Characterization of Leachate from Municipal Solid Waste (MSW) Landfilling Sites of Ludhiana, India: A Comparative Study

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ABSTRACT

The paper discusses the characteristics of leachate generated from municipal solid waste landfilling sites of Ludhiana City, Punjab (India). Leachate samples were collected and analyzed for various physico-chemical parameters to estimate its pollution potential. This study aims to serve as a reference for the implementation of the most suitable technique for reducing the negative environmental effects of discharge leachate. All the three landfilling sites of Ludhiana city are non-engineered low lying open dumps. They have neither any bottom liner nor any leachate collection and treatment system. Therefore, all the leachate generated finds its paths into the surrounding environment. It has been found that leachate contains high concentrations of organic and inorganic constituents beyond the permissible limits. While, heavy metals concentration was in trace amount as the waste is domestic in nature. The data presented in this study indicated that the age of the landfill has a significant effect on leachate composition. In older landfills, the biodegradable fraction of organic pollutants in the leachate decreases as an outcome of the anaerobic decomposition occurring in the landfill. The concentration of leachate contaminants at Jamalpur and Noorpur belt landfilling site were comparative greater than that of Jainpur landfilling site which is older than both. Based on the characterization of landfill leachate, Jamalpur and Noorpur belt landfilling site demonstrated low bio-degradability i.e. $BOD_5/COD=0.19$ and $BOD_5/COD=0.20$ compared with Jainpur landfilling site i.e. $BOD_5/COD=0.24$. Indiscriminate dumping of municipal solid waste without proper solid waste management practices should be stopped or some remedial measures were required to be adopted to prevent contamination.

Keywords- Landfilling, Leachate, Organic and Inorganic constituents, Groundwater contamination.

1. INTRODUCTION

With the rapid industrialization and population growth, the status of our environment is degrading day by day. As the limits of urbanization are extending to far flying areas in India, the problem of solid waste management is causing a great concern to our environment. MSW generation, in terms of kg/capita/day, has shown a positive correlation with economic development at world scale. Due to rapid industrial growth and migration of people from villages to cities, the urban population is increasing rapidly. Waste generation has been observed to increase annually in proportion to the rise in population and urbanization. The per capita generation of MSW has also increased tremendously with improved life style and social status of the populations in urban centers [1]. As more land is needed for the ultimate disposal of these solid wastes, issues related to disposal have become highly challenging [2]. Seeing the scenario of increase in generation, improper utilization and disposal of waste in the country, the Ministry of Environment and Forest (MoEF) has Municipal Solid Waste (Management and Handling) Rules, 2000 [3], which states that Municipal Solid Waste (MSW) is commercial and residential wastes generated in a municipal or notified areas in either solid or semi-solid form, excluding industrial hazardous wastes but including treated biomedical wastes. These solid wastes are generally disposed off in a low lying area called sanitary landfill area by the municipal authorities. These rules have specified many compliance for the management of solid waste for the State Committee and Pollution Board, which includes proper segregation of solid waste into biodegradable waste, recyclable and others i.e., non-recyclable wastes are stored in colored bins at the source of generation and properly treated, recycled and disposed to landfill areas.

The quantity of municipal solid waste in developing countries has been consistently rising over the years [4]. Today more than 45 million tonnes/year of solid waste is generated from the urban centres of India which are collected inefficiently, transported inadequately and disposed unscientifically [5]. The generation is expected to rise to 125 million tonnes/ year by the year 2025 [6]. According to Ministry of Urban Affairs, Govt. of India estimate, India is generating approximately 100,000 metric tonnes of solid waste everyday of which 90 % is dumped in the open place [7]. In Delhi, the capital of India alone, more than 5,000 tonnes of MSW is generated everyday and is expected to rise to 12,750 tonnes per day by 2015 [8]. The MSW generated per day in India's other major cities are Mumbai- 6,050 tonnes, Kolkata-3,500 tonnes, Chennai-2,500 tonnes, Bangalore-2,000 tonnes, Hyderabad-1,800 to 2,000 tonnes, Lucknow-1,500 tonnes and Ahmedabad- 1,280 tonnes [7]. The municipal solid waste composition varies from place to place and also bears a rather consistent correlation with the average standard of living [9].

