Chapter 15
Characterization of Leachate and Groundwater in and Around Saduperi Municipal Solid Waste Open Dump Site, Vellore District, Tamil Nadu, India

N. Manoj Kumar and M. Chaithanya Sudha

Abstract In India, a large portion of the landfill is open or unlined. The administration of municipal solid waste (MSW) requires proper infrastructure, upkeep in all actions. This turns out to be extremely costly and complex due to the unconstrained improvement of urban dominion. The landfill has been concerned with air contamination, soil contamination, surface and groundwater contamination. The origin of landfill gases is subjective to various factors such as the composition of solid waste product, decomposition of waste, oxygen availability, moisture and rain percolation, pH, organic amount and microorganism population. Dioxins are exceedingly dangerous and can cause reproductive and developmental problems. The waste put in the landfills influences the groundwater stream, and rainwater may permeate through the waste. The water gets mixed with organic and inorganic compounds and accumulated at the bottom of the landfill. The present study represents a real-time case study of a solid waste dump yard located at Saduperi, Vellore District, Tamil Nadu, India. Groundwater samples are collected in and around landfill site to analyse the possible impact of leachate on the quality of groundwater. Various physicochemical parameters and heavy metal concentration of groundwater and leachate sample are analysed and reported. Leachate analysis showed a neutral pH (7.4) and BOD concentration of 9100 mg/L. Total hardness and alkalinity were found to be 5500 and 10,000 mg/L, respectively. The chloride concentration was found to be higher (5317.5 mg/L). The concentration of heavy metals such as nickel, cadmium and chromium was found in concentrations of 0.05, 0.09 and 2.84 mg/L, respectively. Groundwater samples showed slightly acidic to

N. Manoj Kumar
Department of Civil Engineering, Builders Engineering College, Kangayam, Tamil Nadu, India

M. Chaithanya Sudha (✉)
CO_2 Research and Green Technologies Centre, VIT University, Vellore, Tamil Nadu, India
e-mail: mchaithanyasudha@gmail.com

S. J. Varjani et al. (eds.), *Waste Bioremediation*, Energy, Environment, and Sustainability, https://doi.org/10.1007/978-981-10-7413-4_15

neutral pH values with higher concentration in TDS (9690 mg/L) and chloride (2153 mg/L) parameters. Further leachate pollution index was calculated to know the potential of impact from the dump site leachate.

Keywords Municipal solid waste · Leachate · Groundwater contamination Water quality

1 Introduction

In the past decades, the collection, conveyance and disposal of municipal solid waste (MSW) have become a crucial issue especially in major cities all over the world. Due to rapid urbanization, almost half of the world's population was residing in cities and future projection shows that population may reach 5 billion by 2030 (Omar et al. 2012). The increase in population eventually increases the amount of waste generated in the major cities. In 2012, MSW generation in world cities is estimated to be 1.3 billion tonnes per annum, and it is expected to reach 2.2 billion tonnes per annum by 2025 (Hoornweg and Bhada-Tata 2012). The per capita MSW generation in developed countries and developing countries ranges from 522–759 and 109–526 kg per person per year (Karak et al. 2012). The MSW is usually collected from each home, academic institutions, offices and commercial complexes and is composed of organic materials (food waste, market waste, yard leaves, wood, etc.), plastic, glass, metals and other refuses (Albores et al. 2016). The quantity, composition and proportion of MSW vary from one part of the world to another. This variation in the composition depends on culture, location, climatic conditions, lifestyle, type of energy source and economic status. However, a study by Hoornweg and Bhada (Hoornweg and Bhada-Tata 2012) shows that in global scale, 46% consists of organic waste in MSW followed by paper (17%), plastic (10%), glass (5%) and metal (4%). In the same study, it is explained that OECD member countries have a low organic fraction of 27% when compared to East Asia and Pacific region countries which have a high organic fraction of 62%.

The cities are unable to manage increased MSW generation due to their lack of regulatory, financial, knowledge, institutional, and public participation. As a result of improper MSW management, degradation of the environment and human health effects occur. The major impacts could be contamination of soil, surface water, groundwater by heavy metals in the leachate (Xiaoli et al. 2007; Prechthai et al. 2008), toxic emissions while burning (McKay 2002), human health problems (Giusti 2009; Rovira et al. 2015) and methane emissions (Boeckx et al. 1996; Das et al. 2016). Hence by knowing these effects, there should be a proper MSW management for safe disposal of wastes. The management of waste involves the collection of waste, resource recovery and recycling, transportation and processing or disposal. Of these, the most important one is processing/disposal of waste (Reddy 2011). The common processing/disposal practices adopted in various countries are open burning, landfilling, composting, incineration and recycling or recovery from waste. Open burning and unsystematic landfilling are carried out widely in low-income and developing countries because they are very cheap–cum-rapid process. On the other hand, it will degrade the environment and affect human health, whereas, in developed countries systematic landfilling is carried out extensively. But for systematic landfilling, a vast land resource is required which is a major constraint in cities. In such places, incinerators are preferred which require less place and has the benefit of heat recovery and waste reduction by volume. If the MSW has high organic content, low calorific value and high moisture content (especially in low-income and developing countries) then incinerators will not be a suitable option. Those wastes which have high organic content are preferred for composting in which wastes are transformed into stabilized product. Only after the segregation of organic and inorganic wastes, the composting will become the alternative for the incinerator and landfill (Karak et al. 2012). Recycling and recovery of useful material from MSW at its source leads to waste reduction and recovery of valuable materials (Jha et al. 2011). A study by Lavee (2007) showed that reduction in direct cost up to 11% can be achieved when adopting recycling of MSW.

1.1 MSW Management in India

India is the second highest populated country (1.21 billion) in the world with annual urban population growth rate of 3.35%. In 2011 census, there are 7935 towns and it has increased by 2774 since 2001. The number of Class I towns were also increased from 394 to 468 which includes 53 million-plus cities. The Indian urban population has increased to 31.16% (377 million) in 2011 from 17.29% in 1951, and correspondingly rural population has come down to 68.84% in 2011 from 82.7% in 1951 (Census 2001 and 2011). The projection shows that by next 10 years nearly 50% of Indian population will reside in urban areas (Vij 2012). Activities associated with such population create solid waste in large quantity (Zhu et al. 2008). The solid waste includes solid or semi-solid domestic waste, agriculture, dairy waste, horticulture waste, commercial waste, sanitary waste, institutional waste, street sweepings, silt from the surface drains, catering and market waste and other non-residential wastes, treated biomedical waste (Solid Waste Management Rules 2016). In developing countries like India, the management of solid waste has become crucial since it is a major source of contamination of air, soil and water. The common activities involved in MSW management are waste generation, storage of waste in individual or community bins, waste collection, transport, processing and waste disposal. Generally, the waste generated in urban areas are of large quantities when compared to rural areas.

