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SUSTAINABLE ENVIRONMENTAL SANITATION AND WATER SERVICES

Threat to the Groundwater from the Municipal Landfill Sites in Delhi, India

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INTRODUCTION :

It has been estimated that country is generating approximately 1,00,000 MT of municipal solid waste (MSW) daily[1]. The capital of India, Delhi generates approximately 7,000 MT of MSW daily. The generation rate is 500 gm/person/day, which is almost five times the national solid waste generation rate. More than 90% of the solid waste collected is disposed of by landfilling only. Landfills do not have any liners or leachate collection and treatment systems. Any precipitation or external source of water contributes to leachate generation. The amount of leachate generated is dependent on the available water, landfill constituents, its surface and the foundation soils[2,3]. The available water is affected by the moisture content in the refuse itself, precipitation, surface runoff, irrigation water moving through the landfill, rise in an otherwise low groundwater table, and water generated from the decomposition of the waste. The quantity of water infiltrating into the landfill is affected by the surface runoff, evapotranspiration, and the field capacity of the soil cover. Leachate may become a potential source of contamination, if it joins a surface water or ground water source[4].

WATER BALANCE METHOD :

The water balance method allows the estimation of percolation based on one-dimensional flow, conservation of mass, and the retention and transmission characteristics of the soil cover and solid waste in the landfill. Figure 1 shows the leachate generation parameters.The basic equations are:

$$P + SR + IR = I + R_O$$

where P = Input water from precipitation,
SR = Input water from surrounding surface runoff,
IR = Input water from irrigation,
I = Infiltration, and
Ro = Surface runoff.

The portion of the infiltrating liquid, I, that will percolate through the soil cover, PER_S, is given by:

$$PER_S = I - AET - dS_{TS}$$

where AET = Actual Evapotranspiration (i.e. the sum of water loss from evaporation and plant water use), and dS_{TS} = Change in moisture storage in soil.

Simillarly, the portion of I percolating through the refuse, PER_R, which represents the leachate volume, is given by :

$$PER_R = I - AET - dS_{TS} + W_D - dS_{TR}$$
$$= PER_S + W_D - dS_{TR}$$

where W_D = Water from decomposition of solid waste, and dS_{TR} = Change in moisture storage in refuse.

If there is groundwater intrusion (WGW), the amount of leachate generated, L, is modified as:

$$L = PER_R + W_{GW}$$

The precipitation, P, is the amount of water (in inches or mm) that accumulates on a sealed level surface. It is determined in the field and is available from the Indian Meteorological Department. Gauges installed near the landfill site are used to take an average monthly reading over a long period of time.

Surface runoff, R_O, can be determined by actual measurements, graphical methods, or by empirical methods such as the rational formula. The runoff is given by:

$$R_O = CP$$

where C = Runoff coefficient which is a function of type of surface, vegetation, slope, etc. Its values for different conditions are given by Parry[2].

Figure 2 shows the water-holding characteristics of various soils with the Unified Classification system. The abbreviated version in form of an expanded table for estimating the soil moisture retention after the potential evapotranspiration is also given by Oweis and Khera[2].

Potential evapotranspiration can be calculated by the equation given by International Rice Research Institute[5]. For South East Asia to convert evaporation rate to evapotranspiration, equation is as follows:

Potential Evapotranspiration (PET) =
0.93 x Pan Evaporation.

DELHI SCENARIO:

Leachate generation rate for the landfill sites in Delhi has been estimated by the water balance method and is presented in Table 1. Line 1 gives the Average Pan Evaporation for different months of the year (Calculated

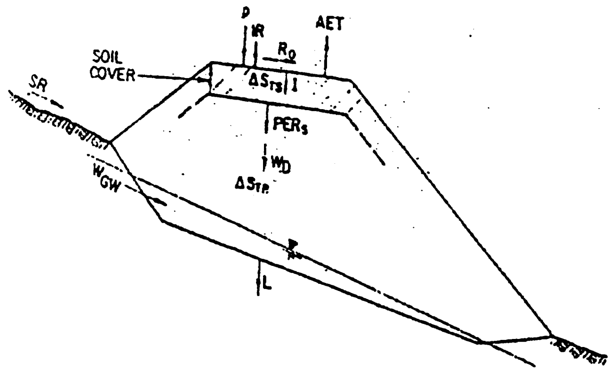

Figure 1: Leachate Generation Parameters (Source: Oweis and Khera, 1990)

