoes various physico-chemical and biological changes. Consequently, the degradation of the organic fraction of the wastes in combination with percolating rainwater leads to the generation of a highly contaminated liquid called leachate (Kurniawan et al., 2006). The leachate so produced is a high strength wastewater with the levels of wastewater parameters, such as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), ammonium nitrogen, turbidity, solids, being many times greater than those in municipal wastewaters. Leachate generated owing to moisture release, precipitation and infiltration, are easily increased by soluble or suspended organic matters, ammonium nitrogen and inorganic ions such as heavy metals, and may cause severe environmental hazards if they are not properly collected, treated and safely disposed (Li et al., 1999). The most commonly reported danger to the human health from these landfills is from the use of groundwater that has been contaminated by leachate. Various studies have reported contamination of groundwater resources by MSW Landfill leachate, particularly from unlined and uncontrolled landfills (Chian and DeWalle 1976; Kelley 1976; More et al., 2006). Threat to groundwater resources from such landfills is higher in underdeveloped and developing countries, where landfills are generally uncontrolled open dumps and hazardous industrial waste is also co-disposed with municipal waste.

In a country like India where urbanization is progressing at a faster rate, there are tremendous problems associated with solid waste and it's by products like leachate and gaseous products arising from it. A large quantity of leachate is produced despite the semi-arid climate due to the co-disposal of liquid and sludge waste with MSW. Recent estimates indicate that approximately 100,000 metric tons of MSW is generated daily in India and more than 90% of the solid waste collected is disposed of by landfilling only. In Delhi itself, which generates approximately 7000 metric tons of MSW daily, the monthly production of leachate has been estimated to be 81.5 m^3 (Kumar et al., 2002). At present there are three active landfill sites in Delhi, namely Gazipur, Bhalswa and Okhla. All the three are unlined and fall under the category of uncontrolled solid waste disposal facility. Leachate generated from these landfills generally gets collected in low lying areas or percolate down the soil surface, contaminating both surface and groundwater resources.

Landfill leachate is a complex wastewater with considerable variations in both composition and volumetric flow. Many factors influence the leachate composition including the types of wastes deposited in the landfill, composition of wastes, moisture content, the particle size, the degree of compaction, the hydrology of the site, the climate, and age of the landfill and other site-specific conditions including landfill design and type of liners used, if any (Leckie et al.,1979; Kouzeli-Katsiri et al.,1999). The characteristics of the leachate also depend on the pre-treatment of the solid waste such as segregation of recyclable material like plastics, paper, metals, glass, etc, shredding and /or bailing of the waste. Containing hundreds of different chemicals, the characteristics of municipal landfill leachate vary greatly within an individual landfill over space and time. Therefore, keeping in view the variation in leachate composition and its pollution potential, its regular monitoring is important to provide assurance that the landfill operation does not cause harm to human health The present study was undertaken to determine the likely pollution of groundwater by the Okhla landfill leachate over a period of time due to the discharge of contaminants from leachates to the underlying groundwater.

Materials and Methods

Site details

Delhi, capital of India sprawls over 1483 km^2. With a population approaching to 14 millions, Delhi is estimated to generate approximately 7 X 10^6 kg/d MSW. The collection and disposal of solid wastes is the responsibility of Municipal Corporation of Delhi (MCD), New Delhi Municipal Corporation (NDMC) and Delhi Cantonment. The current disposal practices of MSW in Delhi are not safe for humans and the environment. The landfill site receives all kinds of wastes such as food wastes, oil products, debris, agricultural wastes, chemical materials, hospital waste, slaughterhouse waste and liquid wastes. There is no segregation of waste at the source and no specific landfill for each type of waste. Pre-treatment is not being practiced for municipal or hazardous waste before dumping. Proper management of landfill has not been established in any of Delhi's waste disposal sites. The waste pile is usually not covered at the site due to the steep slopes. Bad odours and self-waste combustion due to high temperature are also noted. At present only three landfill sites are in operation namely Ghazipur, Okhla and Bhalsawa (Figure 1).