The wastes generated are collected separately as biodegradable and non-biodegradable waste. This segregation will help in the recovery of useful products for processing and eventually reduce the amount of waste to be handled. However, this segregation practice is not done properly by local authorities and individuals (Vij 2012). The collected wastes are stored in either movable or fixed bin. For transportation, movable bins are flexible while the fixed bins are time-consuming (Shekdar 2009). The stored wastes are transported to transfer station or taken directly to processing/disposal sites. The segregation step can also be carried out in the transfer station. In India, the waste management system rarely comprises the waste processing unit because of the cost involved in setting up of such units. Further, the unpredictable urban growth makes it more complex process. Without processing unit, the volume of waste to be dumped in landfills will be nearly equal to generated volume. In India, more than 90% of solid waste is disposed of unscientifically in landfills and open dump sites. Apart from landfilling, some of MSW disposal mechanisms such as composting, incineration, refuse-derived fuel and biomethanation are adopted (Sharholy et al. 2008; Kalyani and Pandey 2014).

To make the MSW management more effective in India, a revised and much-defined version of The Municipal Solid Wastes (Management & Handling) Rules, 2000, named Solid Waste Management Rules (SWMR) came into effect from April 2016. Some of the important highlights are discussed here. In SWMR, 2016, the jurisdiction is unfolded beyond municipal area to encompass outgrowths in agglomerated urban areas, notified industrial townships, census towns, areas under the control of Indian airports, railways, port and harbour, defence establishments, central and state government organizations, places of pilgrims, places of historical importance and special economic zones. The SWMR, 2016, gives priority in promoting waste to energy plant by (1) encouraging industries to use refuse-derived fuel, (2) non-recyclable combustible waste having calorific value of 1500 kcal/kg or more shall be utilized for generating energy through refuse-derived fuel, and (3) high calorific wastes shall be used for co-processing in cement or thermal power plants. The SWM Rules, 2016, mandate all local bodies for (1) setting up MSW processing facilities when the population is 1 lakh or more, (2) setting up common or stand-alone sanitary landfills and (3) carrying out bioremediation or capping of old and abandoned dump sites. It also provides specific criteria for site selection of sanitary landfills, setting up development facilities in landfill sites like MSW processing and its treatment facility, SWM in hilly areas, specifications for operation, closure of landfill and rehabilitation of old dump sites (Solid Waste Management Rules 2016).

1.2 MSW Generation in India

The Central Pollution Control Board estimated that 1, 41,064 tonnes of municipal solid waste was generated per day during 2014–2015. Of the total generated waste, 90% of wastes are collected by local bodies and only 34,752 tonnes of collected waste are treated. Maharashtra state generated highest MSW of 22,570 tonnes per day (TPD) followed by Uttar Pradesh (19,180 TPD) and Tamil Nadu (14,500 TPD) (Annual Status Report on Municipal Solid Waste Management 2014–2015). It is estimated that urban India will generate 2,76,342 TPD by 2021, 4,50,132 TPD by 2031 and 11,95,000 TPD of MSW by 2050 (Planning Commission's Report of the Task Force on Waste to Energy 2014). Another estimate shows that MSW generation will reach 300MT by 2047 and about 169.6 km^2 of land is required for disposal (Pappu et al. 2007; Management of Municipal Solid Waste 2010). The average per capita waste generation was found to be 0.11 kilograms per day (Mani and Singh 2016). The MSW composition at the source of generation and waste collection points was calculated on a wet weight basis, and it comprises 40–60% of organic fraction, 30–40% of ash and fine earth, 3–6% of paper and each less than 1% of plastic, glass and metals. The C/N ratio of MSW ranges from 20 to 30, and the calorific value ranges from 800 to 1000 kcal/kg (Sharholy et al. 2008; Gupta et al. 2015).

1.3 Environmental Issues of MSW

Almost all anthropogenic activities will have an impact on the environment and so MSW disposal. Even though proper waste management does reduce the magnitude of impact, it will not eliminate the impact totally. The assessment of the environmental impacts is important to protect environmental settings (Chandrappa and Das 2012). Groundwater is a substantial and invaluable resource for human beings. Groundwater contamination is accelerated after the establishment of industrial development and urbanization (Maiti et al. 2016). MSW unlined and lined landfills are considered to be primary sources of groundwater pollution due to the leachate migration from waste (Reyes-López et al. 2008; Sizirici and Tansel 2015). In India, most of the landfills do not have a barrier or leachate collection system to restrict the migration of leachate into groundwater (Naveen et al. 2016). Leachate is a complex mixture of pollutants having high biochemical oxygen demand, chemical oxygen demand, suspended particles, ammonium nitrogen and toxic characteristics (Kurakalva et al. 2016; Han et al. 2016; Fatta et al. 1999; Regadio et al. 2012). The leachate composition depends upon the nature of MSW, chemical and biochemical processes responsible for the decomposition of waste materials and total water content in waste (Naveen et al. 2016; Fatta et al. 1999). Therefore, groundwater contamination resulting from the landfill leachate shall be considered as a major environmental concern (Singh et al. 2008). Various studies have indicated that total dissolved solids, total hardness, organic matter, sodium, chloride and heavy metals are the important groundwater contaminants emanating from landfill leachate (Akinbile 2012; Smahi et al. 2013; Marzougui and Ben Mammou 2006). The major potential environmental effects associated with leachate are contamination of groundwater and surface water (Kjeldsen et al. 2002). Physicochemical and heavy metal parameters reported in the Indian literatures are presented in Table 1. Apart from leachate, MSW impacts include air pollution and global warming, fires and explosions, unpleasant odours, vegetation damage and landfill settlement (Shenbagarani 2013; Raman and Narayanan 2008).

Table 1 Physicochemical and heavy metal parameters reported in the Indian literature

Location of dump site/landfill	Reported water parameters	References
Perungudi, Chennai, Tamil Nadu, India	pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, Cl^-, Zn, Cd, Ni, Fe, Cu, Cr and Pb	Shenbagarani (2013)
Pallavaram, Chennai, Tamil Nadu, India	Colour, odour, taste, pH, EC, TDS, TSS, TA, TH, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-}, K^+, Na^+, Cu and Mn	Raman and Narayanan (2008)
Raipur, Chhattisgarh, India	Temperature, pH, EC, TDS, Turbidity, TA, TH, Cl^-, DO and MPN Test	Agrawal et al. (2011)
Erode, Tamil Nadu, India	pH, EC, TDS, TA, TH, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-}, K^+, Na^+, and F^-	Nagarajan et al. (2012)
Hyderabad, Telangana, India	pH, EC, TDS, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-}, K^+, Na^+, F^-, HCO_3^-, As, Cd, Cr, Cu, Fe, Mn, Pb and Zn	Kurakalva et al. (2016)
Dhapa, Kolkata, West Bengal, India	pH, EC, TDS, TH, Cl^-, PO_4^{3-}, SO_4^{2-}, BOD_5, COD, As, Cu, Cr, Cd, Hg, Pb and Zn	Maiti et al. (2016)
Ahmedabad, Gujarat, India	pH, EC, TDS, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-}, K^+, Na^+, Fe, Cr, Zn, Mn, Cd, Pb, Ni and Cu	Singh et al. (2008)
Vijayawada city, Andhra Pradesh, India	Odour, turbidity, pH, EC, dissolved solids, TA, TH, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, NO_2^-, SO_4^{2-}, Fe and F^-	Raju (2012)
Navi Mumbai, Maharashtra, India	pH, EC, TDS, SS, TA, BOD_5, COD, Cl^- and SO_4^{2-}	Rathod et al. (2013)
Nanded, Maharashtra, India	pH, EC, TDS, TA, Ca^{2+}, Mg^{2+}, Cl^-, K^+, Na^+, PO_4^{3-}, SO_4^{2-}, Fe, Cr, MPN test, salinity	Shaikh et al. (2012)
New Delhi, India	pH, TDS, Cl^-, Fe, As, Cn^-, Pb, Total Cr, Hg, Ni, Cu and Zn	Gupta and Arora (2016)
Thiruvananthapuram, Kerala, India	TDS, TA, Cl^-, TH, Ca^{2+}, Mg^{2+}, NO_3^-, SO_4^{2-} and F^-	Anilkumar et al. (2015)

