GROUNDWATER VULNERABILITY ASSESSMENT USING THE DRASTIC MODEL AT BHALSWA LANDFILL, DELHI

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Abstract - *The Bhalswa landfill in North Delhi, operational since the early 1990s without an engineered base liner, is one of the largest and most heavily loaded municipal solid waste (MSW) dumpsites in the city. Continuous percolation of untreated leachate from the unlined waste mound threatens the underlying shallow Quaternary alluvial aquifer, on which a large surrounding population depends for domestic water use. This study applies the DRASTIC model, implemented in a Geographic Information System (GIS) environment, to delineate zones of groundwater vulnerability around the Bhalswa site by integrating seven hydrogeological parameters: depth to water table, net recharge, aquifer media, soil media, topography, impact of the vadose zone, and hydraulic conductivity. The resulting vulnerability zonation map was validated against field-measured groundwater and leachate quality data collected from ten groundwater and five leachate/surface sampling stations, analysed for electrical conductivity, total dissolved solids, pH, chlorides, nitrate, phosphate, sulphate, hardness, and alkalinity, and benchmarked against Bureau of Indian Standards (BIS) drinking-water limits. Point-wise comparison at eight cross-validation stations showed complete agreement between the DRASTIC-predicted vulnerability class and the observed contamination status, with high-vulnerability zones coinciding with elevated TDS, chloride, and conductivity values. The study also evaluates ongoing bio-mining and zero-dumping remediation interventions at the site and argues that, given three decades of unlined infiltration, groundwater recovery will lag behind visible surface remediation. The validated DRASTIC map is proposed as a monitoring and remediation-prioritisation tool for the site.*

Key Words: Landfill, Bhalswa, DRASTIC model, Groundwater vulnerability, Leachate, GIS, Solid Waste Management, Delhi

1. INTRODUCTION

The management of municipal solid waste (MSW) is among the most pressing environmental challenges facing rapidly urbanising Indian cities, and Delhi is no exception. Rising population and inadequate waste-processing infrastructure have led to continued reliance on open dumping, of which the uncontrolled migration of landfill leachate into the subsurface is one of the most serious and least visible consequences.

The Bhalswa landfill, located in North Delhi, is one of the oldest and most heavily loaded dumpsites in the city. Operational since the early 1990s and originally intended as an engineered disposal site, it has grown over three decades into an unlined, overburdened waste mound standing at an approximate height of 50 m and receiving an estimated 2,000-2,500 tonnes of mixed waste per day. The absence of a bottom liner and a functional leachate collection system have allowed leachate to percolate largely unchecked into the underlying shallow Quaternary alluvial aquifer that supplies groundwater to the surrounding settlements of Bhalswa Dairy, Jahangir Puri, Mukundpur and Burari, home to an estimated 6-8 lakh residents, many of whom depend on shallow groundwater for domestic use.
Groundwater vulnerability to contamination from such sources depends on the interplay of several hydrogeological factors [12]. The DRASTIC model, developed by the United States Environmental Protection Agency [1], provides a structured, index-based framework that combines seven such parameters into a single Groundwater Vulnerability Index (GVI), identifying zones of relatively higher and lower susceptibility to contamination.

1.1 Objectives

The specific objectives of this study are: (a) groundwater vulnerability assessment around the Bhalswa landfill using the DRASTIC model within a GIS environment; (b) field-based validation of the DRASTIC vulnerability index against measured groundwater and leachate quality; and (c) assessment of ongoing remediation interventions at the site and their hydrogeological implications.