Generally in India, MSW is disposed of in low-lying areas without taking proper precautions or operational controls. Therefore, municipal solid waste management (MSWM) is one of the major environmental problems of Indian megacities. MSW management encompasses planning, engineering, organization, administration, financial and legal aspects of activities associated with generation, storage, collection, transport, processing and disposal in an environmentally compatible manner adopting principles of economy, aesthetics and energy conservation [10]. The management of MSW is going through a critical phase, due to the unavailability of suitable facilities to treat and dispose of the larger amounts of MSW generated daily in metropolitan cities. The MSW amount is expected to increase significantly in the near future as India strives to attain an industrialized nation status by the year 2020 [11,12,13]. The management of MSW requires proper infrastructure, maintenance and upgrade for all activities. This becomes increasingly expensive and complex due to the continuous and unplanned growth of urban centres. The difficulties in providing the desired level of public service in the urban centres are often attributed to the poor financial status of the managing municipal corporations (14,15,8].

Inefficient management and disposal of MSW is an obvious cause for degradation of environment in the developing countries. Ecological impacts such as land degradation, water and air pollution are related with improper management of municipal solid waste [16]. In Asian developing countries, most of the municipal solid waste is dumped on land in more or less uncontrolled manner. Lack of sufficient awareness at the grassroots level of the waste generators add to the problem of littering. As a result there is a serious threat to public health due to environmental pollution. Unscientific disposal causes an adverse impact on all components of the environment and human health [17,18,19,20,21,22].

1.1 Laws for Management of MSW

Prior to 1974 certain laws at regional and national level were there to punish the offender for making nuisance in public places and pollution of water bodies. Even in 300-400 B.C. in Arthasastra of Kautilya (Chanakya) provisions were there to punish offenders for making nuisance in public places but these were either ineffective or not strictly enforced. Even the Environment Protection Act, 1986 was silent in solid waste management and the Govt. of India's consciousness is mostly after United Nations declaration and declaration by some developed countries. Laws pertaining to Solid Waste Management (SWM) since 1974 are as enumerated below [23]:

Post independence period

1974 Water (prevention and control of pollution) act amended in 1978 and 1988.
1981 Air (prevention and control of pollution) act - amended in 1987.
1986 Environment Protection Act (umbrella act) even was silent in MSW management.
1989 Hazardous waste management and handling rule.
1990 Govt. of India and Supreme Court insti-gated on the necessity of solid waste management.
1998 Bio-medical waste (management and handling) rules amended in 2000.
1999 Recycled plastic manufactured and usage rules.
1999 Solid waste management in Class-1 cities in India-guidelines by Supreme Court.
2000 Municipal waste (management and handling rules).

1.2 MSW Status in Punjab

In Punjab, growth of population, industrial-ization and urbanization has resulted in generation of large volumes of municipal solid waste. At present most of the solid waste is being disposed off in an unscientific manner [24]. A large volume of domestic solid waste is generated in both urban as well as rural areas of Punjab. As per Punjab Pollution Control Board [25], a total of 3034.65 tons per day of solid waste is being generated in municipal areas including Cantonment boards. Table 1 shows generation of MSW in major cities of Punjab [25]. The major municipal solid waste is from class I cities as more than half of the state's urban population (58.39%) lives in these cities. Further, out of total municipal solid waste generation, 71% of waste is from the five corporations (Ludhiana, Amritsar, Jalandhar, Patiala and Bathinda). The Ludhiana alone generates 31% of total MSW generated in the state. However, all municipal bodies do not have adequate infrastructure for handling the same. In urban Punjab, municipal solid waste is generally dumped outside the houses, shopping centre, offices, streets, etc or at some collection sites and is left for municipal authorities for taking it to a common dumping ground. It is common to find solid waste dumps near towns and cities. These dumps are mostly in depression or in open grounds. Widespread water, air and land pollution is caused from these dumps. The dumping sites are not properly managed nor have been planted with suitable plant species to help in quick degradation of solid waste by way of creating conducive for the growth of microorganism besides providing greenery. Appropriate post dumping practices are also seldom performed causing perpetual problem of air and water pollution. Table 2 and 3 shows the physical and chemical composition of the MSW generated in Punjab[25].