1.4 *MSW in Vellore City*

Vellore is a Sprawling city situated on the banks of River Palar in the north-eastern part of Tamil Nadu. Vellore City has an area of 87.91 km^2 with a population of 5.02 lakhs. In the past 20 years, the normal rainfall per year ranges from 917 to 1030.3 mm. Vellore City has a semi-arid climate with very high temperature. Dry and hot weather exists throughout the year. The open dump site is located at the Saduperi village which is 5 km from Vellore City, and it has coordinates of 12° 90′ N and 79° 09′E.

The area of open dump site is about 11 acres. For the past 50 years, MSW was dumped here. In dump site, segregation of organic and inorganic waste was not

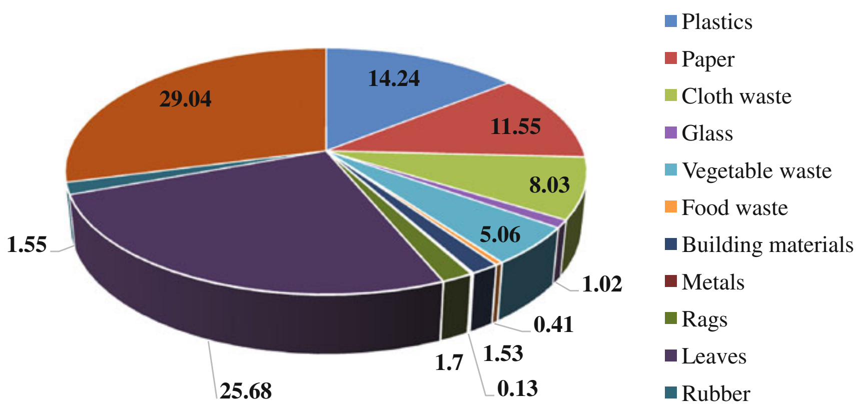

Fig. 1 Weight percentage of components in Vellore MSW (Saravanan and Bhagavanulu 2004)

practised. Earlier manure preparation was done and now because of large proportion of plastics waste, separation of plastic process becomes tedious and manure production was stopped. MSW generation per head in Vellore City was 400 grams per day, and total solid waste dumped per day is of 200 tonnes. 563 sanitation workers are employed in Vellore Corporation. A total of 276 vehicles are engaged in sanitary works. With the help of these vehicles, only 150 tonnes of waste are collected daily. The ultimate analysis of Vellore MSW was done by Saravanan et al. (Saravanan and Bhagavanulu 2004), and it was represented in Fig. 1.

2 Materials and Methodology

2.1 Sampling of Groundwater and Leachate

The sampling wells were identified in and around the solid waste dump site using a random sampling method with 3 km as the periphery. Twenty-two samples are collected for characterization. Of 22 samples, one is leachate sample and remaining 21 are groundwater samples. Within the stretch, we identified and collected 20 borewell samples and 1 open well sample. The open well was situated very closely to landfill. In 20 borewells, one well is situated inside landfill site and others are scattered in 3 km stretch (Table 2). The samples were collected once in 15 days for about six months and transferred to Environmental Laboratory at VIT University, Vellore. The leachate sample is collected from the leachate collecting pit at the dump site.

Table 2 Sampling locations in and around Saduperi MSW dump site

Sample no.	Place name	Latitude	Longitude	Source of water
GW-1	Fort Road	12° 55′ 06.08″	79° 07′ 30.96″	Borewell
GW-2	Virupakshipuram	12°54′ 12.86″	79° 07′ 14.91″	Borewell
GW-3	Sirukanchi 1	12°53′ 52.07″	79° 05′ 48.25″	Borewell
GW-4	Sirukanchi 2	12° 53′ 40.70″	79° 05′ 27.07″	Borewell
GW-5	Kuppam	12° 53′ 09.14″	79° 04′ 48.05″	Borewell
GW-6	Kembedu	12° 53′ 31.98″	79° 05′ 17.25″	Borewell
GW-7	Jamalpuram	12° 54′ 08.12″	79° 06′ 32.29″	Borewell
GW-8	Saduperi dumpsite	12° 54′ 06.71″	79° 06′ 00.97″	Borewell
GW-9	Palavansathu	12° 53′ 11.58″	79° 06′ 07.21″	Borewell
GW-10	Kamaraj Nagar	12° 53′ 06.95″	79° 06′ 56.95″	Borewell
GW-11	Gandhi Nagar	12° 55′ 22.29″	79° 07′ 09.21″	Borewell
GW-12	Bajanaikov	12° 55′ 14.89″	79° 06′ 20.31″	Borewell
GW-13	Aavarampalayam	12° 55′ 12.16″	79° 05′ 40.87″	Borewell
GW-14	Abdullah Puram 1	12° 54′ 49.69″	79° 04′ 46.59″	Borewell
GW-15	Abdullah Puram 2	12° 54′ 48.53″	79° 05′ 08.76″	Borewell
GW-16	Sirukanchi 3	12° 53′ 50.80″	79° 05′ 24.08″	Borewell
GW-17	Saduperi 1	12° 53′ 56.84″	79° 06′ 12.89″	Borewell
GW-18	Jamalpuram Road	12° 54′ 09.95″	79° 06′ 44.64″	Borewell
GW-19	Ariyur	12° 52′ 31.90″	79° 06′ 10.78″	Borewell
GW-20	Palavansathu	12° 53′ 39.89″	79° 07′ 31.89″	Borewell
GW-21	Saduperi 2	12° 53′ 56.33″	79° 05′ 58.40″	Open well

2.2 *Analytical Methods*

The collected samples are taken to laboratory and are immediately stored at 4 °C. All groundwater samples were analysed for pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), chemical oxygen demand (COD), turbidity, alkalinity, total hardness, calcium, magnesium, chloride, sulphate, nitrate, nitrite, potassium (K), sodium (Na), and heavy metals like nickel (Ni), cadmium (Cd) and chromium (Cr). The experimental analyses are carried out as per Bureau of Indian Standard and American Public Health Association Standard methods (Table 3).

