Chapter: 1

Introduction

1.1 General

Rising waste generation, environmental degradation, health hazard, climatic change and social conflicts have major influence on waste management practices.Environment friendly management of municipal solid waste (MSW) has become a worldwide challenge nowadaysbecause of its unscientificdumping in open areas.Fast economic growth, unplanned industrialization, increasing population and urbanization are responsible factors for the increase in municipal solid waste generation in most of the developing countries from the lastfew decades.

As per an estimate by Ministry of Environment Japan in 2006 [1] the amount of waste generated around the world stands at 12.7 billion tonnes in 2000 which will be increased to approximately 19 billion tonnes in 2025 and to approximately 27 billion tonnes in 2050.The management of municipal solid waste is a high priority issue for many communities throughout the world including India. Rising MSW generation rates and disposal costs, environmental and health concerns, limited landfill space, legislative changes, climate, and social attitudes have a significant impact on waste management efforts.

About 960 million tonnes of solid waste is being generated annually in India. Approximately, 350 million tonnes are organic wastes whereas 4.5 million tonnes are found to be hazardous in nature[2]. Hence, it is a big challenge for developing countries for complete recycling, reusing and scientific landfilling of solid wastes.According to CPCB (Central pollution control board) and IIR (Indian infrastructure report) reports, the annual MSW generation in India ranges between 40-55 million tons per year and this figure could be 270 million tons by 2047. About 0.1 million tonnes of MSW is generated in India per day, meansapproximately 36.5 million tonnes annually.Per capita waste generation in major Indian cities ranges from 0.2 to 0.6 Kg.Out of the total municipal waste collected, on an average 94% is dumped on land and 5% is composted. It is expected that the waste composition of Indian garbage will undergo the following changes between 2000 and 2025.Organic waste will go up from 40% to 60%,Plastic will rise from 4% to 6%,Metal will escalate from 1% to 4%,Glass will increase from 2% to 3%, Paper will climb from 5% to 15% and others (ash, sand, grit) will decrease from 47% to 12%[3].

According to Central Pollution Control Board 1, 27,486 TPD (tons per day) MSW were generated in India during 2011-12. Out of which only 5,881 TPD (12.45%) is processed or treated and rest is dumped unscientifically at open places. Sustainability in waste management is also more complex in the country due to rapid industrialization and urbanization and changing the waste composition and generation rates[4]. Pollution of air, water, and soil, due to the unmanaged dumping sites leads to risk for disease, disability, and death, also hamper economic growth and development in most of the developing countries [5].

The solid and liquid wastes generated out of the household and industrial activities are dumped and released in open dumping sites.During rainfall, the dumped solid wastes are decomposed and form a toxic inorganics and organics liquid called as leachate that contaminates groundwater. Such contamination of groundwater results in a substantial risk to local groundwater resource userand to the natural environment. Leachate produced from these waste dumping sites is heterogeneous and exhibit huge temporal and seasonal variations. The leachate from these dumping sites passes on to the adjoining soil and percolates through the landfill base. Colloid-facilitated transport mechanism increases the Contaminants leaching by direct dissolution of the MSW dumping waste [6]. This leachate has the potential to contaminate the groundwater sources due to the occurrence of a large number of pollutants such as acids, bases, inorganic contaminants and toxic organic materials[7].Landfill leachate is a very complex mixture comprising manytypes of contaminants (organics and inorganics) with variable concentration. In recent years researchers have found that landfill leachate formed by the process of hydrolysis and solubilization of MSW waste has the potential to contaminate local groundwater and may cause a possible health risk [8],[9],[10].Iwalewa and Makkawi (2015) [11] found in their result that toxic metals such as Pb, Cr, and Cd showing the same tendency in landfill leachate as in groundwater sample near the landfill sites.

Landfills have been identified as one of the main threats to groundwater resources and are exposed to either by groundwater underflow or infiltration from precipitation [12]. MSW (management and handling) rules 2000[13]of India is ensuring scientific collection, segregation, transportation, processing and disposal of MSW and upgrade of the present services to stop contamination of soil and groundwater. However, more than 90% of the MSW generated in India is directly disposed on land in an unsatisfactory manner [14]. Such poor disposal practices lead to problems that will harm the surrounding environment and human health through exposure routes like ingestion, dermal contact and inhalation in the shower[11]. Comparing the assessment of this highly toxic landfill leachate is essential for managing the impact of municipal landfills to control the groundwater contamination.Generally, the large amount of MSW is disposed off in low elevation areas without taking any protection measures and equipped controls that result in a serious threat to the human health and groundwater system.