Table 1 Generation of MSW in major cities of Punjab

Municipal Corporation	MSW in TPD	Per capita per day generation in grams
Patiala	180	560
Ludhiana	850	610
Jalandhar	350	450
Amritsar	450	460
Total	1830	2080

TPD: Tonnes per day

Table 2 Physical Composition of MSW generated in Punjab

Category	Item	Percentage
Recyclable Material	Paper, Plastic, Rags	3-5
	Leather, Rubber, Synthetic	1-3
	Glass, Ceramics	0.5-1
	Metals	0.2-2
Compostable Material	Food articles, Fodder, Dung, Night soil, Leaves, Organic material	40-60
Inert Material	Ash, Dust, Sand, Building material	20-50
Moisture		40-80
Density		250-500 kg/m^3

Table 3 Chemical Composition of MSW generated in Punjab

Item	Percentage
Nitrogen	0.56-0.71
Phosphorus	0.52-0.82
Potassium	0.52-0.83
C/N	21-30
Calorific value	800-1010 Kcal/Kg

1.3 Leachate Generation and Characterization

One of the major pollution problems caused by the MSW landfill is landfill leachate, which is generated as a consequence of precipitation, surface run-off and infiltration or intrusion of groundwater percolating through a landfill, biochemical processes and the inherent water content of wastes themselves. Leachate is the liquid residue resulting from the various chemical, physical and biological processes taking place within the landfill. 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 transfer pollutants from the waste material to the percolating water [26]. After a landfill site is closed, a landfill will continue to produce contaminated leachate and this process could last for 30-50 years. Generally, leachate may contain large amounts of organic matter (biodegradable, but also refractory to biodegradation), as well as ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts, which are a great threat to the surrounding soil, groundwater and even surface water [27,28]. The compositions of leachate can be divided into four parts of pollutants. Organic matter such as: COD (chemical oxygen demand) and TOC (total organic carbon); specific organic compounds, inorganic compounds and heavy metals [29]. However, the organic content of leachates is often measured through analyzing sum of parameters such as COD, BOD (biochemical oxygen demand) and TOC and dissolved organic carbon.

The composition of landfill leachate, the amount generated and the extraction of potential pollutants from the waste depend upon several factors, including solid waste composition, degree of compaction, absorptive capacity of the waste and waste age, seasonal weather variations, levels of precipitation, landfill temperature, size, hydro-geological conditions in the vicinity of the landfill site, engineering and operational factors of the landfill, pH, landfill chemical and biological activities [30,31,32,33]. A simplified water balancing equation takes all of these factors into account and allows designers to predict an amount of leachate that will be produced by the landfill.

Canziani and Cossu [34] created this equation in particular:

$$\mathbf{L = P - R - DUs - ET - Duw}$$

L = leachate production
P = precipitation
R = surface run-off
Us = change in soil moisture
ET = actual evaporative losses from the bare-soil/ evapotranspiration losses from a vegetated surface
Uw = change in the moisture content of the refuse components

The production of leachate also varies widely through the successive aerobic, acetogenic, methanogenic and stabilization stages. The degradation process of the waste in a landfill passes through different phases. The first phase which is normally short is characterized by the aerobic degradation of organic matter. When the oxygen is depleted, the degradation continues anaerobically. The anaerobic degradation process consists of two major fermentation phases, the acidogenic phase generating "young", biodegradable leachate and the methanogenic phase, generating "old", stabilised leachate [35]. During fermentation organic molecules are broken down into simpler substances in an energy yielding process. Some physico-chemical characteristics are typical for each phase whereas other parameters are not specifically phase dependant.

"Young" leachate from the early acidogenic phase contains large amounts of readily biodegradable organic matter. The complex organic compounds are fermented anaerobically, yielding mainly soluble organic acids such as free volatile fatty acids (VFAs), amino acids, other low molecular weight compounds and gases like H_2 and CO_2 [36]. The concentration of VFAs can be quite significant, representing 95% of the TOC, leading to low pH (around 5). Typical COD values are 3,000-60,000 mg/l [37]. High ratio BOD_5/COD values of 0.5-0.7 indicate large amounts of biodegradable organic matter [38,39]. During this phase the metals are more soluble because of lower pH and the bonding with the VFAs, leading to relative high concentrations of Fe, Mn, Ni and Zn [36].