Table 3 Details of measured parameters, its adopted methods and instruments used

Parameter	Adopted method	Instrument/apparatus used
pH	IS:3025 Part 11, electrometric method	pH meter
Turbidity	IS:3025 Part 10, nephelometric method	Turbidimeter
TDS	IS:3025 Part 16, gravimetric method	Desiccator and analytical balance
EC	IS:3025 Part 14, laboratory method	Conductivity meter
Alkalinity	IS:3025 Part 23, indicator method	–
Total hardness	IS:3025 Part 21, EDTA method	–
Magnesium	IS:3025 Part 46, EDTA method	–
Chloride	IS:3025 Part 32, argentometric method	–
Calcium	IS:3025 Part 40, EDTA titrimetric method	–
DO	IS:3025 Part 38, Winkler method	Incubator
COD	IS:3025 Part 58, reflux Method	Reflux apparatus and digestion vessels
Sodium and potassium	IS:3025 Part 45, flame photometry method	Flame photometer
Nitrates	APHA 4500-NO_3^-, ultraviolet spectrophotometric screening method	Spectrophotometer
Nitrites	APHA 4500-NO_2^-, colorimetric method	Spectrophotometer
Sulphates	IS:3025 Part 24, turbidity method	Turbidimeter
Ni	IS:3025 Part 54, atomic absorption method	Atomic absorption spectrophotometer
Cd	IS:3025 Part 41, atomic absorption method	Atomic absorption spectrophotometer
Cr	IS:3025 Part 52, atomic absorption method	Atomic absorption spectrophotometer

3 Results and Discussion

3.1 Leachate Characteristics

MSW composition, temperature, time, moisture and oxygen are the major factors influencing the quality of leachate (Naveen et al. 2017). Various physiochemical parameters of dump site leachate are presented in Table 4. In this study, leachate has pH value of 7.2, and it indicates the mature stage of dumping site (Jorstad et al. 2004), whereas pH values ranging from 6.9 to 9.8 are observed in similar studies (Raju 2012; Rathod et al. 2013; Shaikh et al. 2012). In MSW, organic matter is degraded to CO_2 and NH_3 and it further leads to the production of carbonic acid and ammonium ions. This carbonic acid is dissociated to form hydrogen cations and bicarbonate anions (Mahapatra et al. 2011).

BOD_5 of leachate was 9100 mg/L and value of COD was 13,200 mg/L. This high level of BOD indicates the presence of organic matter in the leachate (Rathod

Table 4 Dump site leachate characteristics

Parameters	Leachate concentration
pH	7.2
TDS	12,820
COD	13,200
BOD	9100
Chlorides	5317.5
NO_3^-	4.12
Cd	0.09
Cr	2.84
Ni	0.053
Sodium	230
Potassium	20.56

Note Except pH, all values are in mg/L

et al. 2013). From the BOD and COD values, the BOD_5/COD ratio was found to be 0.68. BOD and COD values are well correlated with (Rathod et al. 2013) and (Archana and Dutta 2014). The BOD5/COD ratio is the good indicator of leachate age. The young leachate (3–12 months) has BOD_5/COD ratio of 0.6–1, followed by a medium leachate (1–5 years) of 0.30–0.60 and old leachate (greater than 5 years) of 0–0.30 (Alvarez-Vazquez et al. 2004). Hence, this dump sites leachate is found to be in young age. The young leachate is mainly composed of organic compounds that will not easily decompose and biodegrade. It also produces refractory compounds that are resistant to biochemical degradation (Agrawal et al. 2011; Abd El-Salam and Abu-Zuid 2015).

The concentration of TDS was recorded as 12,820 mg/L, and this extremely high value of TDS indicates the existence of inorganic materials. In the literature, TDS values ranges from 2027 to 81,000 mg/L (Agrawal et al. 2011; Rathod et al. 2013; Naveen et al. 2017; Jorstad et al. 2004; Bhalla et al. 2012; Aderemi et al. 2011). The chloride content of 5317.5 mg/L in leachate may be due to the mixing of domestic waste. The chloride content is well correlated with (Regadio et al. 2012; Jorstad et al. 2004) similar studies were done in the past. In leachate, the nitrogen cycle is dominated by microbial decomposition of organic carbon. As the time progresses, the nitrogen concentration decreases because of microbial utilization of nitrate compounds and denitrified as ammonia gas. Nitrate concentration was recorded as 4.12 mg/L, which is low in comparison to the reference values (Bhalla et al. 2012). In our study, chromium is abundant with a concentration of 2.84 mg/L.

The metallic elements such as nickel and cadmium are found to be 0.05 and 0.09 mg/L, respectively. Heavy metals concentration in landfills will be high in initial stages because the higher metal solubility is higher as a result of low pH (Kulikowska and Klimiuk 2008). The decrease in solubility of metal occurs in later stages, and a sharp decrease in heavy metal's concentration is observed (Harmsen 1983). Na^+ and K^+ in the leachate are recorded with a concentration of 230 and

20.56 mg/L. These ions are not affected due to microbiological activities inside the dump site. Both Na^+ and K^+ are derived from domestic waste and vegetable residues (Christensen et al. 2001).

3.2 Groundwater Characteristics

Various physicochemical characteristics of leachate-contaminated groundwater samples are given in Tables 5 and 6. The collected groundwater samples were tested for pH and have an average value of 7.07 with 6.58 (GW-8) being the lowest and highest being 7.34 (GW-14). The least and the highest pH values are below the BIS standard values. In earlier studies, the pH of the leachate-contaminated groundwater varied between 4 and 8.16 (Rathod et al. 2013; Anilkumar et al. 2015; Alvarez-Vazquez et al. 2004; Lee et al. 2010; Moody and Townsend 2017; Banar et al. 2006). Dissolved gases and materials influence the pH of the water and shift it to alkaline or acidic side. Acidity in water is because of the presence of carbonic, fulvic, humic and organic acids (Mahapatra et al. 2011). The alkaline pH values can sustain with a high amount of dissolved substances and were good in supporting plant life.

Total dissolved solids represent both dissolved and suspended matter in a water sample. All groundwater samples exceeded the permissible limit of 500 mg/L. The highest TDS values are recorded in GW-8 and GW-21 with a concentration of 9690 and 7620 mg/L, respectively. The very high TDS observed in the groundwater samples suggests percolation of leachate into groundwater and indicates the presence of inorganic materials (Mor et al. 2006). In the literature, TDS values of the groundwater ranges from 1440 to 25,514 mg/L (Bhalla et al. 2012; Alvarez-Vazquez et al. 2004; Kulikowska and Klimiuk 2008). High concentration of TDS makes water unpalatable and also causes irritation in gastrointestine in humans. Electrical conductivity (EC) indicates the presence of metals and amount of materials dissolved in water. The EC values in this study range from 757 to 6492 μS/cm. EC values up to 11,560 μS/cm are observed in the literature (Smahi et al. 2013). Except for GW-1 and GW-16, all groundwater samples exceeded the BIS limits which make them hard water and unfit for drinking. The highest values of calcium and magnesium hardness are 2050 and 5950 mg/L, respectively. Even the lowest hardness recorded in GW-16 (582.5 mg/L) is very close to BIS limit of 600 mg/L. By Piper plot (Fig. 2), calcium and magnesium are found to be major ions in groundwater sample. Hardness values from 1070 to 2890 mg/L are reported in the literature (Kulikowska and Klimiuk 2008; Harmsen 1983). Alkalinity is caused by the presence of carbonate, bicarbonate and hydroxide compounds.

