Assessment of groundwater quality near municipal solid waste landfill by an Aggregate Index Method
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ABSTRACT

Leachate generated from municipal solid waste landfill site affects the groundwater quality in the adjacent areas through percolation in the subsoil. In this study, Aggregate Index method is applied to determine the quality of groundwater around a municipal solid waste dumping site. As the aggregate index is an increasing function of the distance from the landfill site, the groundwater quality improves as one move away from the landfill site. Aggregate index decreases with increase in time. Thus, water quality goes down with time. It may be due to the reason that with the passage of time the solid waste material gets degraded and the waste constituents percolate down along with rainwater thereby polluting groundwater. Hence, some remedial measures are required to prevent further contamination of groundwater in the vicinity.

Keywords: Leachate, landfill, municipal solid waste, groundwater, aggregate index

Notations

The following symbols are used in this paper:

\begin{align*}
E & = \text{average error}; \\
I & = \text{aggregate index}; \\
m & = \text{exponent}; \\
N & = \text{number of subindices}; \\
n & = \text{parameter}; \\
p & = \text{parameter}; \\
q & = \text{quality variable}; \\
q_c & = \text{characteristic value of } q; \\
q_* & = \text{optimal value of } q; \\
r & = \text{subindex for } q = 0; \\
s & = \text{subindex}; \\
x & = \text{distance from landfill site}; \text{ and} \\
x_* & = \text{parameter}.
\end{align*}

Subscripts

\begin{align*}
a & = \text{aggregate index}.
\end{align*}
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1. Introduction

Landfilling of municipal solid waste is a common waste management practice and one of the cheapest methods for organized waste management in many parts of the world (El-Fadel et al., 1997; Dsakalopoulous et al., 1998, Jhammani et al., 2009, Longe and Balogun, 2010). Landfills poses serious threat to the quality of the environment if incorrectly secured and improperly operated. The threat to surface and ground waters could be deleterious. The scale of this threat depends on the composition and quantity of leachate and the distance of a landfill from water sources (Slomczynska and Slomczynski, 2004). Groundwater contamination is a major concern in landfill operations because of pollution effects of landfill leachate and its potential health risks (Lee and Jones-Lee, 1993; Christensen et al., 2001; Stollenwerk and Colman, 2003). Landfill leachate is generated by excess rainwater percolating through the waste layers in a landfill. A combination of physical, chemical and microbial processes in the waste, transfers pollutants from the waste material to the percolating water (Christensen and Kjeldsen, 1989). Municipal landfill leachate are highly concentrated complex effluents which contain dissolved organic matters; inorganic compounds, such as ammonium, calcium, magnesium, sodium, potassium, iron, sulphates, chlorides and heavy metals such as cadmium, chromium, copper, lead, nickel, zinc; and xenobiotic organic substances (Lee and Jones-Lee, 1993; Christensen et al., 2001; Tengrui et al., 2007; Ogundiran and Afolabi, 2008). The composition of landfill leachate, the amount generated and the extraction of potential pollutants from the waste depend upon several factors, including waste composition, degree of compaction, absorptive capacity of the waste, age of the waste, the climate, and levels of precipitation, landfill temperature, size, geology, engineering and operational factors of the landfill (Leckie and Pacey, 1979, Kouzeli-Katsiri et al.,1999).