"Old" leachate from the methanogenic phase is partially characterized by the lower concentration of VFAs [38]. This is due to their conversion into CH_4 and CO_2 as gaseous end products during this second fermentation period. As the content of VFAs and other readily biodegradable organic compounds in the leachate decreases, the organic matter in the leachate becomes dominated by refractory compounds, such as humic like compounds and fulvic acid like substances [36]. Thus a low ratio BOD_5/COD, most often close to 0.1, is a characteristic value for stabilised leachates [39]. The humic substances give a dark colour to stabilised leachates. The decrease of VFAs results in an increase in pH. A characteristic pH value for stabilised leachates is around 8 [39]. The concentration of metal ions is in general low due to the decreasing solubility of many metal ions with increasing pH. However, lead is an exception, since it forms very stable complexes with the humic acids [36]. Besides the effect of the shifting pH on metal-ions, there is the reduction of sulphate to sulphide during this phase, which increases the precipitation of metals ions.

In general, the strength of leachate decreases with time due to biological breakdown of organic compounds and precipitation of soluble elements such as heavy metals. Due to its biodegradable nature, the organic compounds decrease more rapidly than the inorganic compounds with increasing age of leachate production. Therefore the ratio of total volatile solids to total fixed solids (VS/FS) decreases with the age of the landfill [38].

Three main groups of landfills are classified as young (less than five years), intermediate (5-10 years), and old or stabilized (more than 10 years). Table 4 summarizes the typical characteristics of leachate according to age of landfill [27,40]. The typical chemical concentrations in young and old landfill leachates comparing with sewage and groundwater are also shown in Table 5 [41].

Table 4 Characteristics of leachate at different ages of landfill

Parameter	Young	Intermediate	Old
Age (years)	< 5	5-10	>10
pH	6.5	6.5-7.5	>7.5
COD (mg/l)	> 10,000	4,000-10,000	<4,000
BOD_5/COD	> 0.3	0.1-0.3	<0.1
Organic compounds	80% volatile fat acids (VFA)	5-30% VFA+ humic and fulvic acids	Humic and fulvic acids
Heavy metals	Low-medium	Low	Low
Biodegradability	Important	Medium	Low

Table 5 Typical concentrations in landfill leachate comparing with sewage and groundwater

Parameters*	Young leachate concentration	Old leachate concentration	Typical sewage concentration	Typical groundwater concentration
COD	20,000-40,000	500-3,000	350	20
BOD_5	10,000-20,000	50-100	250	0
TOC	9,000-25,000	100-1,000	100	5
Volatile fatty acids	9,000-25,000	50-100	50	0

*All values in mg/l

Normally, young landfill leachate (the acid-phase landfill, <5 years) contain large amounts of biodegradable organic matter. More than 95% of the dissolved organic carbon (DOC) consists of volatile fatty acids, and little of high molecular weight compounds. In mature landfills (the methanogenic-phase landfill), the organic fraction in the leachate becomes dominated by refractory compounds, and the DOC content consists of high molecular weight compounds [42,43]. According to the study of Diamadopoulos, the concentration of the organic substances and the ratio of BOD to COD are generally higher during the active stage of decomposition and decrease gradually due to leachate stabilization [44].

In the present study, the experimental work is carried out to ascertain the composition of leachate generated from municipal solid waste landfilling sites of Ludhiana City, Punjab. Leachate samples were collected and analyzed for various physico-chemical parameters to estimate its pollution potential. The effect of landfill age on leachate composition was also studied. This study aims to serve as a reference for the implementation of the most suitable technique for reducing the negative environmental effects of discharge leachate.

1.4 Study Location

Ludhiana is the largest city in Punjab, both in terms of area and population. It lies between latitude $30^0$55'N and longitude $75^0$54'E.

