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Review Article

A Review of Groundwater Pollution Potential Threats from Municipal Solid Waste Landfill Sites: Assessing the Impact on Human Health

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Abstract

An attempt has been made in this paper to review various studies associated with groundwater contamination near landfill sites, basically caused by non-engineered landfills or open dumps in India and overseas, and its impact on human health. Landfill leachate contains different kinds of municipal toxic wastes as well as heavy metal, which finally percolates into the ground and joins the groundwater table. Consuming such water results in severe health hazards and may sometimes be fatal if consumed for long periods. Several studies have shown evidence on the high concentration of heavy metals in leachate as well as in nearby groundwater sources. Moreover, various studies have confirmed the fact that there is an increased threat of adverse health effects (low birth weight, birth defects, and certain types of cancers), congenital malformations in children, and higher risks for malformations of the nervous and musculoskeletal systems for skin, hair, and nails in local residents. Pregnant women and children are more vulnerable to these pollutants, and newborn children are more prone to the health risk. These findings may signify the real health risks associated with residents residing near landfill sites.

Keywords: Municipal Solid Waste, Landfill Leachate, Groundwater Pollution, Health Impacts, India

1. Introduction

With the rapid industrial and economic development coupled with liberalization, globalization and ever increasing population of the world, billions of tons of municipal solid waste is generated every day worldwide (1). In India, the quantity of municipal solid waste (MSW) is expected to increase significantly in the years to come as India strives to attain an industrialized nation status by the year 2020 (2, 3). In most of the developing countries, particularly in high population density areas, high production of solid waste and scarcity of adequate land for landfills sites have caused the major problem of MSW disposal (4). Landfills are the most preferable way to dispose MSW without any necessary precautions.

Disposal of waste and pollution are indistinguishably linked. The open dumping of waste gives rise to many environmental risks such as water pollution, land pollution, air pollution, and health hazard. Ground water contamination from the leachate generated from the landfill site is an important health concern for many researchers and professionals around the world. Leachate is any liquid that percolates through the solid waste, extracts solutes, suspended solids, or any other toxic component of the material through which it has passed. The frequently reported threat to the human health is due to the use of groundwater that has been contaminated by leachate (5). The leachate problem is getting worse by the fact that many landfills are devoid of an appropriate bottom liner and adequate leachate collection system. This increases the possibility of percolation of leachate through the landfill layers to contaminate ground water of the surrounding areas (6). Landfill leachate causes severe health and environmental impacts represented by toxicity, groundwater, and surface water contamination (7), which entails the necessity for its treatment before its ultimate disposal.

2. Solid Waste Generation Trend in Indian Metro Cities

Developing countries such as India, where economic growth and urbanization has become more rapid, are faced with the severe problem of solid waste. As per the report of Ministry of Environment in Japan in 2006, the amount of wastes generated in the year 2000 was about 12.7 billion tons, which is estimated to increase to approximately 19 billion tons worldwide by 2025 and to approximately 27 billion tons by 2050. Moreover, in India the MSW generation was about 0.46 kg/person/day in the year 1995, which was estimated to grow to 0.70 kg/person/day by 2025 (8). The per day MSW generation rate for the 7 most important metros are presented in Table 1 (9, 10). National Capital Territory of Delhi currently generates 7000 to 8,000 tons/day of solid waste, which is expected to increase up to 17,000 to 25,000 tons/day by the year 2021 (11).

Table 1. Municipal Solid Waste Generation in Metro Cities (India) (12)

Name of City	Municipal Solid Waste, Tons per Day		
	1999 - 2000[a]	2004 - 2005[b]	2010 - 11[c]
Ahmedabad	1683	1302	2300
Bangalore	2000	1669	3700
Mumbai	5355	5320	6500
Kolkata	3692	2653	3670
Delhi	4000	5922	6800
Lucknow	1010	475	1200
Chennai	3124	3036	4500

[a] EPTRI (environment protection training research institute, 1999 - 2000).
[b] NEERI-Nagpur (national environmental engineering research institute, 2004 - 2005).
[c] CIPET (Central Institute of Plastic Engineering and Technology, 2010 - 11).

Today, Indian cities generate 8 times more MSW than they did in 1947. The annual per capita generation of municipal solid waste is estimated to rise at the rate of 1% to 1.33% (13, 14). Therefore, the data on generation and quantity deviation are useful in planning for suitable solid waste management systems. In India, many researchers (15-18) have reported that the MSW generation rates are lower in small towns than in megacities.

3. Composition and Characteristics of Indian Municipal Solid Waste

MSW differs significantly with respect to the composition, characteristics, and hazardous nature in India (19, 20). The composition and characteristics of MSW is significantly influenced by various factors such as living standards, food habits, rituals, literacy rate, culture, economic development, and topographical conditions (21).