In developing countries, several unregulated landfills exist adjacent to large cities, releasing harmful contaminants to the underlying aquifer (Singh et al., 2009). In India, open dumping of solid waste in low lying areas is practiced in most of the centers which are managed by municipal agencies. In urban areas the groundwater is contaminated due to leachate from municipal solid waste disposal site and in rural areas, leachate from fertilizers used for agricultural purposes has contaminated the groundwater (Eldho, 2001). Jeevanrao and Shantaram (1995) found that total hardness, alkalinity, BOD and COD were beyond the prescribed limit in the groundwater at both Amberpet and Golkonda solid waste landfill sites at Hyderabad. Mor et al. (2006) has reported the effect of municipal solid waste disposal on groundwater around a Gazipur landfill site at Delhi. Concentration of various physico-chemical parameters including heavy metal (Cd, Cr, Cu, Fe, Ni, Pb and Zn) and microbiological parameters were determined in groundwater and leachate samples. The moderately high concentrations of Cl⁻, NO₃⁻, SO₄²⁻, NH₄⁺, Phenol, Fe, Zn and COD in groundwater, likely indicate that groundwater quality is being significantly affected by leachate percolation. Vasanthi et al. (2007) studied that leachate produced by waste disposal site in Chennai contains potential contaminants which are likely to contaminate groundwater. The effects of dumping activity on groundwater appeared most clearly as high concentrations of total dissolved solids, electrical conductivity, total hardness, chlorides, chemical oxygen demand, nitrates and sulphates. Leachate collected from the site showed presence of heavy
metals. Jhamnani et al. (2009) have reported the effect of municipal solid waste disposal on groundwater around Bhalaswa landfill site at Delhi. The leachate from Bhalaswa landfill was found to be having a high concentration of chlorides, DOC and COD.

The present study was undertaken to determine the impact of leachate percolation around the municipal solid waste disposal site on groundwater quality by Aggregate Index Method.

2. Materials and Method

2.1 Groundwater Sampling

Groundwater samples were collected from the municipal solid waste disposal site at Suchi Village; Jalandhara near National Highway No.1 that spreads over 0.8 hectares of low lying land area. These groundwater samples were collected from the hand pumps nearby to solid waste dumping site. The ground water of the studied area is used for domestic and other purposes. Six groundwater sampling points (at distances \( x = 5 \) m, 10 m, 20 m, 25 m, 30 m and 50 m) were chosen representing six hand pumps. Figure 1 shows a sketch of the studied area with groundwater sampling points.

Groundwater sampling was carried out in late July and early August 2007 during the rainy season when there was a rise in water table. Both the leachate and groundwater samples were analyzed for parameters of interest. Groundwater samples were then again collected from the same locations after a time interval of two years (i.e. in July, 2009) to determine the effect of leachate discharge from solid waste dumping site on groundwater of the adjoining area with time. The parameters were selected based on their relative importance in municipal landfill leachate composition and their pollution potential on groundwater resources.

![Figure 1: A sketch of the studied area with groundwater sampling points](image-url)
2.2 Analytical Work

Analytical methods as specified by American Public Health Association (APHA, 1998), have been used in the present investigation. The pH was measured by electronic pH meter (4500-H+ B of Standard Methods) whereas, Turbidity was measured by Nephelometer by using optical properties of light (2130.B of Standard Methods). Properly shaken unfiltered ground water samples were used to determine total solids and estimated by gravimetric method (2540.B of Standard Methods). Ammonical Nitrogen and Phosphate was estimated using Spectro-photometer (UV-VIS Smart Spectrophotometer, 2000).

3. Results and Discussion

Water quality characteristics may be classified into three broad categories: physical, chemical and biological. Within each category, a number of quality variables may be employed. The suitability of a given water source for an intended use depends on the magnitude of these quality variables. To describe water quality, it is useful to employ a subindex of a quality variable to indicate the quality of the water on a zero (worst quality) to unity (best quality) scale. The overall water quality can be described by aggregating all the subindices to form an aggregate index \( I \). (Ott, 1978).

3.1 Description of Subindices

For the quality variable considered here the variation of subindices is described as (1) uniformly decreasing and (2) unimodal. For uniformly decreasing subindices, Swamee and Tyagi (2000) gave the following relationship:

\[
 s = \left(1 + \frac{q}{q_c}\right)^{-m}
\]

(1)

where \( q = \) quality variable; \( q_c = \) characteristic value of \( q \); and \( m = a \) positive number. The parameters \( q_c \), and \( m \) are given in Table 2 (Swamee and Tyagi, 2000). On the other hand, for unimodal variation of subindices Swamee and Tyagi (2000) gave the following equation:

\[
 s = \frac{pr + (n + p)(1 - r)\left(\frac{q}{q_s}\right)^n}{p + n(1 - r)\left(\frac{q}{q_s}\right)^{n+p}}
\]

(2)

where \( r = \) subindex for \( q = 0 \); and \( n \) and \( p \) = exponents. These parameters, as obtained by Swamee and Tyagi (2000) for various quality variables that are given in Table 3. Using Eqs. (1) and (2) along with Tables 1 and 2 and 3, the subindices for various quality variables are obtained. These subindices are tabulated in Table 1.