The Municipal Corporation limit of city is spread over an area of 141 sq.km. The population of the city within the Municipal Corporation area is estimated at 34,87,882 in 2011 [45]. The climate of Ludhiana is semi arid with maximum mean temperature reaching upto 42.8^0C and minimum mean temperature is as below as 11.8^0C. Total rainfall during the year is 600-700 cm; 70% of total rainfall occurs from July to September. The altitude varies from 230m to 273m from mean sea level [46]. Leachate sample for the present study is collected from three major designated municipal solid waste landfilling sites available at Ludhiana (Table 6). No cover of any description is placed over the spread waste to inhabit the ingress of surface water or to minimize litter blow and odours or to reduce the presence of vermin and insects. Rag pickers regularly set fire to waste to separate non-combustible materials for recovery. Since, there are no specific arrangements to prevent flow of water into and out of landfill site, the diffusion of contaminants released during degradation of landfill wastes, may proceed uninhibited. None of these three landfill sites are lined and waste is directly dumped (without segregation) into the site. No proper compaction is done to compress the waste into the site.

Table 6 Landfilling sites of Ludhiana City

Sr.No.	Sites	Land area (acres)	Average depth (in ft.)	Future life (years)	Distance from city centre
1.	Jainpur	10	Filled	Nil	10 km
2.	Jamalpur	25	8 to 10	25	11 km
3.	Noorpur Belt	21	12 to 15	25	14 km

Source: Vision 2012, Ludhiana City Development Plan

2. MATERIALS AND METHODS

2.1 Leachate sampling and analysis

To determine the quality of leachate, integrated samples was collected from different landfill locations. Leachate sample for the study was collected from all the three landfilling sites of Ludhiana city i.e. first landfilling site is on Hambran Road at Jainpur Village having 10 acres of low lying land area which is oldest of other two and is now completely filled, second landfilling site is on Tajpur Road at Jamalpur Village having 25 acres of low lying land area and third landfilling site is at Noorpur Belt on an low lying land area of about 21 acres. These sites are non-engineered low lying open dumps. They have neither any bottom liner nor any leachate collection and treatment system. Therefore, all the leachate generated finds its paths into the surrounding environment. These landfilling sites were not equipped with leachate collectors. Leachate samples were collected from the base of solid waste heaps where the leachate was drained out by gravity. Leachate samples were collected in January end, 2012. Various physico-chemical parameters like *viz* pH, Total Solids (TS) Suspended Solids (TSS), Total Dissolved Solids (TDS), Turbidity, Hardness, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Chloride (Cl^-), Nitrate (NO_3^-), Total Phosphorus (TP), Sulphate (SO_4^{2-}) and heavy metals like Iron (Fe), Lead (Pb), Chromium (Cr), Cadmium (Cd), Copper (Cu), Zinc (Zn), Nickel (Ni) and Arsenic (As) were analyzed to determine pollution potential of leachate discharge from solid waste landfilling sites to estimate its pollution potential.

2.2 Analytical work

Analytical methods were according to "Standard methods for examination of water and wastewater" specified by American Public Health Association [47]. The pH was measured by electronic pH meter (4500-H^+.B of Standard Methods). Total Solids (TS) was determined by properly shaken unfiltered sample and estimated by gravimetric method (2540.B of Standard Methods). Total Dissolved Solids (TDS) was determined by filtered sample through Whatman filter paper-44 and estimated by gravimetry (2540.C: Standard Methods). Turbidity was measured by Nephelometer by using optical properties of light (2130.B of Standard Methods). Chemical Oxygen Demand (COD) was determined by refluxion of sample followed by titration with Ferrous Ammonium Sulphate (FAS) was adopted (5220.C: Standard Methods). Biological Oxygen Demand (BOD) - Winkler's method was used for estimating initial and final DO in the sample and BOD was determined (5210-B of Standard methods). Argentometric volumetric titration method in the presence of Potassium chromate provides reliable results of chloride (4500-Cl^-.B of Standard Methods). Nitrate was analyzed by HACH Portable

Spectrophotometer (DR 2800) by Cadmium Reduction Method (8039) adapted from Standard Methods at a wavelength of 450 nm [48]. Total Phosphorus was analyzed by HACH Portable Spectrophotometer (DR2800) by Molybdovanadate Method (10127) with Acid Persulfate digestion adapted from Standard Methods at a wavelength of 420 nm [48]. Sulphate was analyzed by HACH Portable Spectrophotometer (DR 2800) by SulfaVer 4 Method (8051) adapted from Standard Methods at a wavelength of 520 nm [48]. Heavy metals *viz* Iron, Lead, Chromium, Cadmium, Copper, Zinc, Nickel and Arsenic were analyzed using ELICO double beam SL 210 UV-VIS Spectro-photometer [49].

