Groundwater Contamination due to Bhalaswa Landfill Site in New Delhi

Bharat Jhamnani and SK Singh

***Abstract*—**Sampling and analysis of leachate from Bhalaswa landfill and groundwater samples from nearby locations, clearly indicated the likely contamination of groundwater due to landfill leachate. The results of simulation studies carried out for the migration of Chloride from landfill shows that the simulation results are in consonance with the observed concentration of Chloride in the vicinity of landfill facility. The solid waste disposal system presently being practiced in Delhi consists of mere dumping of wastes generated, at three locations Bhalaswa, Ghazipur, and Okhla without any regard to proper care for the protection of surrounding environment. Bhalaswa landfill site in Delhi, which is being operated as a dump site, is expected to become cause of serious groundwater pollution in its vicinity. The leachate from Bhalaswa landfill was found to be having a high concentration of chlorides, as well as DOC, COD. The present study was undertaken to determine the likely concentrations of principle contaminants in the groundwater over a period of time due to the discharge of such contaminants from landfill leachates to the underlying groundwater. The observed concentration of chlorides in the groundwater within 75m of the radius of landfill facility was found to be in consonance with the simulated concentration of chloride in groundwater considering one dimensional transport model, with finite mass of contaminant source. Governing equation of contaminant transport involving advection and diffusion-dispersion was solved in matlab7.0 using finite difference method.

***Keywords*—** Groundwater, landfill, leachate, solid waste.

I. BACKGROUND

SOLID waste includes all the discarded solid materials from commercial, municipal, industrial, and agricultural activities [1]. Landfilling is the preferred method of municipal solid waste (MSW) disposal due to its favorable economics. However, poorly designed landfills can create contamination of groundwater, soil, and air. The most commonly reported danger to the human health from these landfills is from the use of groundwater that has been contaminated by leachate [2]-[4]. As water percolates through the landfill, contaminants are leached from the solid waste. Leachate is produced when moisture enters the refuse in a landfill, extracts contaminants into the liquid phase, and produces a moisture content sufficiently high to initiate liquid flow. Leachate is generated in a landfill as a consequence of the contact of water with solid waste. Leachate may contain dissolved or suspended material associated with wastes disposed off in the landfill, as well as many byproducts of chemical and biological reactions. Strength of leachate from MSW landfills varies with the progress of biological activity occurring in landfill. Leachate from young landfill has both high dissolved solids, as well as high concentration of organic matter. Leachate tended to migrate in surrounding soil may result in contamination of underlying soil and groundwater. The rate and characteristics of leachate produced depends on many factors such as solid waste composition, particle size, degree of compaction, hydrology of site, age of landfill, moisture and temperature conditions, and available oxygen. During the course of stabilization of landfilled wastes, non-conservative constituents of leachate (primarily organic in nature) tend to decompose and stabilize with time, whereas conservative constituents will remain long after waste stabilization occurs. Conservative constituents include various heavy metals, chloride, and sulfide. Metals often are precipitated within the landfill and are infrequently found at high concentrations in leachate, with the exception of iron.

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II. WATER REQUIREMENT OF DELHI

As per an estimate of the Central Pollution Control Board (CPCB), the landfills of the National Capital Territory (NCT), Delhi, cumulatively generate a significant amount of leachates annually, which is alarming in terms of groundwater. In many parts of India, especially in the arid and semiarid regions, due to the vagaries of monsoons and scarcity of surface water, dependence on the groundwater resource has increased tremendously in recent years. Viewed from the international standard that '<1,700 m^3/person/year' qualifies as water-stressed and '1,000 m^3/person/year' as water scarce, India is water-stressed today and is likely to face severe water scarcity by 2050. Delhi, as the rapidly growing capital city of Asia, is facing problems in terms of both the groundwater quality and quantity.