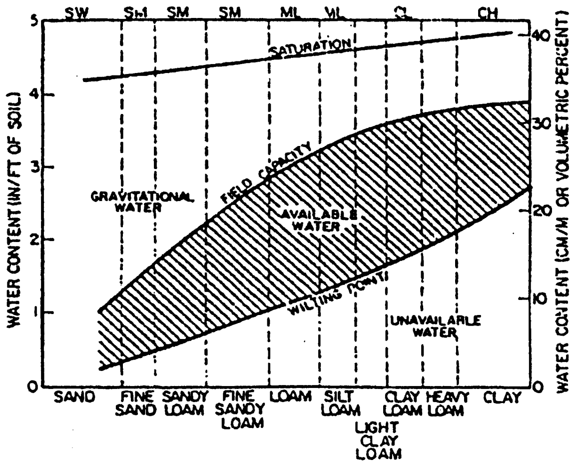

Figure 2: Water Holding Capacities of Various Soils with USDA Classification

from the daily evaporation data obtained from the Indian Metrological Department for the period 1987-1999). Line 2 gives the factor for the calculation of Potential Evapotranspiration i.e. 0.93. The Potential Evapotranpiration (PET) is computed in Line 3. The average monthly precipitation data is given in Line 4 (Calculated from daily rainfall data obtained from the Indian Meteorological Department from the period 1987-1999).

The runoff coefficient for a sandy soil cover with 2% slope is 0.25[2]. The runoff in Line 6 is computed by multiplying the runoff coefficient by the precipitation, and the infiltration, I, is computed in Line 7.

The negative values of I-PET, from September to July, represent potential moisture deficiency where infiltration fails to supply the water needed for vegetation. These deficiencies are summed up on cumulative bases in Line 9. A sum of zero is assigned to the last month having a positive value of I-PET, because, at the end of the wet season, the soil moisture is at the field capacity. If the moisture content in the soil cover remains below the field capacity, leachate will not be generated from rainfall. An effective cover could produce such conditions. Generation of leachate at a rate similar to the rate of percolation can be achieved only after the soil cover saturation.

Usually a grassed sandy soil cover with a thickness of 0.61 m (2 ft) is provided at the landfill sites. For this condition, the available water by volume from Figure 2 is 7.8% (i.e. 10.8-3.0) or 78 mm/m. The root depth is limited by a cover thickness of 0.61 m. The potentially available soil moisture is 0.6 × 78 or about 50 mm. This value of soil moisture storage, S_T, is assigned to the initial wet month. For months with negative values of (I - PET), the storage is derived[2]. After the dry period when (I - PET) becomes positive, the storage S_T in any given month is the sum of the storage in the previous month plus the value of (I - PET) for that month; but this value cannot exceed the storage capacity (i.e. 50 mm in this case). Where positive (I - PET) occurs between two negative values, S_T is calculated by direct addition of (I - PET) to the previous S_T. Change in storage, dS_T, is the storage from this month less the storage from the previous month.

The actual loss due to evapotranspiration (AET) in Line 12 during the wet months is equal to PET as the soil is at its storage capacity and there is more than adequate moisture available. For dry months, i.e., the months with negative (I - PET), the infiltration drops to below the PET and the actual evapotranspiration becomes less than the potential evapotranspiration. AET cannot exceed the infiltration plus the change in soil moisture storage (I+|dST|) calculated in Line 12. For months with maximum moisture storage (50 mm), any excess moisture becomes the percolation into the refuse underlying the cover and is calculated in Line 13. For negative dS_T, the percolation is equivalent to zero. For positive dS_T, the percolation is equal to (I - AET - dS_T). As one would expect, the annual percolation (PERC) in Table 1 is equal to the annual infiltration (I) less the actual evapotranspiration (AET) (i.e. 33.95 mm = 590.59 mm -556.64 mm). The change in storage is zero.