3. RESULTS AND DISCUSSION

Leachate samples of municipal solid waste landfilling sites of Ludhiana were collected and analyzed for various physico-chemical parameters to estimate its pollution potential. It has been found that leachate samples contain high concentration of organic and inorganic constituents beyond the permissible limits. While, heavy metals concentration was in trace amount as the waste is domestic in nature. The results of leachate analyzed for various physico-chemical characteristics and also standards for the discharge of treated leachates on Inland surface water, Public sewers and Land disposal were shown in Table 7.

3.1 Color and Odour

The color of leachate samples were orange brown or dark brown. Associated with the leachate was a malodorous smell, mainly due to the presence of organic acids, which come from the high concentration of organic matter when decomposed. The high concentration of colour in landfill leachate is due to the presence of high organic substances [50]. In general, leachate produced by an old landfill with low biodegradability is classified as stabilized leachate. Stabilized leachate contains high levels of organic substances such as humic and fluvic compounds, which can be indicated by leachate colour [51]. Humic substances are natural organic matter made up of complex structures of polymerized organic acids, carboxylic acids and carbohydrates [52].

3.2 pH

pH value of leachate samples of the landfilling sites were 9.3, 9.8 and 9.5, respectively. The results are consistent with those published by previous authors [53,54,55,56]. Higher pH values of 8.3-9.10 were recorded from the stabilized leachate of semi-aerobic landfill [51]. The pH varied according to the age of landfills [57]. Generally, the pH of a stabilized leachate is higher than that of a young leachate [58]. Leachate is generally found to have pH between 4.5 and 9 [59]. The pH of young leachate is less than 6.5 while old landfill leachate has pH higher than 7.5 [60]. Initial low pH is due to high concentration of volatile fatty acids [61]. Stabilized leachate shows fairly constant pH with little variations and it may range between 7.5 and 9. Chian and DeWalle reported that the pH of leachate increased with time due to the decrease of the concentration of the partially ionized free volatile fatty acids [38]. The increase in pH suggested that a steady state has been reached between acid producing processes (e.g., cellulose and lignin degradation) and acid consuming processes (e.g., methane formation) at the landfill [62].

3.3 TS, SS and TDS

TS and SS values of leachate samples of the landfilling sites were 5963 mg/l, 7695 mg/l, 6579 mg/l and 615 mg/l, 1132 mg/l, 886 mg/l, respectively. Typical SS values of 200-2000 and 100-400 mg/l were recorded for the new (less than two years) and mature landfills (more than 10 years), respectively [10]. TDS values of leachate samples of the landfilling sites were 5348 mg/l, 6563 mg/l and 5693 mg/l, respectively. TDS comprises mainly of inorganic salts and dissolved organics. TDS is one of the parameters taken into consideration for licensing discharge of landfill leachate in many countries such as in UK [63].

3.4 Turbidity

Turbidity values of leachate samples of the landfilling sites were 43 NTU, 79 NTU and 68 NTU, respectively. The leachate samples of Jamalpur and Noorpur belt landfilling site contained higher turbidity than that at Jainpur landfilling site due to the landfill age and stabilization of leachate. The turbidity values in the present study are consistent with those in previous studies [53, 64,65,66].

3.5 Hardness

Hardness values of leachate samples of the landfilling sites were 585 mg/l, 638 mg/l and 621 mg/l, respectively. The measured hardness values were considerably higher than the standard limit. The hardness values in the present study are consistent with those in previous studies [64,65,66].