Dissolution of CO_2 and carbonate minerals supplies bicarbonate into nearby groundwater. MSW in unlined dump site and oxidation of organic materials are the potential sources of alkalinity in groundwater (Mor et al. 2006). In present study the alkalinity concentration of the groundwater samples are recorded in the range of 660–2400 mg/L. The maximum value 2400 mg/L is 12 times higher than the desirable limit, i.e. 200 mg/L.

Table 5 Physicochemical characteristics of leachate-contaminated groundwater samples

Parameter	GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8	GW9	GW10	GW11	GW12	GW13	GW14	GW15	GW16	GW17	GW18	GW19	GW20	GW21
pH	7.29	7.2	7.29	7.16	7.17	7.05	6.8	6.58	7.15	6.9	7.18	7.03	7.08	7.34	7.18	7.15	6.91	7.16	6.71	7.03	6.74
TDS	1440	3810	1130	2380	2790	2690	3290	9690	3050	2670	2410	2070	1410	1820	3230	3090	4080	4330	1720	2210	7620
EC (μS/cm)	965	2553	757	1595	1869	1802	2204	6492	2044	1789	1615	1387	945	1219	2164	2070	2734	2901	1152	1481	5105
COD	128	96	32	32	32	160	320	960	64	192	416	40	34	256	64	32	128	288	160	160	1600
Turbidity	21.05	12.6	24.3	22.7	11.8	15.55	3.75	6.25	4.75	5.2	5.45	27.2	5.05	3.9	5.75	15	27.05	4.6	42.85	8.65	10.3
Alkalinity	875	2400	660	1287	1512	1137	1372	1850	750	1050	937.5	960	827.5	1082	1870	670	777.5	1015	1875	1277	1125
TH	590	920	692.5	895	1330	750	1705	8000	1262	1060	782.5	792	687	857	1025	582.5	2950	2075	1227	907	2677.5
Chloride	758	877	386	638	665	638	796	2154	678	573	558	638	465	346	784	578	1157	1037	572	532	2034
Sulphate	7.47	14.5	11.69	12.05	10.71	12.02	11.24	9.26	7.19	11.41	13.36	10.05	12.02	11.38	13.03	7.12	10.88	12.36	10.45	11.48	10.69
Nitrate	0.15	0.07	0.02	1.32	0.14	0.02	0.22	0.03	0.03	0.16	0.03	0.32	0.05	0.01	0.37	0.06	0.05	0.04	0.01	0.57	1.32
Nitrite	3.87	4.29	4.47	3.87	4.47	4.78	4.29	4.12	4.47	4.12	4.12	3.99	3.77	4.29	4.12	4.12	3.87	4.12	3.99	3.79	3.87
K	1.28	26.06	2.8	1.9	3.45	2.43	4.28	9.53	1.43	4.18	2.45	4.51	1.42	2.49	18.42	2.64	1.49	2.09	1.39	42.74	64.76
Na	180.9	765.5	110.6	299.8	430.8	358.2	424.6	1966	502.4	425.2	387.2	467.7	222.1	34.9	481.7	522.7	190.3	497.4	193.7	263.9	1083.7
Ni	0.485	0.109	0.027	0.011	0.04	0.105	0.007	0.067	0.048	0.07	0.059	0.06	0.067	0.125	0.039	0.006	0.146	0.02	0.048	0.123	0.067
Cd	0.013	0.024	0.023	0.018	0.022	0.017	0.009	0.041	0.026	0.032	0.017	0.028	0.027	0.012	0.47	0.057	0.051	0.012	0.045	0.039	0.01
Cr	0.249	0.678	0.204	0.339	0.415	0.56	0.764	1.025	0.647	0.845	0.658	0.951	0.874	0.894	1.082	0.957	1.041	0.745	0.977	1.103	1.064

Table 6 Minimum, maximum and average values of water quality parameters

Parameters (mg/L)	Minimum	Maximum	Average	BIS standards
pH	6.58	7.40	7.07	6.5–8.5
TDS	1410.00	9690.00	3187.14	2000
EC (μS/cm)	945	6492	2135	–
COD	32	1600	247.33	NA
Turbidity	3.75	42.85	13.51	10
Alkalinity	670	2400	1205.36	600
Total Hardness	582.5	8000	1512.86	600
Chloride	346	2153.39	802.91	1000
Sulphate	7.12	14.50	10.97	400
Nitrate	0.01	1.32	0.24	45
Nitrite	3.77	4.78	4.13	NA
K	1.39	64.76	9.61	NA
Na	34.9	1966.00	413.582	NA
Ni	0.01	0.49	0.08	NA
Cd	0.01	0.47	0.05	0.01
Cr	0.42	1.10	0.77	0.05

Note In Tables 5 and 6, all values are in mg/L except pH and EC

An excess of Cl^- in water is usually taken as an index of pollution and considered to be a tracer for groundwater contamination (Loizidou and Kapetanios 1993). The range of chloride concentration is between 345.64 and 2153.39 mg/L. High concentration of chloride in groundwater is in correlation with leachate chloride concentration. The only source of anthropogenic contamination near sampling area is dump site indicating migration of leachate into groundwater. The chloride content, exceeding the concentration level of 250 mg/L, causes odour and taste problems.

Chemical oxygen demand (COD) is a measure of oxygen equivalent to the organic matter content of the water susceptible to oxidation by a strong chemical oxidant and thus is an index of organic pollution. Previous studies used COD as organic indicators to assess the groundwater pollution caused by the landfill (Mor et al. 2006). In this study, the average COD values of all samples are estimated to be 247 mg/L. Hence, it shows the strong correlation of organic matter in the leachate and shows the state of pollution level. Nitrate is a common contaminant of groundwater that originates from septic systems, manure storage and fertilizers. Nitrates, most highly oxidized form of nitrogen compounds, are the end product of the aerobic decomposition of organic nitrogenous matter (Moody and Townsend 2017; Al Sabahi et al. 2009). Nitrate concentration in samples was in the range between 0.01 and 1.32 mg/L which is within the standard limits.