III. SOLID WASTE AND ITS DISPOSAL IN DELHI

Delhi generates 6,000 metric tonnes of solid waste every day which is likely to increase to 18,000 metric tonnes per year by 2021. The generation rate is about 500 gm per person per day, which is almost 5 times the national average. The main waste generated in Delhi is from the markets for agricultural products, retail and commercial markets, hospital and nursing homes, slaughterhouses, industries and construction and demolition activities. Solid waste management in Delhi is mainly based on the disposal of the waste through the three operational landfills located at Bhalaswa, Okhla, and Gazipur. These sites do not have any infrastructure to collect landfill gas emissions. For conversion of biodegradable components of solid waste, the MCD has set up anaerobic, semi-mechanical compost plant near Okhla in 1980, and manual method of composting is practiced at Bhalaswa. All of these sites fall under the category of

TABLE I
CHARACTERISTICS OF LEACHATE FROM BHALASWA LANDFILL SITE, AND GROUNDWATER SAMPLES FROM NEARBY LOCATIONS

Parameter	Concentration in landfill leachate	Concentration in groundwater sample at radial distance from landfill facility					
		≤75m	75-500m	500-1000m	1000-1500m	1500-2000m	2000-2500m
Iron	20 mg/L	7.04 mg/L	6.53 mg/L	5.11 mg/L	3.61 mg/L	1.73 mg/L	0.64 mg/L
Copper	<10 mg/L	0.1 mg/L	0.08 mg/L	0.06 mg/L	0.05 mg/L	0.02 mg/L	0.01 mg/L
Nickel	<3 mg/L	0.43 mg/L	0.32 mg/L	0.22 mg/L	0.13 mg/L	0.43 mg/L	0.43 mg/L
Zinc	<10 mg/L	3.37 mg/L	3.27 mg/L	2.14 mg/L	1.11 mg/L	0.06 mg/L	0.02 mg/L
Chloride	4000 mg/L	1174.2 mg/L	1032.24 mg/L	845.45 mg/L	543.12 mg/L	324.23 mg/L	135.36 mg/L

uncontrolled solid waste disposal facility. Many of the tip faces are steep and unstable and methane generation in the uncovered waste piles is spontaneously igniting causing smoldering surface fires. Bhalaswa sanitary landfill is located in a North West corner of Delhi. It is surrounded by localities such as Bhalaswa and Jehangirpuri. The Bhalaswa landfill site occupies 21.06 hectares of land out of which about 6 hectares of land are devoted to compost plant. The site was once used for sugar cane plantation. The landfill at present receives about 2200 tonnes per day of waste out f which about 700 tonnes per day goes to compost plant. The landfill has already reached about 22m of height. The landfill is publicly owned and is managed by MCD. The contract concerns operation and management of the site consists mainly of activities relating to receipt of the waste, processing and burial, on-going site preparation and restoration. The weighing bridge system is run by a private agency under contact with MCD. The incoming wastes originate mainly from households and commercial areas, but there are also some wastes that are brought to the landfill from industries.

IV. CHARACTERISTICS OF LEACHATE AND GROUNDWATER SURROUNDING BHALSWA LANDFILL

Systematic study conducted to determine the impact of municipal solid waste disposal at Bhalaswa landfill Site in Delhi has reveled that the groundwater is being significantly contaminated due to the leachate from landfill. The average concentrations of Chlorides, and heavy metals in leachate, and in the groundwater samples collected at varying radial distances from the landfill are shown in Table I. The data indicate the landfill as the point source for all the contaminants because groundwater flow is outward away from the Bhalaswa landfill, and the concentration of pollutants decreases radically as we move away from the landfill along the groundwater flow. As can be seen, landfill leachates contain high concentrations of Cl^- (~4,000 mg/l), higher than the values recommended by the Central Pollution Control Board, Delhi, India. 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. High concentrations of other heavy metals (Ni, Cu, Zn) were observed, which is hazardous for 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. The iron can be released into the groundwater by natural processes such as oxidation- reduction reactions, ion-exchange processes and other physiochemical reactions in the groundwater aquifer system. 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. High concentrations of other heavy metals (Mn, Ni, Cu, Zn Pb) were observed, which is hazardous for health (Table I).