Various studies have revealed that authorities of small towns pay more attention to this problem and act more responsibly about MSW generation rate (15, 16, 20). In India, MSW usually contains approximately 40% to 60% compostable waste, 30% to 50% inert waste, and 10% to 30% recyclable waste. According to NEERI, the Indian MSW mainly consists of 0.64 $\pm$ 0.8) % of nitrogen content, (0.67 $\pm$ 0.15) % phosphorus, (0.68 $\pm$ 0.15) % potassium, and C/N ration (26 $\pm$ 5) %. Table 2 displays the composition of MSW generated by some selected states in India, which may change over time.

In India, characteristics of waste in composition and hazardous nature show huge variation compared to the West part of the world (18, 19). Table 3 demonstrates that Mumbai has the highest percentage of organic waste (62%). Moreover, moisture content ranges from 41% to 64 %, which is high, except Ahmadabad. The calorific value CV is very low and ranges between 742 and 2632 kcal/kg, and the C/N ratio ranges between 18 and 37.

4. Heavy Metals in Leachates and Ground Water Pollution

In developing countries, the landfills are generally built without engineered liners, leachate collection systems, collection equipment, or landfill gas monitoring facility. Inefficient solid waste management system and improper dumping of MSW employed for an open landfill are the main reasons behind ground water and surface water contamination at various places of Delhi (24). Groundwater in landfill adjacent area is more prone to contamination in view of the fact that the potential pollution source of leachate originates from the nearby landfill site. There are number of studies on the negative impact of landfill leachate on the surface and groundwater as well (25-27).

Leachate contains dissolved or suspended material, which is associated with landfill wastes as well as many byproducts of chemical and biological reactions (28). The rate and characteristics of leachate 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. Different types of wastes are liable for the heavy metal occurrence in the landfills. Metals are often precipitated within the landfill and are sometimes found at high concentrations in leachate. Heavy metals are one of the most hazardous components in generated leachate. A number of cases of ground water pollution through continuous percolation of leachate have been recorded across the world(29) (Table 4).

Table 4 displays that the concentration of chromium (Cr) have exceeded the discharge standards [the environment (protection) rules, 1986] 2.80 mg/L in landfill leachate of Oman (30), 0.519 - 1.999 mg/L in landfill leachate of Bangladesh (31), and 1.47 - 10.43 mg/L in leachate of Kolkata (32). It may be attributed to the disposal of cement (contains chromium), asbestos lining erosion that contain chromium, topsoil and rocks, effluents from chemical plants, and paints/pigments (insoluble Cr [VI]). In 2016, Mishra et al. found high concentrations of copper (Cu) (1.42 - 6.03 mg/L) at the landfill site of Mumbai, which may be due to the electronic waste disposal and mineral leaching (33). In 2013, Abu-Daabes et al. studied 3 landfill sites of Jordan and found high concentrations of Cr (0 - 5.0 mg/L), manganese (Mn) (10.56 - 38.17 mg/L), and cadmium (Cd) (0 - 0.042 mg/L) in leachate samples (34). They exceeded the standards for the maximum allowable discharge limit of industrial wastewater JIEC (Jordan inter-

Table 2. Change in Composition of Municipal Solid Waste With Time (in %)[a]

Year	Biodegradables	Paper	Plastic/Rubber	Metal	Glass	Rags	Others	Inert
1996	42.21	3.63	0.60	0.49	0.60	-[b]	-	45.13
2005	47.43	8.13	9.22	0.50	1.01	4.49	4.02	25.16
2011	42.51	9.63	10.11	0.63	0.96	-	-	17.00

[a]Source: planning commission report 2014 (22).
[b]Not available.

Table 3. Composition and Characteristics of Indian Municipal Waste[a]

City	Organic, %	Recyclables, %	Others, %	Moisture Content, %	C/N Ratio	CV, Kcal/kg
Ahmadabad	41	12	47	32	30	1,180
Bengalu	52	22	26	55	35	2,386
Bhopal	52	22	26	43	22	1,421
Bhubane	50	13	37	59	21	742
Chandigarh	57	11	32	64	21	1,408
Chennai	41	16	43	47	29	2,594
Delhi	54	16	30	49	35	1,802
Guwhati	54	23	23	61	18	1,519
Indore	49	13	38	31	29	1,437
Kanpur	48	12	40	46	28	1,571
Kolkata	51	11	38	46	32	1,201
Lucknow	47	16	37	60	21	1,557
Mumbai	62	17	21	54	39	1,786
Nagpur	47	16	37	41	26	2,632
Punducherry	50	24	26	54	37	1,846

[a]Source: status report on municipal solid waste management, CPCB 2004 - 2005 (23).