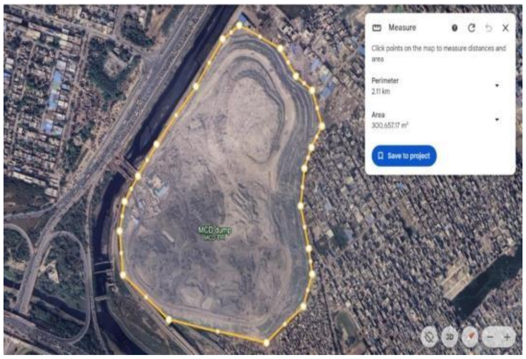

Fig -1: Bhalswa landfill site, North Delhi (imagery: Google Earth Pro)

2. LITERATURE REVIEW

Srivastava and Ramanathan [2] carried out an early geochemical assessment of groundwater near Bhalswa, identifying a Na-Cl hydrochemical facies indicative of anthropogenic pollution rather than natural evolution. Kumar and Alappat [3] subsequently recorded chloride concentrations of about 4,000 mg/l in leachate and confirmed a radial, plume-dispersion pattern of contamination around the landfill. Ahamad et al. [4] computed a Leachate Pollution Index (LPI) of 31.51 (pre-monsoon) and 29.36 (post-monsoon) for Bhalswa, both classed as critically high, and reported Target Hazard Quotient values indicating serious health risk to nearby residents.

Angmo and Shah [5] compared Delhi's three major dumpsites and found Bhalswa produced the most severe leachate contamination, with electrical conductivity reaching about 14,892 µS/cm. Mehra et al. [6] applied a sensitivity-tested DRASTIC assessment across the National Capital Territory and found the eastern border of Delhi - the zone including Bhalswa - to carry the highest vulnerability, with net recharge, depth to water table and vadose-zone impact as the most influential parameters. Singh et al. [7] reported a site-specific DRASTIC index of 136 for Bhalswa, classified as very high vulnerability, with the landfill boundary more vulnerable than its interior. Barbulescu's review [8] situates Bhalswa within the DRASTICA framework as an open dumpsite scoring 8/9 on contamination potential, and supplies standard vulnerability thresholds (low: 140-159; moderate: 160-179; high: 180-199; very high: ≥200) used for classification in comparable studies. Collectively, these studies establish that Bhalswa's contamination is anthropogenic, persistent and spatially heterogeneous, but - with the partial exception of [6] and [7] - stop short of a validated, field-checked spatial vulnerability product specific to the site's present hydrogeological and remediation context, which is the gap addressed here.

3. METHODOLOGY

The methodology comprised two complementary stages: development of the DRASTIC vulnerability model within a GIS environment, and field-based validation of the model output against measured groundwater and leachate quality.

3.1 DRASTIC Model Development

Spatial and hydrogeological data were compiled from the Central Ground Water Board [10] (water level and aquifer characteristics), the Bhuvan (NRSC/ISRO) geospatial portal (land use, soil, terrain), India-WRIS (hydrology and recharge), SRTM digital elevation data (slope), NBSS&LUP soil maps, and Geological Survey of India reports (aquifer/vadose-zone lithology). All datasets were imported into QGIS and re-projected to UTM Zone 43N (EPSG:32643).

Each of the seven DRASTIC parameters - Depth to water table (D), net Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of the vadose zone (I), and hydraulic Conductivity (C) - was converted into a continuous raster surface at 30 m resolution and reclassified on the standard 1-10 DRASTIC rating scale, with fixed weights (1-5) assigned per the original DRASTIC framework [1]. The composite Groundwater Vulnerability Index (GVI) was then computed for every raster cell using the standard weighted overlay equation:

$$GVI = (D_r \times D_w) + (R_r \times R_w) + (A_r \times A_w) + (S_r \times S_w) + (T_r \times T_w) + (I_r \times I_w) + (C_r \times C_w)$$

where subscripts r and w denote the rating and weight of each parameter. The raster calculation was performed using the Raster Calculator tool in QGIS, and the resulting GVI raster was classified into discrete vulnerability categories (Very Low to Very High) and rendered as a colour-coded vulnerability zonation map (Fig-2).

3.2 Field-Based Validation

A reconnaissance site visit was conducted to observe leachate seepage, surface drainage and the accessibility of groundwater abstraction points. Sampling locations were selected using a combination of field observation and QGIS-based slope/elevation analysis, prioritising lower-lying and steeper-gradient zones more prone to leachate accumulation and flow. A total of ten groundwater samples (GW1-GW10) and five leachate/surface samples (SW/Leachate 1-5) were collected around the landfill.