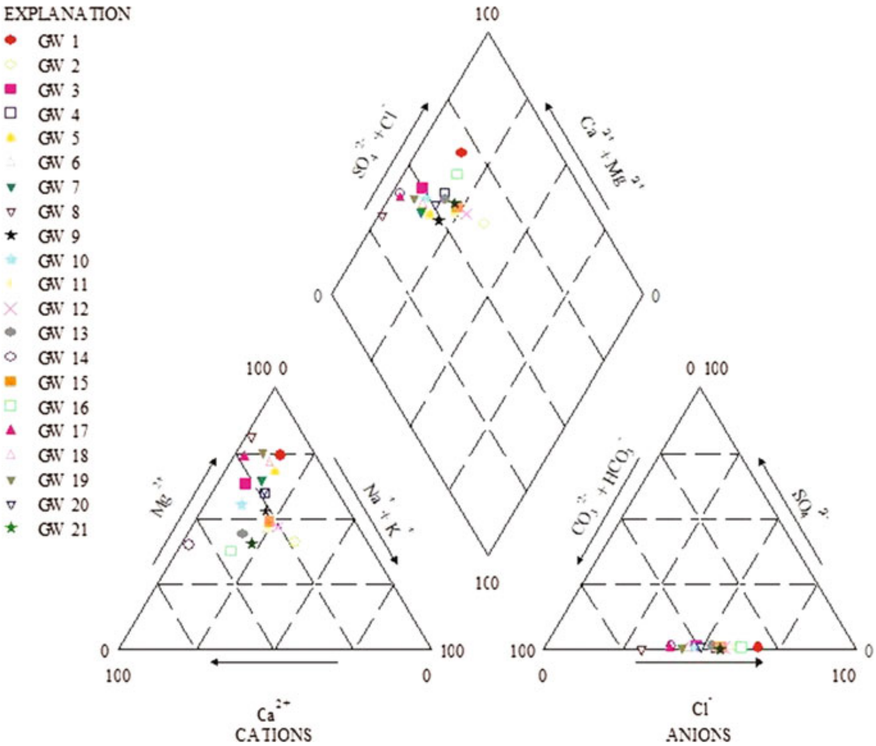

Fig. 2 Piper trilinear plot of major ions in the groundwater samples

As per World Health Organization (WHO), the concentration of potassium should be within 200 mg/L. Potassium is weakly hazardous in water, but it does spread pretty rapidly, because of its relatively high mobility and low transformation potential (Bali and Devi 2013). Potassium has been reported being an indication of the leachate effect, and their concentration in the sample is between 1.28 and 64.76 mg/L. All samples are within desirable limits. Maximum sulphate concentration was found in GW-2. The sulphate ion concentration in groundwater is due to the presence of domestic waste. In similar studies, maximum potassium and sulphate concentrations are 76 and 300 mg/L (Nagarajan et al. 2012).

Chromium in drinking water should be less than 0.05 mg/L. In most of the samples, the concentration is exceeding the standard value. Maximum concentration is found in sample GW-20 (1.1 mg/L), and lowest concentration is 0.2 mg/L in sample GW-3. Cadmium has a standard limit of 0.003 mg/L. In sample GW-21, the concentration is 0.05 mg/L which is highest. In the case of nickel, the maximum concentration observed was 0.48 which exceeds the standard limit.

3.3 Piper Plot

Piper plot represents the chemistry of water samples graphically. In general, we can classify the sample points in the piper diagram into six fields (Kumar 2013). They are as follows:

(i) Ca–HCO_3 type,
(ii) Na–Cl type,
(iii) Ca–Mg–Cl type,
(iv) Ca–Na–HCO_3 type,
(v) Ca–Cl type,
(vi) Na–HCO_3 type.

Piper plot was created for collected samples using results obtained from analytical tests. Piper diagram consists of anion triangle, cation triangle and a diamond apex which shows combined plot of anions and cations.

Anions are plotted as a percentage of $SO_4{}^{2-}$, Cl^-, $HCO_3{}^-$ and $CO_3{}^{2-}$. Cations are plotted as a percentage of Na^+, K^+, Ca^{2+} and Mg^{2+} (Shenbagarani 2013). From the plot, it is concluded that most of the samples are in Ca–Mg–Cl and Ca–HCO_3 type. Similar result was observed in the previous study (Nagarajan et al. 2012). This result indicates Ca^{2+}, Mg^{2+} of cations and Cl^-, $HCO_3{}^-$ of anions are dominant in water samples. It is well correlated with higher concentration of hardness and chlorides in groundwater samples.

3.4 Leachate Pollution Index (LPI)

Leachate pollution potential varies according to geographical area, and for comparing potentials of the different landfill site, 80 panellists were surveyed. The survey was conducted using multiple questionnaires to formulate LPI based on Rand Corporation’s Delphi Technique (Kumar and Alappat 2005). LPI is a number ranges from 5 to 100 that expresses the overall leachate contamination potential of a landfill based on several leachate pollution parameters at a given time. It is an increasing scale index, wherein a higher value indicates a poor environmental condition. The LPI can be used to report leachate pollution changes in a particular landfill over time (Mor et al. 2006; Umar et al. 2010). LPI can be used as an environmental monitoring tool and indicator for remedial measures. LPI depends on various parameters like m, P_i, W_i which represents the number of leachate pollutant parameters, the sub-index score of the ith leachate pollutant variable and the weight for the ith pollutant variable, respectively. The stepwise detail of formulation of LPI is presented in (Kumar and Alappat 2005).

3.5 Parameters Considered for LPI Calculation

In this study, the parameters available for calculating LPI are pH, TDS, COD, BOD, chlorides, chromium and nickel. LPI for these parameters are calculated in Tables 7 and 8. For calculation, the following formula was used.

$$\mathrm{LPI} = \frac{\sum_{i=1}^{m} w_i p_i}{\sum_{i=1}^{m} w_i}$$

where

LPI	Leachate pollution index
m	Number of leachate pollutant parameters available
P_i	The sub-index score of the *i*th leachate pollutant variable
W_i	The weight for the *i*th pollutant variable

The sub-index scores of the *i*th leachate pollutant and the weight for the *i*th pollutant variable were taken from the literature (Bali and Devi 2013; Umar et al. 2010). LPI of leachate from Saduperi dump site was found to be 34.14 which is higher than untreated leachate in Jamalpur landfill site of Ludhiana City (Bhalla et al. 2014). LPI ranging from 19.5 to 45.01 was observed in previous studies (Bali and Devi 2013; Umar et al. 2010). The LPI calculation for standards given in municipal solid waste management and handling rules 2013 was also done. LPI value was found to be 7.88 for inland surface water disposal and 6.64 for land disposal. When compared with suggested LPI standards (7.88 and 6.64), the leachate from Saduperi dump site has high pollution potential with LPI of 34.14 and hence immediate remedial measures are recommended.

Table 7 Leachate pollution index of Saduperi dump site sample

Parameters	Concentration at Saduperi landfill site	Significance	Pollutant weight (W_i)	P_i	$P_i \times W_i$
pH	7.2	3.509	0.055	5	0.275
TDS	12,820	3.196	0.050	30	1.5
COD	13,200	3.963	0.062	75	4.65
BOD	9100	3.902	0.061	60	3.66
Chlorides	5317.5	3.078	0.048	50	2.4
Cr	2.84	4.057	0.064	10	0.64
Ni	0.053	3.321	0.052	5	0.26
Total			0.392		13.385
LPI value					34.14

Table 8 LPI calculation for standards (solid waste management rules)

Parameters	W_i	LPI standard for inland surface water disposal			LPI standard for land disposal		
		Standard	P_i	$P_i \times W_i$	Standard	P_i	$P_i \times W_i$
pH	0.055	5.5–9	5	0.275	5.5–9	5	0.275
TDS	0.050	2300	7	0.35	2300	7	0.35
COD	0.062	250	10	0.62	–	–	–
BOD	0.061	30	6	0.366	100	9	0.549
Chlorides	0.048	1000	8	0.384	600	7	0.336
Cr	0.064	2	9	0.576	2	9	0.576
Ni	0.052	3	10	0.52	3	10	0.52
Total	0.392			3.091			2.606
LPI Value				7.88			6.64

4 Conclusions

This work represents a real-time case study of MSW open dump site located at Saduperi, Vellore District, Tamil Nadu, India. Leachate and groundwater samples are collected in and around open dump site to analyse the possible impact of leachate on the quality of groundwater. Various physicochemical parameters and heavy metal concentration are carried out and reported. Results showed that leachate collected from dump site is of young age and has a high BOD, COD and TDS values. To quantify leachate pollution potential, LPI was calculated for standard concentration given in MSW rules and dump sites leachate. The LPI value was found to be four times greater than the corresponding standard LPI values. By this result, the leachate emanated from dump site should have contaminated nearby resources. The water quality analysis showed that wells situated near the dump site (e.g. GW-8) are highly contaminated than the wells that are far away. This is due to the fact that leachate being a viscous fluid is hindered due to the mass of solid soil matter. One of the significant findings is that the concentration of TDS, alkalinity and total hardness in most of the groundwater sample exceeds the BIS limits. The heavy metal concentrations present in the samples are found to have a potential threat to public health. Since there is no other source of contamination of wells, it is concluded that due to leachate from dump site groundwater has been contaminated. Proper management of dump site should be done to minimize the effect of leachate on groundwater. Engineered landfill sites should be provided with impermeable liner and drainage.