Deshmukh and Aher (2016)[15]investigated the groundwater quality status by using inverse distance weight (IDW) method using Arc GIS, around the landfill area and revealed that groundwater is not safe for drinking and domestic purpose. To protect the groundwater contamination from the MSW leachate, characterization and assessment of leachate become essential for a sustainable waste management[16]. Leachate pollution index (LPI) is a useful tool for easy comparison of leachate contamination potential of different landfill leachate in a given geographical area. The index will also be useful in monitoring the leachate trends at a given landfill over a period of time apart from the many other proposed uses.Water quality index (WQI) is another effective monitoring tool, based on a mathematical model, for assessing the overall water quality for drinking purpose around any pollution source.

1.2 Municipal Solid Waste and leachate

Municipal solid waste (MSW) includes commercial and residential wastes generated in municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated bio-medical wastes [13]. Leachate formation is the result of the reaction between the various mineral phases in waste and the leaching fluid.Waste Management Hierarchy that is prevention, minimization, materials recovery, incineration and landfill has been included in municipal solid waste management strategies by most industrialized nations. These management strategies varies country to country depending on a large number of factors, including population density, transportation, topography, infrastructures, socioeconomics and environmental regulations [17].

Landfilling is the most commonly utilized strategy for the transfer of MSW. It has been accounted that 95 % of total MSW is being disposed of openly in landfills around the world. This method of transfer generates a complex liquid ordinarily known as leachate, because of abundant water in rainy season permeating through the waste layers. MSW characterization is very challenging due to its diversity. In the waste, not only food waste, paper and ash it also includes non-biodegradable plastic, electronic gadgets etc.

The biological process which is responsible for degradation of organics is very slow and may remain active as long as 25 years after the landfill closes the overall decomposition completed in four distinct phases. Biodegradation of organic waste is the main process in a landfill that manages the landfill biogeochemistry. During the first phase, aerobic organisms are active which may last for 0–5 years after this transition phase landfill entersinto the second phase (5−10) years in which acid-formers cause degradation. The third phase is the methane fermentation stage (15-20 years), and the final, steady-state maturation phase (greater than 20 years) occurs when microbial activity has stabilized[18].To assess the degree of impact of landfill leachate on the groundwater, both qualitative and quantitative methods are available [19]. But, none of both assured an exact evaluation of the actual situation due to the complexity of the leachate characteristic and soil and aquifer environment.

The main problem with the landfills is ground and surface water pollution with leachate [20]. Most of the groundwater contamination generally occurs during the first 20 years. After 25 years, the rate of contamination decreases and becomes very low. The groundwater contamination is mainly studied within1000 meters of a landfill. Therefore, the groundwater contamination caused by MSW landfills is a major point of concern for society [21]. When the landfill does not impose a threat to human health and environment in the absence of active controls, it is considered as functional stable landfill.A post-closure care of uncontrolled landfills is very essential for risk assessment over a long period which is based on the threat to human and environmental receptors. These threats are based on leachate quality and quantity, landfill gas production, system integrity and groundwater quality [22].

Leachate from the non-engineered landfill is one of the major sources of groundwater contamination in the vicinity of the landfill site. Clean and hygienic water is a vital commodity for the wellbeing of human society. Unfortunately, the groundwater is severely being deteriorated by anthropogenic forces like municipal landfill which consists of toxic materials and acts as one of the major pollutant source [23]. Therefore, it is emerging as a serious environmental threat to surface and sub-surface drinking water. The contaminated water is responsible for the transmission of many water-borne diseases like cholera, diarrhoea, dysentery, hepatitis, typhoid and posing a threat to public health[24]. Polluted water loses its economic and aesthetic value. Therefore, monitoring and assessment of groundwater quality are an important socio-economic necessity.