3.6 BOD_5

BOD is the measure of biodegradable organic mass of leachate and that indicates the maturity of the landfill which typically decreases with time [67]. In this study, the BOD values for leachate at landfilling sites were 329 mg/l, 495 mg/l and 406 mg/l, respectively. The measured BOD values were considerably higher than the standard limit. BOD value varies according to age of landfills. For new landfills, BOD values were 2000-30000 mg/l; for mature landfills, BOD value varies from 100-200 mg/l [10]. Greater BOD values were reported by previous researchers [53,50,68,69].

3.7 COD

COD represents the amount of oxygen required to completely oxidize the organic waste constituents chemically to inorganic end products. The COD values for leachate samples of the landfilling sites were 1335 mg/l, 2535 mg/l and 2018 mg/l, respectively. The measured COD values were considerably higher than the standard limit. Greater COD values were recorded by other studies [54,64,51,70,66].

3.8 BOD_5/COD Ratio

Organics in leachate are characterized by different levels of biodegradability. In this study, the BOD_5/COD ratios for the collected leachate samples of the landfilling sites were 0.24, 0.19 and 0.20, respectively. The BOD_5/COD ratio is consistent with those recorded by other researchers [54,71,50]. Generally, the BOD_5/COD ratio describes the degree of biodegradation and gives information on the age of a landfill. The low BOD_5/COD ratio shows the high concentration of non-biodegradable organic compounds and thus the difficulty to be biologically degraded [68].

3.9 Chlorides

The chloride values of leachate samples of the landfilling sites were 1448 mg/l, 1836 mg/l and 1653 mg/l, respectively. The measured chloride values were considerably higher than the standard limit. Higher ranges of 490-1190, 360-4900 and 580-10100 mg/l were previously recorded by other researchers [53,57,72,69]. For new and mature landfills, the chloride values are 500 and 100-400 mg/l, respectively [10]. According to Deng and Englehardt (2007), the concentration of chlorides may range between 200-3000 mg/l for a 1-2 year old landfill and the concentration decreases to 100-400 for a landfill greater than 5-10 years old [73].

3.10 Nitrate

The nitrate values for leachate at landfilling sites were 12.5 mg/l, 18.6 mg/l and 15.9 mg/l, respectively. The measured nitrate values were considerably higher than the standard limit. Microbial decomposition of organic carbon influences on many processes of the nitrogen cycle. With time, nitrogen concentration decreased due to microbial utilization of nitrate compounds and denitrifying as ammonia gas [74]. Nitrates are the primary contaminant that leaches into groundwater. The United States Environmental Protection Agency (USEPA) has set a maximum contaminant level of 10 mg/l for nitrate in public water supplies [75].

3.11 Total Phosphorus

Total phosphorus values for leachate at landfilling sites were 52.8 mg/l, 83.5 mg/l and 64.3 mg/l, respectively. The measured total phosphorus values were considerably higher than the standard limit. Phosphorus is one of the key elements necessary for growth of plants and animals and is a backbone of the Kreb's Cycle and Deoxyribonucleic acid (DNA). Phosphorus transported from agricultural lands to surface water can promote eutrophication, which is one of the leading water quality issues in lakes and reservoirs. Current recommendations of USEPA, total P should not exceed 0.05 mg/l in a stream at a point where it enters a lake or reservoir and 0.1 mg/l in streams that do not discharge directly into lakes or reservoirs [75].

3.12 Sulphate

Sulphate values for leachate at landfilling sites were 48.7 mg/l, 65.1 mg/l and 53.8 mg/l, respectively. The measured sulphate values were considerably higher than the standard limit. Sulphate values of 98-374 and 22-650 mg/l were previously recorded by other researchers [57,72]. Typical sulphate values of 300 and 20-50 mg/l were recorded for new (less than two years) and mature (more than 10 years) landfills, respectively [10]. However, the measured sulphate values were exceeded the permissible level (0.50 mg/l). The sulphate content of leachate mainly depends on the decomposition of organic matter present in the solid wastes. It is expected to decrease with refuse age. This decrease is caused by the reduction of sulphate to sulphide coincident with the initiation of anaerobic conditions in the landfill [76]. Thus, the sulphate concentration in leachate can also be used as an indicator of waste stabilization within landfill.