Samples were analysed for pH, electrical conductivity (EC), total dissolved solids (TDS), chloride, nitrate, phosphate, sulphate, total hardness, calcium, magnesium and alkalinity, using the methods summarised in Table-1, and benchmarked against BIS IS 10500:2012 drinking-water limits [9]. To test the reliability of the vulnerability map, theexperimentally observed contamination status (High/Low) at eight cross-verification stations was compared against the vulnerability class ('Dark' = high, 'Light' = low) assigned by the model at the corresponding location.

Table -1: Analytical methods and equipment used

Parameter	Method	Equipment
pH, EC, TDS, Salinity	Electrometric	Multi electrode water quality meter
Sulphate, Nitrate, Phosphate	UV Spectrophotometry	UV Spectrophotometer
Chloride	Argentometric (Mohr's method)	Manual titration setup
Hardness, Calcium, Magnesium	EDTA titration	Manual titration setup
Alkalinity	Acid-base titration	Manual titration setup

4. RESULTS AND DISCUSSION

4.1 Groundwater Quality

Groundwater EC around Bhalswa ranged from 279 µS/cm (GW10) to 3,729 µS/cm (GW4), with GW3, GW4, GW1 and GW7 exceeding the BIS limit of 750 µS/cm by up to five-fold. TDS ranged from 139 to 1,581 mg/l against a BIS limit of 500 mg/l, with GW1, GW3, GW4, GW7 and GW8 in exceedance. Chloride exceeded or approached the 250 mg/l BIS limit at GW1, GW2, GW4, GW7 and GW8. Nitrate ranged up to 69.0 mg/l (GW8), exceeding the 45 mg/l safe limit at one station, while phosphate exceeded the 1 mg/l guideline at eight of ten stations, most markedly at GW7 (6.31 mg/l) and GW4 (5.2 mg/l). Total hardness, calcium and magnesium were elevated at nearly every station relative to BIS limits (200, 75 and 30 mg/l respectively), with GW1, GW2 and GW7 recording the highest mineral loads. pH remained slightly to moderately alkaline (7.19-8.8), within the BIS envelope. Sulphate stayed within the 200 mg/l limit at all stations. The spatial pattern is consistent: stations closer to the landfill core (GW1, GW3, GW4, GW7) are consistently the most degraded, while stations farther away (GW9, GW10) remain comparatively acceptable.

4.2 Leachate Quality

Leachate EC ranged from 4,599 to 67,999 µS/cm (mean ~37,558 µS/cm) and TDS from 2,339 to 33,911 mg/l (mean ~19,910 mg/l), both indicative of an advanced state of waste decomposition typical of an aging, unengineered site. Leachate pH was slightly acidic (5.01-5.7, mean 5.3), a condition known to increase heavy-metal mobility. Chloride (mean ~3,548 mg/l), phosphate (mean ~1,856 mg/l) and especially nitrate (mean ~20,189 mg/l) were extremely high, reflecting intense nitrogen and organic-matter breakdown within the waste mass. Total hardness averaged 2,360 mg/l as $CaCO_3$, with calcium and magnesium contributing 1,566 and 795 mg/l respectively, while alkalinity averaged 660 mg/l as $CaCO_3$, providing substantial buffering capacity despite the acidic pH.