The leachate used in the study was collected from the Okhla landfill site, Delhi. It accepts all types of wastes from various sources. The site has a large volume of buried waste as it has been in operation since 1996, and is located near residential communities. Currently an average of about 1200 tonnes of MSW is being deposited at the site every day. A high waste density of 1.2 tonnes per cubic metre is assumed to be due to a high content of construction and demolition waste and inert waste. The total amount of waste disposed at Okhla Landfill is estimated to be 2.83 million tons till 2004. The organic content of the landfill is assumed to be as low as 35% and out of which approximately 75% is biodegradable [COWI 2004]. The fact that all the three active landfills lie in the alluvial plains of river Yamuna, increases the risk of pollution to the groundwater aquifers (Figure1).

Figure 1. Location of Okhla and other landfill sites and the geology of the study area. (source: CGWB 2001)

Results and Discussion

Leachate characteristics

The leachate used in the study was collected from the Okhla landfill site, Delhi. The leachate samples were collected at four different time periods of the year, which can be categorized into summer and winter months. Leachate L1 and L2 were collected during summer, while L3 and L4 were collected during winter. The collected leachate was stored in the laboratory at 4^oC for further analysis. The following parameters were employed to evaluate characteristics of leachate: Chemical Oxygen Demand (COD), ammoniacal nitrogen (NH_3-N), Total Kjeldahl nitrogen (TKN), pH, alkalinity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and heavy metals. Leachate toxicity was determined using static 96-h fish bioassays. *Poecilia reticulata*, commonly known as guppy fish, was used as test organism. Toxicity was expressed as the leachate concentration (% v/v) that causes death for 50% of fish (LC50). Each bioassay test set consisted of six leachate dilutions and a control. For all the tests LC50 were calculated using the Spearman-Karber method (Hamilton et al., 1977). All analysis was performed in accordance with the Standard Methods for the Examination of Water and Wastewater 20th Edition (APHA,1998).

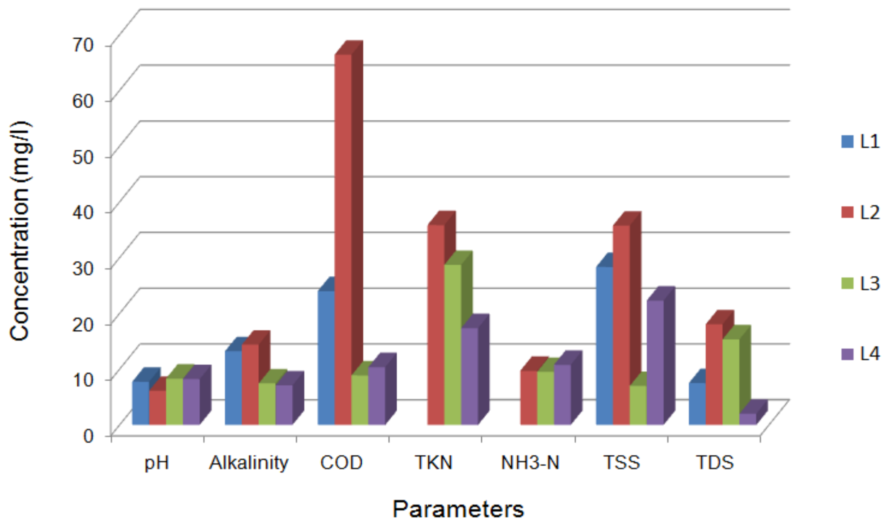

Figure 2. Seasonal variation in physicochemical characteristics of Okhla (All values presented in mg/l except pH. Alkalinity, COD, TSS and TDS presented in multiplication of 1000, TKN and NH_3-N in multiplication of 100).