References

Abd El-Salam MM, Abu-Zuid GI (2015) Impact of landfill leachate on the groundwater quality: a case study in Egypt. J Adv Res 6(4):579–586

Aderemi A, Oriaku Ada V, Adewumi Gbenga A, Otitoloju Adebayo A (2011) Assessment of groundwater contamination by leachate near a municipal solid waste landfill. Afr J Environ Sci Technol 5:933–940

Agrawal A, Pandey R, Agrawal ML (2011) Impact of solid waste leachate on ground water. Int J chem Environ Eng 2(2):113–118

Akinbile CO (2012) Environmental impact of landfill on groundwater quality and agricultural soils in Nigeria. Soil Water Res 7(1):18–26

Al Sabahi E, Rahim SA, Zuhairi WYM, Selangor B (2009) The characteristics of leachate and groundwater pollution at municipal solid waste landfill of Ibb City, Yemen. Water and Environ 5(3):256–266

Albores P, Petridis K, Dey PK (2016) Analysing efficiency of waste to energy systems: using data envelopment analysis in municipal solid waste management. Proc Environ Sci 35:265–278

Alvarez-Vazquez E, Jefferson B, Judd SJ (2004) Membrane bioreactors vs conventional biological treatment of landfill leachate: a brief review. J Chem Technol Biotechnol 79(March):1043–1049

Anilkumar A, Sukumaran D, Vincent SGT (2015) Effect of municipal solid waste leachate on ground water quality of Thiruvananthapuram District, Kerala. Appl Ecol Environ Sci 3(5):151–157

Annual Status Report on Municipal Solid Waste Management 2014–2015, Central Pollution Control Board, India

Archana, Dutta V (2014) Seasonal variation on physico-chemical characteristics of leachate in active and closed municipal solid waste landfill site in Lucknow, India. J Environ Sci Technol 1(4):90–95

Bali L, Devi KS (2013) Leachate characterization and assessment of water pollution near municipal solid waste landfill site. Ind J Appl Res 3:62–64

Banar M, Ozkan A, Kurkcuoglu M (2006) Characterization of the leachate in an urban landfill by physicochemical analysis and solid phase microextraction-GC/MS. Environ Monit Assess 121 (1–3):437–457

Bhalla B, Saini MS, Jha MK (2012) Characterization of leachate from municipal solid waste (MSW) landfilling sites of Ludhiana, India: a comparative study. Int J Eng Res Appl 2(6):732–745

Bhalla B, Saini M, Jha M (2014) Assessment of municipal solid waste landfill leachate treatment efficiency by leachate pollution index. Assessment 3(1):8447–8454

Boeckx P, Van Cleemput O, Villaralvo I (1996) Methane emission from a landfill and the methane oxidising capacity of its covering soil. Soil Biol Biochem 28(10–11):1397–1405

Census 2001 and 2011, Ministry of Home affairs, Government of India

Chandrappa R, Das DB (2012) Solid waste management: principles and practice. Environ Sci Eng 3:413

Christensen TH et al (2001) Biogeochemistry of landfill leachate plumes. Appl Geochem 16(7–8):659–718

Das D, Majhi BK, Pal S, Jash T (2016) Estimation of land-fill gas generation from municipal solid waste in Indian Cities. Energy Proc 90:50–56

Fatta D, Papadopoulos A, Loizidou M (1999) A study on the landfill leachate and its impact on the groundwater quality of the greater area. Environ Geochem Health 21:175–190

Giusti L (2009) A review of waste management practices and their impact on human health. Waste Manage 29(8):2227–2239

Gupta B, Arora SK (2016) Assessment of impact of leachate on groundwater, in the vicinity of the first engineered landfill site in Delhi, India. Asian Rev Civ Eng 5(1):13–20

Gupta N, Yadav KK, Kumar V (2015) A review on current status of municipal solid waste management in India. J Environ Sci (China) 37:206–217
Han Z, Ma H, Shi G, He L, Wei L, Shi Q (2016) A review of groundwater contamination near municipal solid waste landfill sites in China. Sci Total Environ 569–570(1):1255–1264
Harmsen J (1983) Identification of organic compounds in leachate from a waste tip. Water Res 17 (6):699–705
Hoornweg D, Bhada-Tata P (2012) What a waste: a global review of solid waste management. Urban Development Series Knowledge. Paper no.15, World Bank, p 116
Jha AK, Singh SK, Singh GP, Gupta PK (2011) Sustainable municipal solid waste management in low income group of cities: a review. Trop Ecol 52(1):123–131
Jorstad LB, Jankowski J, Acworth RI (2004) Analysis of the distribution of inorganic constituents in a landfill leachate-contaminated aquifer: Astrolabe Park, Sydney, Australia. Environ Geol 46 (2):263–272
Kalyani KA, Pandey KK (2014) Waste to energy status in India: a short review. Renew Sustain Energy Rev 31:113–120
Karak T, Bhagat RM, Bhattacharyya P (2012) Municipal solid waste generation, composition, and management: the world scenario. Crit Rev Environ Sci Technol 42(15):1509–1630
Kjeldsen P, Barlaz MA, Rooker AP, Baun A, Ledin A, Christensen TH (2002) Present and long-term composition of MSW landfill leachate: a review. Crit Rev Environ Sci Technol 32 (4):297–336
Kulikowska D, Klimiuk E (2008) The effect of landfill age on municipal leachate composition. Bioresour Technol 99(13):5981–5985
Kumar PJS (2013) Interpretation of groundwater chemistry using piper and chadha's diagrams: a comparative study from Perambalur taluk. Elixir Geosci 54:12208–12211
Kumar D, Alappat BJ (2005) Evaluating leachate contamination potential of landfill sites using leachate pollution index. Clean Technol Environ Policy 7(3):190–197
Kurakalva RM, Aradhi KK, Mallela KY, Venkatayogi S (2016) Assessment of groundwater quality in and around the Jawaharnagar Municipal Solid Waste Dumping Site at Greater Hyderabad, Southern India. Proc Environ Sci 35:328–336
Lavee D (2007) Is municipal solid waste recycling economically efficient? Environ Manage 40 (6):926–943
Lee AH, Nikraz H, Hung YT (2010) Characterization of acetogenic and methanogenic leachates generated from a sanitary landfill site. Int J Civil Environ Eng 4(7):595–600
Loizidou M, Kapetanios EG (1993) Effect of leachate from landfills on underground water quality. Sci Total Environ 128(1):69–81
Mahapatra DM, Chanakya HN, Ramachandra TV (2011) Assessment of treatment capabilities of Varthur Lake, Bangalore, India. Int J Environ Technol Manage 14(1/2/3/4):84
Maiti SK, De S, Hazra T, Debsarkar A, Dutta A (2016) Characterization of leachate and its impact on surface and groundwater quality of a closed dumpsite—a case study at Dhapa, Kolkata, India. Procedia Environ Sci 35:391–399
Management of Municipal Solid Waste (2010) Central Pollution Control Board (Ministry of Environemntal and Forests), Government of India
Mani S, Singh S (2016) Sustainable municipal solid waste management in India: a policy agenda. Proc Environ Sci 35:150–157
Marzougui A, Ben Mammou A (2006) Impacts of the dumping site on the environment: case of the Henchir El Yahoudia Site, Tunis, Tunisia. Comptes Rendus Geosci 338(16):1176–1183
McKay G (2002) Dioxin characterisation, formation and minimisation during municipal solid waste (MSW) incineration: review. Chem Eng J 86(3):343–368
Moody CM, Townsend TG (2017) A comparison of landfill leachates based on waste composition. Waste Manage 63:267–274
Mor S, Ravindra K, Dahiya RP, Chandra A (2006) Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Environ Monit Assess 118(1–3):435–456