V. GEOLOGY OF THE AREA

Bhalaswa landfill, which is located in one of the most urbanized areas of Delhi between latitudes 28°42'30'' and 28°45' N and longitudes 77°07'30'' and 77°11'54''E (Fig. 1). The geology of the study area is mainly alluvium (Fig. 2). A vertical cross-section of unconfined aquifer is shown in Fig. 3. There are several small patches of aquifers shown in the figures, but scientifically all these comprise a single aquifer system in Delhi [5]. The area of the landfill is about 15 ha.

Fig.1 Landfill sites in Delhi

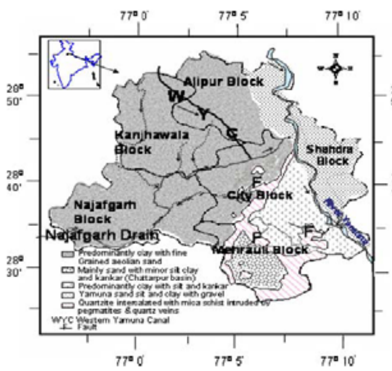


Fig. 2 Geology of the study area

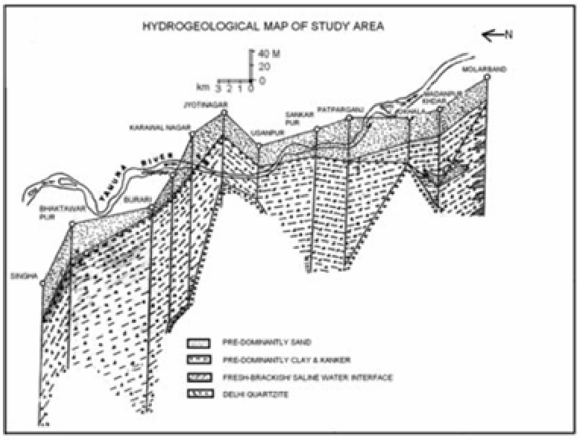


Fig. 3 Subsurface Geological Cross section around Bhalaswa Landfill, Delhi (CGWB, 2001)

VI. Material And Methods

Exercise was undertaken to determine the rate of movement of contaminants from landfill, so as to arrive at expected future concentrations of contaminants in the groundwater around landfill. The study involved use of one dimensional model, and Chloride as contaminant. Equation representing one dimensional mass transport of contaminants in porous media was solve using finite difference method implemented in MatLab.

For the purpose of modeling the transport of contaminants in porous media, the process of groundwater flow is generally assumed to be governed by the relations expressed in Darcy's law and the conservation of mass. The theoretical basis for the equation describing solute transport has been well documented in the literature [6], [7]. Reference [8] provide a conceptual framework for analysing and modelling physical solute-transport processes in groundwater. Governing equation for the transport of contaminant through porous media is expressed by the equation (1), which simply says that the increase in contaminant concentration within a small region is equal to the increase in mass due to advective-diffusive transport minus the decrease in mass due to sorption.

$$\frac{\partial C}{\partial t} = \frac{D_h}{R_f}\frac{\partial^2 C}{\partial z^2} - \frac{v}{R_f}\frac{\partial C}{\partial z} \tag{1}$$

where n is the effective porosity of soil, c is the concentration at depth z and time t, $D_h=D_e+D_{md}$ is the coefficient of hydrodynamic dispersion, v is the seepage velocity, ρ is the dry density of soil, K_d is the distribution or partitioning coefficient. Sorption process is modeled using the retardation factor R_f. and is expressed as $R_f=1+\rho K_d/n$, is the retardation coefficient. Governing one dimensional mass transport equation based on advection dispersion processes represented by equation (1) was solved in Matlab 7.0 using finite difference approach with upwind correction. Thus equation (1) in finite difference form can be written as:

$$\begin{aligned}&\frac{C_i^{m+1}-C_i^m}{\Delta t}+\frac{1}{R_f}\alpha v_x\frac{C_{i+1}^{m+1}-C_{i-1}^{m+1}}{2\Delta x}+\\&\frac{1}{R_f}(1-\alpha)v_x\frac{C_{i+1}^m-C_{i-1}^m}{2\Delta x}-\\&\frac{1}{R_f}\alpha D_x\frac{C_{i+1}^{m+1}-2C_i^{m+1}+C_{i-1}^{m+1}}{(\Delta x)^2}-\\&\frac{1}{R_f}(1-\alpha)D_x\frac{C_{i+1}^m-2C_i^m+C_{i-1}^m}{(\Delta x)^2}=0\end{aligned} \tag{2}$$

where 0≤α≤1. The case of setting α=0, results in explicit finite difference scheme, resulting in equation

$$\begin{aligned}&\frac{C_i^{m+1}-C_i^m}{\Delta t}+\frac{1}{R_f}v_x\frac{C_{i+1}^m-C_{i-1}^m}{2\Delta x}-\\&\frac{1}{R_f}D_x\frac{C_{i+1}^m-2C_i^m+C_{i-1}^m}{(\Delta x)^2}=0\end{aligned} \tag{3}$$

Applying upwind correction, by replacing the forward difference in second term with backward difference, equation(8) can be written as

$$\begin{aligned}&\frac{C_i^{m+1}-C_i^m}{\Delta t}+\frac{1}{R_f}v_x\frac{C_i^m-C_{i-1}^m}{\Delta x}\\&-\frac{1}{R_f}D_x\frac{C_{i+1}^m-2C_i^m+C_{i-1}^m}{(\Delta x)^2}=0\end{aligned} \tag{4}$$

Writing $\kappa_1=\frac{1}{R_f}\frac{v_x\Delta t}{2\Delta x}$ and $\kappa_2=\frac{1}{R_f}\frac{D_x\Delta t}{(\Delta x)^2}$, and rearranging the terms in equation (10), yields

$$\begin{aligned}&C_i^{m+1}=C_i^m-(1-2\kappa_1-2\kappa_2)C_i^m+\kappa_2C_{i+1}^m+\\&(2\kappa_1+\kappa_2)C_{i-1}^m=0\end{aligned} \tag{5}$$

The method is implemented by marching the solution forward at the interior nodes, bringing with it the effects of the initial condition and the boundary nodes. For the implementation of the above solution in MatLab, the domain of problem is discritized in suitable no. of nodes for time and space, in such a way that $\frac{1}{R_f}\frac{D_x\Delta t}{(\Delta x)^2}+\frac{1}{R_f}\frac{v_x\Delta t}{2\Delta x}\le\frac{1}{2}$. Thus the entire domain shall be divided in say, Ntsteps =T/Δt, and Nxsteps=z/Δx. Initial and boundary conditions are implemented by keeping C_i^m at the beginning of solution to be zero everywhere along the entire depth of domain. Thus for the implementation of initial condition, keeping C_i^m to be zero everywhere, one has

$$C_i^m = C_2^m = C_3^m = C_4^m = C_5^m$$
$$= C_6^m = C_7^m = C_8^m \dots\dots\dots\dots\dots\dots C_{Nxsteps}^m$$
$$c_T(t) = c_0 - \frac{1}{H_f}\int_0^t f_T(c,\tau)d\tau \qquad (6)$$