In Figs. 2(a-e), the subindices are plotted with the distance from landfill site, \( x \). A perusal of Fig. 2 indicates that the subindices increase with the increase in distance \( x \) from the landfill site. A typical equation of this curve for a subindex is proposed as

\[
 s = \left[ \left(\frac{x_s}{x}\right)^{m_s} + 1 \right]^{-n_s}
\]

(3)
where $x_{s_i}$, $m_s$ and $n_s$ = parameters. For a given pollutant, adopting trial set of values of $x_{s_i}$, $m_s$ and $n_s$; and using Eq. (3), the computed value of subindex $s_{cl_i}$ for distance $x_i$ is obtained as

$$s_{cl_i} = \left[ \left( \frac{x_{s_i}}{x_i} \right)^{m_s} + 1 \right]^{-n_s}$$  

(4)

where $x_i = 5, 10, 20, 25, 30$ and $50$ m for $i = 1, 2, 6$. The corresponding average error $E$ for a trial set of parameters is written as

$$E(m_s, n_s, x_{s_i}) = \frac{1}{6} \sum_{i=1}^{6} |s_{cl_i} - s_{oi}|$$  

(5)

where $s_{oi}$ = observed values of the subindices as given in Table 1. By varying $m_s$, $n_s$ and $x_{s_i}$, the average error $E$ is minimized by grid search. See Fox (1971). Continuing this procedure, the parameters are obtained for all pollutants. These parameters are listed in Table 4. Figs. 2(a-e) show the experimental and fitted curves for the variation of subindices with the distance from the landfill site. A perusal of Figs 2(a-e) reveals that there is a fairly good agreement between the data points and the fitted curves.

### 3.2 Aggregation

Swamee and Tyagi (2000, 2007) gave the following equation for aggregation of the subindices:

$$I = \left( 1 - N + \sum_{i=1}^{N} s_i^{-2.5} \right)^{-0.4}$$  

(6)

where $I$ = aggregate index; and $N$ = number of subindices to be aggregated.

Using Eq. (6) and subindices given in Table 1, the aggregate indices for various water samples are obtained for the initial year and after 2 years. These Aggregate Indices are listed in Table 5. A perusal of Table 5 indicates that the Aggregate index increases with the increase in the distance. The variation of the aggregate index has the same functional relationship as that of equation for subindices. That is,

$$I = \left( \frac{x_{s_i}}{x} \right)^{m_a} + 1 \right]^{-n_a}$$  

(7)

### Table 1: Observations of water quality variables

| S. No. | Attributes                  | $x$ (m) | Initial year |       |       | After two years |       |
|-------|-----------------------------|---------|--------------|-------|-------|----------------|-------|
|       |                             |         | $q$          | $s$   | $q$   | $s$            |       |
| 1.    | Ammonical Nitrogen(mg/l)    | 5       | 8.9          | 0.547 | 9.6   | 0.524          |       |
|       |                             | 10      | 5.1          | 0.698 | 5.3   | 0.688          |       |
|       |                             | 20      | 3.6          | 0.772 | 4.5   | 0.726          |       |
|       |                             | 25      | 2.4          | 0.840 | 3.6   | 0.772          |       |
|       |                             | 30      | 1.2          | 0.915 | 1.8   | 0.876          |       |
|       |                             | 50      | 0.9          | 0.935 | 0.9   | 0.935          |       |
| 2.    | Phosphate (mg/l)            | 5       | 4.7          | 0.125 | 5     | 0.118          |       |
|       |                             | 10      | 2.8          | 0.193 | 3.1   | 0.178          |       |
|       |                             | 20      | 1.5          | 0.309 | 1.8   | 0.271          |       |
|       |                             | 25      | 1.3          | 0.340 | 1.5   | 0.309          |       |
Table 2: Subindex constants for uniformly decreasing subindices

| Quality variable               | m   | q_e |
|-------------------------------|-----|-----|
| Nitrates/Ammonical Nitrogen (mg/l) | 3   | 40  |
| Phosphate (mg/l)              | 1   | 0.67|
| Turbidity (JTU/NTU)           | 1.5 | 50  |