national energy conference,) and EPA (environmental protection agency) limits, Cr (JIEC limit 0.1 mg/L, EPA limit 0.05 mg/L) Mn (JIEC limit 0.2 mg/L), and Cd (JIEC and EPA limit 0.01 mg/L). The unregulated disposal of old batteries is the main source of Mn and Nickel (Ni) in municipal solid waste. In 2016, Maiti et al. found large amounts of heavy metals like lead (Pb) (0.56 ± 0.33 mg/L) and mercury (Hg) (0.42 ± 0.44mg/L) (beyond the specified standards set by Municipal Solid Wastes Management and Handling Rules of 2000" in the leachates in Kolkata (32). High concentration of Pb may be due to the municipal solid waste containing refused lead batteries, lead based paint products, metallic items etc. (37, 38). Mercury can be found in a variety of products such as fluorescent and other lights, batteries, electrical switches and relays, barometers, and thermometers, which have been dumped into municipal landfills. Most of the researchers investigated the landfill leachate and found significant variation of Fe concentration in leachate (minimum 0.426 mg/L to maximum 70.62 mg/L), which exceeds the standard discharge limit (3 mg/L) of the environment (protection) rules, 1986 (39-42). This may be a sign of disposal of iron and steel scraps in the landfill at a large scale (38). This is the reason behind brown dark color of the leachate, which is a product of oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with humic acid (6). A variety of waste has been dumped at the landfill site, which was possibly the reason behind the origin of Zn, Pb, Cr, Cu, and Ni in leachate (40, 43). In 1994, Christensen et al. also reported the presence of these compounds in leachate (27).

5. Health Impacts

There is direct and indirect association between health impacts and handling, treatment, and disposal methods of waste (44). Shaoli et al. in Kolkata found the evidence of different health issues such as common cough and cold, frequent diarrhoea, and infections (both skin and respiratory); moreover, parasitic infections such as malaria and dengue have frequently occurred among local residents near the landfill as they used groundwater for domestic purposes (44). In 1990, Wrensch et al. investigated and verified that contaminated well near San Jose, California, disposal site has an adverse effect on spontaneous abortions, birth defects, and children heath concerns such as leukemia (45, 46). In 2002, Jarup et al. found cancer risk, leukemia in children as well as in adults who were living around 2 km from landfill sites in Great Britain (47). Brain and bladder cancer and hepatobiliary cancer were reported. Different types of cancer and birth problems were also reported in local residents of European landfills by Vrijheid (2000) and Goldberg et al. (1995) (48-50). Various reports showed 2 clusters of lung cancer in the Southern part of Caserta province and in the Northern part of Naples province (51-54). Paigen and Goldman et al. (1985)

Table 4. Summary of the Selected Previous Studies, Showing Heavy Metal Concentration in Various Landfill Leachates Across the World

Studies No.	Heavy Metal Concentrations, mg/L											Reference
	Cr	Cu	Mn	Zn	Ni	Fe	Co	Al	Pb	As	Cd	
1	2.800	0.185	0.503	0.943	0.773	39.25	0.128	2.050	0.130	-	0.00 - 10.022	(30)
2	0.519 - 1.999	0.13 - 0.65	0.27 - 2.12	0.31 - 2.5	-	4.61 - 7.25	-	-	0.013 - 0.027	0.073 - 0.090	0.05 - 0.09	(31)
3	1.47 - 10.43	-	-	-	-	4.320 - 11.250	0.140 - 0.380	-	0.56	-	0.018 - 0.030	(32)
4	0-1.33	1.42 - 6.03	0.49 - 2.54	0 - 13.08	0.13 - 0.52	-	0 - 0.55	-	-	-	-	(33)
5	0 - 5.0	0 - 1.597	10.56 - 38.17	-	0.105 - 1.847	-	-	-	-	-	0 - 0.042	(34)
6	0.060	0.200	-	0.264	0.070	-	-	-	0.110	-	0.001	(35)
7	0.021	0.151	-	3	1.339	11.16	-	-	0.3	-	0.035	(36)
8	0.29	0.93	-	2.21	0.41	70.62	-	-	1.54	-	0.06	(37)
9	0.029 - 0.094	-	0.260 - 1.39	0.342- 0.974	0.037 -0.167	0.426 -11.49	0.016 -0.172	-	0.008 -0.025	-	0.002 - 0.261	(38)
10	0.14 - 0.28	0.71 - 0.89	-	1.29 - 2.10	0.31 - 0.38	58.40 - 63.41	-	-	1.10- 1.31	-	0.02 - 0.05	(39)