Considerable variations in the quality of leachates produced from different landfills have been reported in the Literature (Booker and Ham, 1982; Robinson, 1993; Gettinby et al.,1996). Variability in leachate in terms of age and dumping locations were observed in this study. The results obtained in this study are graphically presented in figure 2. Significant variation in the physico-chemical characteristics was observed between the leachate collected in the summer and winter seasons. Leachate L1 and L2 were characterized by low pH 7.2 and 6.1, with high organics and nitrogen content, indicating the fresh leachate generation during the summer months. This fresh leachate was also characterized by high COD values, 24,000 and 72,000 mg/l in L1 and L2 respectively. Contrary to this, the winter leachate were characterized by high pH, 8.5 and 8.6 for L3 and L4 respectively, which is typical of old landfill leachate. Similarly, low COD values 8,800 and 12,200 mg/l for L3 and L4 respectively indicate the degraded stage of the old leachate collected during the winter. Among the nitrogenous compound, TKN (3580 mg/l) and ammonia nitrogen (1750 mg/l) were present in high concentration, this is probably due to the deamination of amino acids during the decomposition of organic compounds (Crawford and Smith, 1985; Tatsi and Zouboulis, 2002).

It is noted that variations in leachate generation and chemical characteristics occur seasonally, because of fluctuations in type of waste dumping in each season and varying climates. It is also found from chemical characteristics of leachate that fluctuations in concentration level occur due to aging of waste layers. The waste pits at landfill sites vary in depth so the thickness of waste layer is not uniform. The varying age and thickness of waste compartments are also responsible for the temporal variation of leachate characteristics (Al-Yaqout and Hamoda, 2003).

Although, the values of various parameters in old leachate are much less than fresh leachate, their concentrations are significantly higher than municipal sewage, indicating potential threat to water resources by both fresh and old leachates. The high concentration of TDS can alter both physical and chemical characteristics of receptor groundwater. Meanwhile, the presence of high values of COD, TKN and ammonia in the leachate may cause severe contamination of groundwater.

Metals in the leachate

The mean values of heavy metals in Okhla leachate samples are presented in Figure 3 along with Environmental Protection Agency (EPA) drinking water standards for comparison against reported values of metals in leachates. Pb, Cd, Mn, Cr, Fe and Ni were found to be several times higher than drinking water standards as prescribed by the US EPA.

High concentrations of Lead (1.2 mg/l), Cr (1.5 mg/l), Zn (1.15 mg/l) Ni (3 mg/l) and Fe (6.74 mg/l) were found in all leachates. Possible sources of lead contamination may be batteries, photographic films, old lead-based paints and lead pipes disposed at the landfill, which is toxic to all forms of life at this level. Acidity in leachate causes lead to be released from refuse. Heavy doses of chromium salts even though are rapidly eliminated from human body, could corrode the intestinal tract (WHO, 2004). Zinc with mean concentrations of 1.15 mg/l indicates that the landfill is receiving waste batteries and fluorescent light bulbs. It is a cause of concern with regards to plant and aquatic life. High levels of iron in samples indicate that iron and steel are also dumped in the landfill and may change the color of groundwater (Rowe et al., 1995). Manganese (Mn) with a mean concentration 0.35 mg/l was observed in all the leachate samples. Mn is considered to be a neurotoxin and long term chronic exposure through contaminated water is hazardous for human health. The major anthropogenic source of iron and other iron-containing alloys in Groundwater is steel industry waste, which is dumped in the landfill without prior treatment. The steel industry generally dumped their effluents in nearby landfills that contain high concentrations of iron; over time, the iron seeps into groundwater from landfills with rainwater in monsoon period.