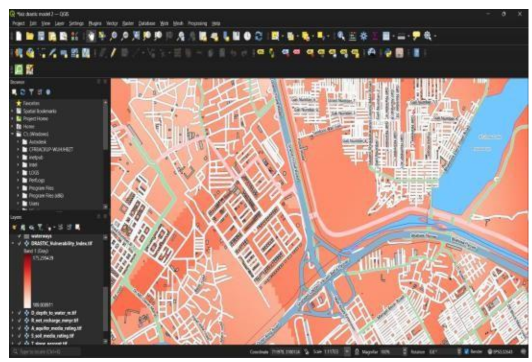

Fig -2: DRASTIC groundwater vulnerability index raster around the Bhalswa landfill (QGIS output; darker shading indicates higher vulnerability)

4.3 Validation of the DRASTIC Vulnerability Map

Table-2 summarises the point-wise comparison between experimentally observed contamination status and the DRASTIC-predicted vulnerability class at eight monitoring stations. All eight stations showed agreement between the two, a 100% validation success rate for the sample set considered. Stations GW1, GW7, SW4 and SW5, located within 'Dark' (high-vulnerability) zones, recorded experimentally high contamination indicators, consistent with shallow depth to water table and high permeability at these locations; stations GW9, GW10, SW1 and SW2, within 'Light' (low-vulnerability) zones, recorded experimentally low contamination levels.

Table -2: Point-wise validation of the DRASTIC vulnerability map

Sample	Experimental Status	DRASTIC Zone	Agreement
GW1	High	Dark(High Vulnerability)	Validated
GW7	High	Dark (High Vulnerability)	Validated
GW9	Low	Light (Low Vulnerability)	Validated
GW10	Low	Light (Low Vulnerability)	Validated
SW5	High	Dark (High Vulnerability)	Validated
SW4	High	Dark (High Vulnerability)	Validated
SW1	Low	Light (Low Vulnerability)	Validated
SW2	Low	Light (Low Vulnerability)	Validated

This agreement, while based on a limited number of monitoring points (n = 8) from a single sampling campaign, indicates that the relative weightings and ratings assigned to the seven DRASTIC parameters have meaningfully captured the dominant controls on contaminant migrationfrom the landfill into the shallow aquifer, rather than reproducing an arbitrary spatial pattern. A larger, temporally repeated dataset would further strengthen statistical confidence, and is recommended for future work.

4.4 Remediation Interventions and Hydrogeological Implications

The site is presently undergoing active remediation through mechanical bio-mining (trommel screening) and a zero-dumping reuse model under which recovered refuse-derived fuel, construction and demolition inerts, and fine soil are diverted to cement kilns, paver-block units and eco-park development respectively, rather than being re-deposited on site. A new 1,800 TPD integrated fresh-waste processing facility is under construction to divert incoming waste away from the legacy mound [11]. These measures represent genuine long-term source control. However, excavation disturbs previously settled waste and dust-suppression watering adds infiltration at exposed surfaces, both of which can transiently increase leachate mobilisation even as the total waste mass declines. Critically, no base liner or leachate-collection system has been retrofitted beneath the historically dumped waste, so three decades of unlined infiltration are likely to leave a residual contamination legacy in the vadose zone and shallow aquifer for years after the mound itself is cleared. The DRASTIC index computed in this study is therefore best read as a present-day baseline against which the lagged hydrogeological effect of remediation can be tracked, rather than a value expected to fall immediately in step with visible surface progress.

5. CONCLUSIONS

This study applied the DRASTIC model within a GIS environment to assess groundwater vulnerability around the unlined Bhalswa landfill and validated the resulting zonation map against field-measured groundwater and leachate quality. Several groundwater stations, particularly those nearest the landfill core, exceeded BIS drinking-water limits for EC, TDS, chloride, phosphate, hardness and, at one location, nitrate, while leachate samples showed very high ionic and nutrient loads consistent with an aging, unengineered dumpsite. Point-wise comparison at eight monitoring stations showed complete agreement between DRASTIC-predicted vulnerability class and observed contamination status, lending strong empirical credibility to the map as a decision-support tool. Ongoing bio-mining and zero-dumping interventions constitute meaningful source control, but the absence of a retrofitted base liner means groundwater recovery will lag behind visible surface remediation. The validated DRASTIC map developed here can support regulatory authorities in prioritising groundwater monitoring locations and remediation resources around the Bhalswa site, and provides a baseline against which post-remediation vulnerability can be re-assessed.

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