studied low birth weight, prematurity, and birth defects in children living near hazardous waste sites (54). Similar results have also been documented by Vianna and Polan in 1984 (55). Low birth weight and preterm births among infants born to women living near a municipal solid waste landfill site were reported. According to the 2012 study report of Bhalaswa Lok Shakti Manch and Hazards Center of New Delhi, there was an increased concentration of contaminants in groundwater near the Bhalaswa landfill (56). The local residents suffered from a number of illnesses, especially gastro-intestinal diseases, musculoskeletal pain, skin and eye irritation, and respiratory problems. Of the sample population in Bhalaswa resettlement colony, 21.1% of women and 31.9% of men suffered from diarrhoea and vomiting. This could indicate occurrence of faecal contamination of the drinking water. On the other hand, 62.6% of people suffered from gas and ache problems. The percentage of people was also found to be significant; 20% of men and 18.2% of women in Bhalaswa resettlement colony had skin problems such as itching and skin rash. This may be due to regular contact with the polluted groundwater for the domestic use such as bathing, washing utensils, and clothes.

Air pollution from unscientific disposal sites of landfill creates major health risk to nearby residents (57). Continuous inhalation of particulate matters including dust, fumes, mist, and smoke is the main reason behind lung damage and respiratory problems (58). The dust released from different sources can raise a variety of diseases from a simple cold to deadly diseases like cancer (59). The high amount of RSPM (respirable suspended particulate matter) are found in either polluted or moderately polluted category (60). The higher concentration of particulate matter causes acute and chronic respiratory disorders and lung damage in humans (61). Population residing in the vicinity of polluted regions by high suspended particulate matter (SPM) was reported to have a higher risk of cardiovascular diseases (62). Children who lived near dangerous waste sites showed poor growth as suggested by Kramer (1987) and Paigen et al. (1987). Moreover, Elliott et al. (2001) documented that those exposed to SPM are at more risks of inborn irregularities (62-64). Kharrazi et al. (1997) had reported that in California the population who lived near large harmful waste landfills showed adverse effects on pregnancy outcome (65).

Increased incidence of many health problems like eye irritation, skin rashes, learning problems, abdominal pain, hypersensitivity, incontinence, and seizures are found in those children who lived close to landfill sites as compared to controls, according to their parents, as reported by Clark in 1982 (65). The odour released from landfill sites may be the reason for many health problems such as irritation of skin, nose and eyes, allergies, psychological disorders, headache, fatigue, nausea, and gastrointestinal problems (66-68). Environmental pollution of waste dumping shows short- and long-term effects on health (69, 70). Respiratory infection, asthma, and congenital anomalies are the short-term health effects (71). In 2012, Kah et al. have also documented its other symptoms like eye and respiratory irritation, headache, stress, anxiety, dizziness, and nausea (72). Vrijheid (2000) and Minichilli et al. (2005) reported health problems including cancer, brain, liver, chronic respiratory, and cardiovascular and nerves disorder due to long-term waste exposure (44, 73).

The report of Bhalaswa Lok Shakti Manch and hazards center of New Delhi in 2012 indicated that landfill leachate can have volatile organic chemicals such as benzene, chloroform, ethylbenzene, toluene etc., which can cause eyes and skin irritation (56). Pigmentation, dry skin, ringworm infection, skin allergy, and rash were also observed. Bathing and other contact of eyes with contaminated water can lead to eye problems such as pink eyes etc. Additionally, gases that are released from landfills such as ammonia, acrylonitrile, carbonyl sulphide, methyl ethyl ketone etc. have negative impacts on eyes and cause problems such as burning sensation, watering, and eye irritation. In Bhalaswa resettlement colony, 22.2% of men and 19.4% of women had persistent burning sensation in their eyes. Other observed problems were itching, redness of the eyes, allergies, eye infections, and problems such as weak eyesight and pain in the eyes. Gases that are released from landfills are carbon monoxide, chloroform, tetrachloroethylene, etc. and they cause neurological effects including headaches, dizziness, and fatigue.

6. Conclusions

Uncontrolled disposal of municipal solid waste has affected the environment in several ways. The major environmental problem due to landfill is the generation of leachate from landfill sites. It impacts the ground water aquifers, as most of the landfill sites are not equipped with appropriate bottom liner or leachate collection system scientifically. The leachate problem is also worsened day by day due to enormous generation of municipal solid waste and its immense divergence of characteristic and composition with economic progress of the society. There is also a growing concern regarding the upsurge of heavy metals in ground water, which can cause severe health disorders and environmental impacts represented by toxicity and groundwater contamination.

Several studies conducted on this subject indicate the potential adverse health effects of landfills. Mainly, researchers have focused on the health of the general population, particularly those living near waste disposal sites. The presence of heavy metals such as Cd, As, Cr, and Ni has been considered to be carcinogenic and has caused an increasing concern. In addition to carcinogenicity, many of these substances can produce other toxic health effects (depending on exposure level and duration) on the central nervous system, liver, kidneys, heart, lungs, skin, and reproduction.

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