VII. Simulation Data

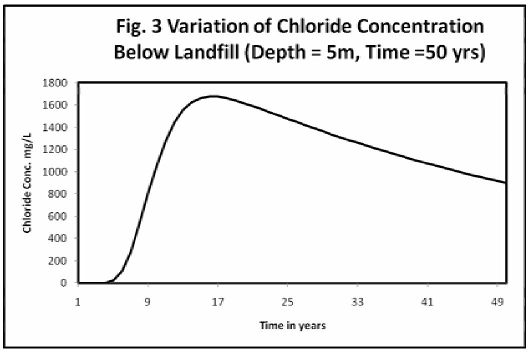
The data used for simulation of chloride migration from the landfill is shown in Table II. The landfill site is situated very close to the area named 'BURARI' in the vertical cross section of unconfined aquifer shown in Fig 3b. As can be seen in this figure, the geological conditions of aquifer immediately bellow are predominantly clay and kankar. Thus an advective velocity of 0.5 m/year was selected for the purpose of simulation [9]. Effective molecular diffusion coefficient was taken as 0.02 m^2/year, and dispersivity was taken as 0.015 [10]. Equivalent height of leachate has been taken on the basis of total mass of chlorides present in landfill, maximum concentration of chlorides in leachate. The total mass of chlorides in landfill, being a Municipal landfill has been taken as 0.2%. Although average concentration of chlorides in the leachate from landfill site has been found to be around 4000 mg/L, for the purpose of simulation the maximum concentration has been taken as 2000 mg/L, as the landfill has been started about 15 years back, with continuous addition of landfill mass at the top of it, resulting in progressive increase of its height to the present day condition of about 22m height. Use of maximum concentration of chlorides as 2000 mg/L, thus seems quite reasonable.

TABLE II
MODEL PARAMETERS FOR CHLORIDE

S.No.	Model Parameter	Unit	Value
1	Time	year	50
2	Depth to the groundwater	m	5
3	Effective molecular diffusion coefficient	m^2/yr	0.02
4	Hydrodynamic dispersion coefficient	m^2/yr	0.095
5	Dispersivity	m	0.015
6	Porosity		0.40
7	Retardation factor (R)		1.0
8	Advective velocity	m/yr	0.2
9	Equivalent height of leachate	m	10
10	Area of landfill	ha	16.188
11	Chloride content in landfill mass	%	0.2
12	Maximum concentration of chlorides in landfill leachate	mg/L	2000

VIII. Results And Discussion

Variation in chloride concentration at a depth of 5m below the bottom of landfill are shown in Fig.2, it can be seen that the variation of chloride concentration shows behavior typical of a conventional landfill system. Simulated chloride concentration in the groundwater at a depth of 5m below the landfill facility, increases, reaches a peak, and then declines. Chloride concentration in this case reaches to a maximum of 1678 mg/L in 16 years of operation of landfill facility, where a constant 2000 mg/L concentration of chlorides in exists in leachate. The observed concentration of chlorides in groundwater sample within 75m of Bhalaswa Landfill has been found to be 1174.2 mg/L. As the landfill has reached a height of 22m as of now from the beginning in 1993, the observed concentration of 1174.2 mg/L appears to be quite in agreement with the simulated concentration 1678 mg/L. However, as the landfill facility is being continually progressing in height in absence of availability of a new landfill site, the total mass of chloride available for leaching is expected to increase, which may further increase the concentration of chloride in groundwater. From results plotted it can be seen that the a concentration of about 1000 mg/L is likely to be present in the aquifer long after, endangering the lives of people dependant on the water supply from surrounding area. Also with the passage of time, water requirement is expected to increase, with additional burden being passed on to the groundwater sources, compounding the problem of contamination of groundwater due to solid waste disposal.



IX. Conclusion

The solid waste disposal system presently being practiced in Delhi consists of mere dumping of wastes generated, at three locations Bhalaswa, Ghazipur, and Okhla without any regard to proper care for the protection of surrounding environment. Bhalaswa landfill site in Delhi, which is being operated as a dump site, is expected to become cause of serious groundwater pollution in its vicinity. The leachate from Bhalaswa landfill was found to be having a high concentration of chlorides, as well as DOC, COD. The present study was undertaken to determine the likely concentrations of principle contaminants in the groundwater over a period of time due to the discharge of such contaminants from landfill leachates to the underlying groundwater. The observed concentration of chlorides in the groundwater within 75m of the radius of landfill facility was found to be in consonance with the simulated concentration of chloride in groundwater considering one dimensional transport model, with finite mass of contaminant source. Urgent attention therefore, needs to be paid to the groundwater supply from this region.

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