3.13 Heavy Metals

Heavy metals *viz* Iron, Lead, Chromium, Cadmium, Copper, Zinc, Nickel and Arsenic values for leachate at landfilling sites were in trace amount as the waste is domestic in nature. In general, the concentration of heavy metals in landfill leachate is fairly low [59]. Concentration of heavy metals in a landfill is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids [57]. As a result of decreased pH at later stages, a decrease in metal solubility occurs resulting in rapid decrease in concentration of heavy metals except lead because lead is known to produce very heavy complex with humic acids [36]. A lower concentration of Cd

(0.006mg/l), Ni (0.13mg/l), Zn (0.61mg/l), Cu (0.07mg/l), Pb (0.07mg/l) and Cr (0.08mg/l) were found in 106 Danish landfills [59,77].

4. CONCLUSIONS

- All the three landfilling sites of Ludhiana city are non-engineered low lying open dumps. They have neither any bottom liner nor any leachate collection and treatment system. Therefore, all the leachate generated finds its paths into the surrounding environment.

- Leachate samples of landfilling sites were collected and analyzed for various physico-chemical parameters to estimate its pollution potential. It has been concluded that leachate samples contain high concentration of organic and inorganic constituents beyond the permissible limits. While, heavy metals concentration was in trace amount as the waste is domestic in nature. The measured leachate samples would need an appropriate treatment strategy to reduce the pollutants to a satisfactory level prior to discharge into receiving system.

- The age of the landfill has a significant effect on leachate composition. In older landfills, the biodegradable fraction of organic pollutants in the leachate decreases as an outcome of the anaerobic decomposition occurring in the landfill. The concentration of leachate contaminants at Jamalpur and Noorpur belt landfilling site were comparative greater than that of Jainpur landfilling site which is older than both. Based on the characterization of landfill leachate, Jamalpur and Noorpur belt landfilling site demonstrated low biodegradability i.e. $BOD_5/COD=0.19$ and $BOD_5/COD=0.20$ compared with Jainpur land-filling site i.e.$BOD_5/COD=0.24$.

- Indiscriminate dumping of municipal solid waste without proper solid waste management practices should be stopped or some remedial measures were required to be adopted to prevent contamination.

4.1 Remedial Measures

- Leachate management can be achieved through effective control of leachate generation, its treatment and subsequent recycling throughout the waste.

- Collected leachate can be distributed throughout the waste by means of spraying the leachate across the landfill surface. Some of the water may be lost through evaporation and therefore leading to reduction in the volume of the leachate for ultimate treatment.

- Engineered landfill sites should be provided with impermeable liner and drainage system at the base of the landfill, which will not allow leachate to percolate into subsoil. All the leachate accumulated at the base of the landfill can be collected for recycling or treatment.

Table 7 Comparative leachate characteristics of landfilling sites

Sr. No.	Parameters*	Jainpur landfilling site	Jamalpur landfilling site	Noorpur Belt landfilling site	Standards (Mode of Disposal)**		
					Inland surface water	Public sewers	Land disposal
1.	Appearance	Brownish	Brownish	Brownish	-	-	-
2.	Odour	Sewage smell	Sewage smell	Sewage smell	-	-	-
3.	pH	9.3	9.8	9.5	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
4.	TS	5963	7695	6579	-	-	-
5.	SS	615	1132	886	100	600	200
6.	TDS	5348	6563	5693	2100	2100	2100
7.	Turbidity (NTU)	43	79	68	5	10	10
8.	Hardness	585	638	621	300	-	-
9.	BOD (5 days at 25^0C) max.	329	495	406	30	350	100
10.	COD	1335	2535	2018	250	-	-
11.	BOD_5/COD	0.24	0.19	0.20	-	-	-
12.	Chloride	1448	1836	1653	1000	1000	600
13.	Nitrate	12.5	18.6	15.9	-	-	-
14.	Total Phosphorus	52.8	83.5	64.3	-	-	-
15.	Sulphate	48.7	65.1	53.8	-	-	-

*All values in mg/l except pH and turbidity
** Municipal Solid Wastes (Management and Handling) Rules, 2000

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