The difference between the field capacity of the solid waste and its moisture content at the time of deposition will delay the generation of leachate. But once the solid waste has reached the field capacity, the leachate will be coming out. Some leachate will be produced prior to the soil cover and the solid waste attaining their field capacity. This is due to channeling. In this study, while evaluating the leachate volume, it has been assumed that moisture content in the waste has already attained its field capacity.

The leachate formation/generation is lesser in the cells having higher depth of fill as compared to the cells

Table 1 Estimation of Leachate Volume from Landfills in Delhi, India, by Water Balance Method

Sr. No.	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Total
1.	Average pan Evaporation (mm) (1987-1999)	69.18	85.63	138.35	192.14	227.83	214.02	146.00	120.33	126.06	115.13	79.40	57.97	
2.	Adjustment Factor for Potential Evapotranspiration.	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	
3.	Potential Evapotranspiration (PET) (mm).	64.33	79.63	128.66	178.69	211.88	199.03	135.78	111.90	117.23	107.07	73.84	53.91	1461.95
4.	Average Precipitation (mm)	25.40	27.24	16.05	7.33	21.06	79.67	178.35	259.80	138.83	13.56	8.63	11.47	787.39
5.	Runoff Coefficient	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	-
6	Runoff R. (mm).	6.35	6.81	4.01	1.83	5.26	19.91	44.58	64.95	34.70	3.39	2.15	2.86	196.80
7.	Infiltration I (mm)	19.05	20.43	12.04	5.50	15.80	59.76	133.77	194.85	104.13	10.17	6.48	8.61	590.59
8.	I-PET	-45.28	-59.20	-116.62	-173.19	-196.08	-139.27	-2.01	+82.95	-13.10	-96.90	-67.36	-45.30	-871.36
9	Neg Σ(I-PET)	-267.94	-327.14	-443.76	-616.95	-813.03	-952.30	-954.31	0.00	-13.10	-110.00	-177.36	-222.66	
10	S_T (mm)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	50.0	41.0	7.0	1.0	1.0	
11	dS_T (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.0	-9.0	-34.0	-6.0	0.0	0.00
12	Actual Evapotranspiration (AET) (mm)	19.05	20.43	12.04	5.50	15.80	59.76	133.77	111.90	113.13	44.17	12.48	8.61	556.64
13	Percolation (mm)	-	-	-	-	-	-	-	33.95	-	-	-	-	33.95

having lesser depth of filling. The leachate will be more concentrated in the fills with higher depth as compared to the fills with shallow depth; because, for the higher depth of fill, more water is required to reach the field capacity and moreover, more water will be required for the gas generation as there is more potential of gas generation in the deeper fills. The water is required not only for gas formation, but also as water vapor going with the gas[6].

According to a report, there are 16 filled up landfill sites covering an area of 180 hectares and 3 active landfill sites covering a filled up area of 60 hectares, in Delhi city[7]. With present estimation the municipal landfills produce approximately 81,480 cum (approx. 81.5 million liters) of leachate annually most of which is produced during the rainy periods. The leachate, which has been proved to contain VOCs, synthetic organic compounds, and heavy metals, in absence of liners and leachate collection & treatment system, undoubtedly poses a threat to the groundwater and the surface water.

Moreover, the use of filled up landfills for greenery purposes demands the use of irrigation water. The amount of water used for irrigation also contributes to the generation of leachate. Using ground water for irrigation by making bore wells at the landfills may prove to be one of the possible routes of the groundwater contamination by leachate.

CONCLUSIONS AND RECOMMENDATIONS:

In Delhi, maximum leachate is produced during the rainy period that is in the month of August. During other periods of the year, the leachate produced due to precipitation is nil as the evapotranspiration is far higher than the precipitation. The leachate production during August is estimated to be about 81,480 cum. Based on the present landfilling scenario in Delhi, the following recommendations are made:

1. The municipal landfills must have liners and leachate collection & treatment system.
2. Leachate produced may pass to the groundwater through the bore wells provided at the landfills for drawing groundwater for irrigation purposes. Therefore, the bore wells shall be avoided at the landfills.
3. The native vegetation, which does not require any artificial irrigation, shall be encouraged.
4. It is important to make sure that as little water as possible shall come in contact with landfill, and irrigation water, if used, shall not exceed the field capacity of the topsoil cover.

5. Landfill sites should not be located near the surface water bodies or in close proximity to the ground water aquifers.

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