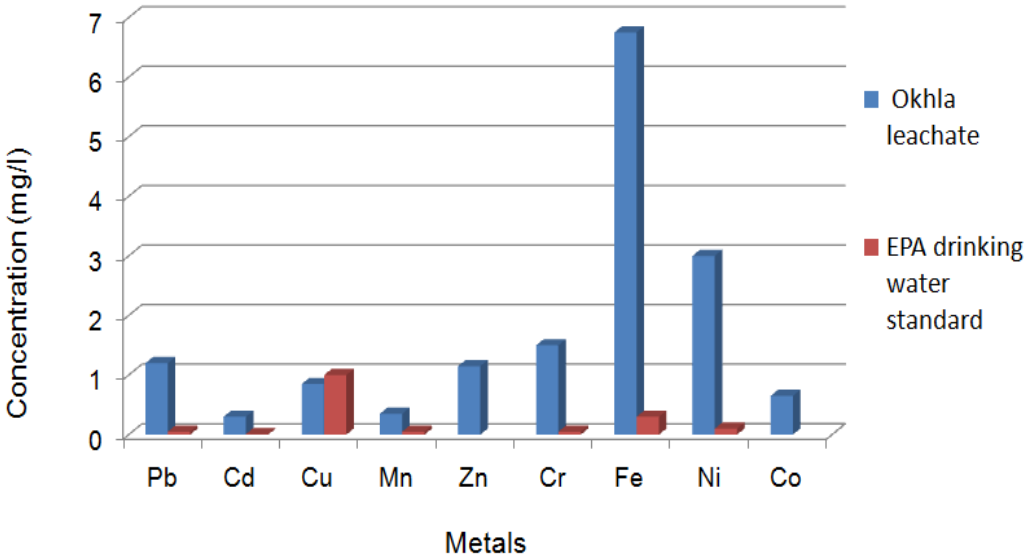

Figure 3. Mean values of metals in Okhla landfill leachate

As leachate is generated by solid waste landfill site, contamination of ground and surface waters may occur. This leads directly to the problem of contamination of drinking water supplies either by contamination of surface supplies or by contamination of an aquifer or well field. When water supplies are contaminated with leachate containing heavy metals, the mechanism leading to health hazards is bioaccumulation. Classic example of the effect of bioconcentrated toxicants are the painful and fatal Itai Itai disease caused by chronic cadmium poisoning. Main sources of Cd in municipal solid waste could include food cans, metal alloys, electronic objects, cement and construction debris, and nickel– cadmium batteries, among several others.

Heavy metals remain in the waste or at the waste–rock interface as a result of redox controlled precipitation reactions (Yanful et al., 1988). Further the metal mobility is also controlled by physical sorptive mechanisms and landfills have an inherent in situ capacity for minimizing the mobility of toxic heavy metals (Pohland et al., 1993). This fixing of heavy metals reduces the risk of direct toxic effects due to ingestion of leachate contaminated groundwater. However, once the leachate leaves the site the situation changes. The leachate is generally a strong reducing liquid formed under methanogenic conditions and on coming into contact with aquifer materials has the ability to reduce sorbed heavy metals in the aquifer matrix. The most important reactions are the reduction of Fe and Mn to more soluble species. Hence the concentration of these components increases under favorable conditions close to a landfill and may lead to a serious toxic risk.

Various studies have reported contamination of groundwater resources in Delhi by MSW Landfill leachate (More et al, 2006; Srivastava and Ramanathan, 2008; Jhamnani and Singh, 2009). High concentrations of heavy metals (Pb, Cd, Ni, Cr, Mn, Co, Zn) were observed, which is hazardous for health. These studies have revealed that landfill act as the point source for all the contaminants because the landfill leachate contains very high concentration of heavy metals and the concentration of pollutants decreases radically as we move away from the landfill along the groundwater flow. The hypothesis that the heavy metals originate from the landfill is also justified because there is no known natural source of these heavy metals in the study area.