Table 3: Subindex constants for unimodal subindices

| Quality variable | q* | n | p | r |
|------------------|----|---|---|---|
| pH               | 7  | 4 | 6 | 0 |
| Total Solids (mg/l) | 75 | 1 | 1 | 0.8 |

Table 4: Parameters of various attributes

| S.No. | Attributes       | Initial year | After two years |
|-------|------------------|--------------|-----------------|
|       |                  | m_s | n_s | x_s (m) | m_s | n_s | x_s (m) |
| 30    |                  | 0.8  | 0.456 | 0.9  | 0.427 |
| 50    |                  | 0.6  | 0.528 | 0.8  | 0.456 |
| 5      | Turbidity (NTU)  | 0.761 | 11    | 0.742 |
| 10    |                  | 0.800 | 9     | 0.780 |
| 20    |                  | 0.844 | 8     | 0.800 |
| 25    |                  | 0.867 | 7     | 0.822 |
| 30    |                  | 0.844 | 7     | 0.822 |
| 50    |                  | 0.891 | 6     | 0.844 |
| 4      | pH               | 0.521 | 9.2   | 0.442 |
| 10    |                  | 0.642 | 8.8   | 0.550 |
| 20    |                  | 0.740 | 8.6   | 0.610 |
| 25    |                  | 0.804 | 8.3   | 0.707 |
| 30    |                  | 0.836 | 8.1   | 0.772 |
| 50    |                  | 0.943 | 7.9   | 0.836 |
| 5      | Total Solids (mg/l) | 0.198 | 978   | 0.172 |
| 10    |                  | 0.208 | 910   | 0.186 |
| 20    |                  | 0.220 | 885   | 0.191 |
| 25    |                  | 0.234 | 793   | 0.215 |
| 30    |                  | 0.244 | 786   | 0.217 |
| 50    |                  | 0.246 | 765   | 0.224 |
Table 5: Variation of aggregate indices with distance from landfill site

| S.No. | $x$ (m) | Aggregate Index, $I$ |
|-------|---------|---------------------|
|       |         | Initial year | After two years |
| 1.    | 5       | 0.110       | 0.102           |
| 2.    | 10      | 0.150       | 0.136           |
| 3.    | 20      | 0.189       | 0.164           |
| 4.    | 25      | 0.204       | 0.186           |
| 5.    | 30      | 0.226       | 0.202           |
| 6.    | 50      | 0.234       | 0.210           |

where $x_{a}$, $m_{a}$ and $n_{a} = \text{parameters. The parameters of Eq. (7) were evaluated by using a similar procedure that was used for finding out parameters occurring in Eq. (3). Thus, the following equations of the variation of aggregate index with distance $x$ are obtained:}

Initial year: $I = \left( \frac{51.04}{x} \right)^{0.318} + 1^{1.953}$ \hspace{1cm} (8)

After 2 years: $I = \left( \frac{56.26}{x} \right)^{0.288} + 1^{-2.062}$ \hspace{1cm} (9)

Eqs. (8) and (9) are depicted in Fig. 3 along with the data points given in Table 5. It can be seen that there is a good agreement between the equations and respective their data points.
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Figure 2(a): Variation of subindex for Ammonical Nitrogen

Figure 2(b): Variation of subindex for Phosphate
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Figure 2(c): Variation of subindex for Turbidity

Figure 2(d): Variation of subindex for pH
Figure 2(e): Variation of subindex for Total Solids

Figure 3: Variation of Aggregate Index

4. Conclusions

From the foregoing development, the following conclusions are drawn:
1. The leachate generated from the dumping site affects the groundwater quality in the adjacent areas through percolation in the subsoil.
2. As the aggregate index is an increasing function of the distance from the landfill site, the groundwater quality improves as one move away from the landfill site.
3. Aggregate index decreases with increase in time. Thus, water quality goes down with time. It may be due to the reason that with the passage of time the solid waste material gets degraded and the waste constituents percolate down along with rainwater thereby polluting groundwater.

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