Mor S, Ravindra K, Dahiya RP, Chandra A (2006b) Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Environ Monit Assess 118(1–3):435–456
Nagarajan R, Thirumalaisamy S, Lakshumanan E (2012a) Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. Iran J Environ Health Sci Eng 9(1):35
Nagarajan R, Thirumalaisamy S, Lakshumanan E (2012) Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. Iran J Environ Health Sci Eng 9(1):35
Naveen BP, Mahapatra DM, Sitharam TG, Sivapullaiah PV, Ramachandra TV (2016) Physico-chemical and biological characterization of urban municipal landfill leachate. Environ Pollut 220:1–12
Naveen BP, Mahapatra DM, Sitharam TG, Sivapullaiah PV, Ramachandra TV (2017) Physico-chemical and biological characterization of urban municipal landfill leachate. Environ Pollut 220:1–12
Omar D, Karuppanan S, AyuniShafiea F (2012) Environmental health impact assessment of a sanitary landfill in an urban setting. Proc Soc Behav Sci 68:146–155
Pappu A, Saxena M, Asolekar SR (2007) Solid wastes generation in India and their recycling potential in building materials. Build Environ 42(6):2311–2320
Planning Commission's Report of the Task Force on Waste to Energy (2014) In the context of integrated municipal solid waste management, vol I
Prechthai T, Parkpian P, Visvanathan C (2008) Assessment of heavy metal contamination and its mobilization from municipal solid waste open dumping site. J Hazard Mater 156(1–3):86–94
Raju MVS (2012) Contamination of ground water due to landfill leachate. Int J Eng Res 53(1):48–53
Raman N, Narayanan DS (2008) Impact of solid waste effect on ground water and soil quality nearer to Pallavaram Solid Waste Landfill Site in Chennai. Rasayan J Chem 1(4):828–836
Rathod M, Mishra H, Karmakar S (2013) Leachate characterization and assessment of water pollution near municipal solid waste landfill site. Int J Chem Phys Sci 2(March):186–199
Reddy PJ (2011) Municipal solid waste management: processing—energy recovery—global examples. BS Publications, CRC Press
Regadio M et al (2012) Pollution profiles and physicochemical parameters in old uncontrolled landfills. Waste Manage 32(3):482–497
Reyes-López JA, Ramírez-Hernández J, Lázaro-Mancilla O, Carreón-Diazconti C, Garrido MML (2008) Assessment of groundwater contamination by landfill leachate: a case in Mexico. Waste Manage 28(Suppl 1):33–39
Rovira J, Vilavert L, Nadal M, Schuhmacher M, Domingo JL (2015) Temporal trends in the levels of metals, PCDD/Fs and PCBs in the vicinity of a municipal solid waste incinerator. Preliminary assessment of human health risks. Waste Manage 43:168–175
Saravanan P, Bhagavanulu DVS (2004) Analysis of municipal solid waste for energy generation potential—a case study of Vellore City. Nat Environ Pollut Technol 3:137–139
Shaikh PR, Bhosle AB, Yannawar VB (2012) The impact of landfill on soil and groundwater quality of the Nanded city, Maharashtra. Researcher 4(7):56–63
Sharholy M, Ahmad K, Mahmood G, Trivedi RC (2008) Municipal solid waste management in Indian cities—a review. Waste Manage 28(2):459–467
Shekdar AV (2009) Sustainable solid waste management: an integrated approach for Asian countries. Waste Manage 29(4):1438–1448
Shenbagarani S (2013) Analysis of groundwater quality near the solid waste dumping site. J Environ Sci Toxicol Food Technol 4(2):1–5
Singh UK, Kumar M, Chauhan R, Jha PK, Ramanathan AL, Subramanian V (2008) Assessment of the impact of landfill on groundwater quality: a case study of the Pirana site in western India. Eviron Monit Assess 141(1–3)
Sizirici B, Tansel B (2015) Parametric fate and transport profiling for selective groundwater monitoring at closed landfills: a case study. Waste Manage 38(1):263–270

Smahi D, El Hammoumi O, Fekri A (2013) Assessment of the impact of the landfill on groundwater quality: a case study of the Mediouna Site, Casablanca, Morocco. J Water Resour Prot 5(April):440–445
Solid Waste Management Rules, 2016, Ministry of Environment, Forest and Climate Change, India
Umar M, Aziz HA, Yusoff MS (2010) Variability of parameters involved in leachate pollution index and determination of LPI from four landfills in Malaysia. Int J Chem Eng 2010:1–6
Vij D (2012) Urbanization and solid waste management in India: present practices and future challenges. Proc Soc Behav Sci 37:437–447
Xiaoli C, Shimaoka T, Xianyan C, Qiang G, Youcai Z (2007) Characteristics and mobility of heavy metals in an MSW landfill: implications in risk assessment and reclamation. J Hazard Mater 144(1–2):485–491
Zhu D, Asnani PU, Zurbrügg C, Anapolsky S, Mani S (2008) Improving municipal solid waste management in India: a sourcebook for policy makers practitioners. World Bank Institute Development Studies, The World Bank

Author Biographies

Mr. N Manoj Kumar is currently working as Assistant Professor in the department of Civil Engineering at Builders Engineering College, Tiruppur, Tamil Nadu. He have almost 2 years of working experience in teaching field. He obtained his bachelor degree in Civil Engineering from EBET- Group of Institutions affiliated to Anna University, Chennai. Later he completed his in the field of Energy & Environmental Engineering at VIT University, Vellore. His research interests are inclined towards Air pollution and Municipal solid waste management.

Dr. M Chaithanya Sudha is an environmental expert working in the fields of Pollution Control and Water quality monitoring. Her major research areas include Lake Ecosystem Monitoring, Wastewater treatment, Solid waste management and Bioremediation.