Leachate toxicity

The studies were aimed to assess acute toxicity (96-h LC50) of leachate by estimating the rate of mortality in *Poecilia reticulata.* Prior to the 96-h toxicity tests, range finding tests were conducted in order to determine the appropriate dilution range for leachate. During the experiments the behavior of fishes were also studied. Before the final affect i.e. mortality, fishes lost equilibrium in water and began to sideways swimming contrary to the control group. Figure 4 presents percentage mortality in the test species *Poecilia reticulata in* various dilutions of leachate. The results in terms of mortality were analyzed using Spearman Karber method to calculate the LC50 values. Samples L3 and L4, collected during winter months were found to be more toxic with 96-h LC50 being less than 3% for L3 and less than 4% for L4, compared to the leachate collected during summer months with LC50 less than 13% for L1 and less than 12 % for L2.

The toxicity bioassay results highlight the high pollution potential of the Okhla landfill leachate. Although the leachate proved to be highly toxic for the fishes, it is very difficult to find out the contribution of particular components of the leachate. It was concluded that, the toxicity of the complex leachate matrix may be due to the synergistic interaction between the various pollutants. High concentration of organic matter and nitrogen (Figure 2) and heavy metals (Figure 3) are known to contribute to extreme elevation of toxicity levels in any environment. These classes of compounds are a risk to the ecosystems and public health.

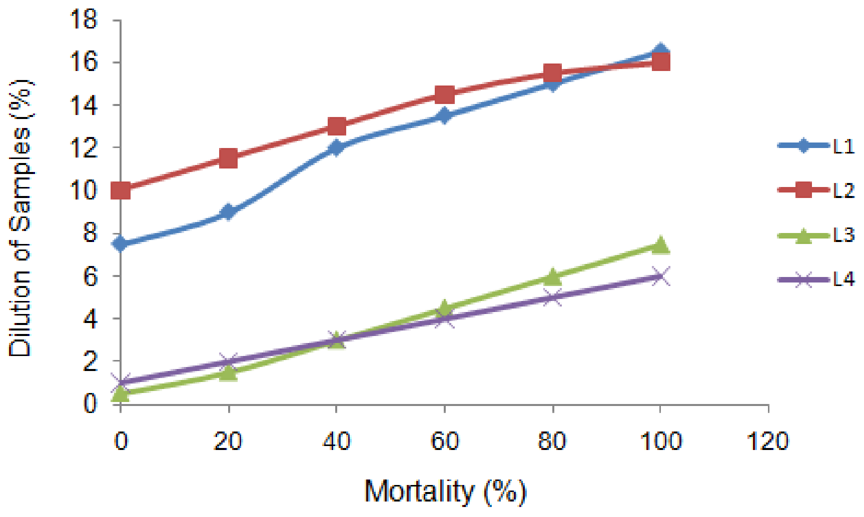

Figure 4. Acute toxicity assessment of leachate by estimating the rate of mortality in *Poecilia reticulata*.

Conclusions

The Okhla landfill is located in one of the most urbanized areas of Delhi, and its influences on the huge population are inevitable in the capital city of India, because it is unplanned, lying in flood plain of the Yamuna River, and its alluvial lithology makes it more susceptible to contamination by leaching of pollutants. Okhla landfill, which is being operated as a dump site, is expected to become cause of serious groundwater pollution in its vicinity.

The observed concentrations of leachate organics, nitrogen, heavy metals and toxicity were found to be very high and varied with the time of sampling. The variation in leachate characteristics indicates that the leachate from an active landfill is influenced by age, type of waste dumped and the climatic conditions. Fresh leachate is characterized by low pH and high organic strength, whereas, in old leachate with high pH, the organic strength is reduced due to degradation. However, both types have very high pollution potential than municipal sewage, posing severe environmental and health risk. The results of leachate toxicity bioassay also highlight the importance of such ecotoxicological assessment to determine adverse effect to the environment. However, in a complex matrix like leachate, the cause of ecotoxicity is difficult to understand and is attributed to the synergistic effects of various components present in it.

The study clearly indicates that if leachate is allowed to drain directly into the surface water or reach to the groundwater aquifer it can cause severe damage. Hence, upgrading of Okhla landfill is highly recommended so as to control and minimize the impact of landfill leachates on groundwater quality around the landfill.

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