1.3 Characteristics of leachate

Two factors are mainly responsible for the leachate characteristics one is volumetric flow rate and other ischemical composition. The climate has also a great influence on leachate production because it affects the input of precipitation and loses through evaporation. Finally, leachate production depends on the nature of the waste itself, namely its water content and its degree of compactness into the dumping sites. The production is generally greater whenever the waste is less compacted since compactness reduces the filtration rate. The flow rate of leachate from open dumping sites varies both from site to site seasonally at each site. It is determined mainly by the climate which affects the input rainfall and losses through evaporation, and by the nature of waste itself. As a first approximation the quantity of leachate produced may be regarded as proportional to the volume of water percolating through the waste.

Assessment of leachate is to be done in designing, operation, planning for durable management of anMSW landfill. Landfills are generally classified into three main groups such as stabilized (>10 years), young (< 5 years) and intermediate (5-10 years). The data described in table 1.1 précises the typical characteristics of leachate according to the age of landfill. In a younglandfill, more than 95% of the dissolved organic carbon comprises of volatile fatty acids and little of high molecular weight compounds. In matured landfills (methanogenic phase landfill) the organic fraction in the leachate becomes dominated by refractory compounds.

Table1.1 Characteristics of leachate at different ages of the landfill[25][26].

Parameters	Young	Intermediate	Old
Age (years)	<5	5-10	>10
pH	6.5	6.5-7.5	>7.5
TDS (mg/l)	10,000-25,000	5000-10,000	<1000
BOD_5 (mg/l)	10,000-25,000	1000-4000	<50
COD (mg/l)	>10,000	4,000-10,000	<4000
BOD_5 /COD	>0.3	0.1-0.3	<0.1
Ca (mg/l)	2000-4000	500-2000	<300
Na, K (mg/l)	2000-4000	500-1500	<100
Mg, Fe (mg/l)	500-1500	500-1000	<100
Zn, Al (mg/l)	100-200	50-100	<10
Cl^- (mg/l)	1000-3000	500-2000	<100
Phosphate	100-300	10-100	<10
Organic compounds	80% volatile fatty acids (VFA)	5-30% VFA+ humic acid and fulvic acids	Humic acid and fulvic acids
Heavy metals	Low-medium	Low	Low
Biodegradability	Important	Medium	Low

Any assessment of the potential impact of the landfill on groundwater quality requires the attention of the leachate impact on the environment as well as the source of leachate contaminants. Landfilling technique (waterproof covers, liner requirements such as clay, geotextilesand plastics) remains primal to control the quantity of water entering the tip and so, to reduce the threat of pollution.

1.4 Groundwater pollution by MSW landfill leachate

The groundwater consists of water contained in the soil or aquifers, i.e., areas underlain by impermeable rock layer, called unconfined aquifer or areas between two impermeable rock layers, called confined aquifers or artisans. The mankind greatly depends on groundwater and because of its excessive use water table levels are reported to drop in many areas of the world.

The Groundwater tables are falling at approximately an average of 0.20 m per year in most of the part of the Ganga river basin and a tendency of groundwater quality deterioration is rising[27]. InIndia around 80% of all diseases are directly related to poor drinking water quality and unhygienic conditions. Polluted water loses its economic and aesthetic value. Therefore, monitoring the quality of water is an important task[28].

Goalsix of the 2030 Agenda for Sustainable Development recognizes the significance of ensuring the accessibility and sustainable management of water and sanitation.

More than 2 billion people lack access to safe drinking water and more than double that number lack access to safe sanitation. With a fast-rising global population, demand for water is estimated to increase by nearly one-third till 2050[29].In developing Asian countries, valuable groundwater resources exacerbated by inadequate financial resources, poor managementand technical skills within municipalities and government authorities.Intensive human activities have caused contamination to groundwater quality which subsequently affects human health[30]. A strong need is now being felt to take appropriate remedial measures to avoid contamination of the underlying soils and groundwater aquifers from the leachate generated from these MSW landfills in many developing nations including India [31]. Today, waste management practices involve disposal of waste in engineered sites known as sanitary landfills to protect the groundwater.

The impact of MSW landfill site has been considered to be an important source of soil, groundwater and surface water contamination due to the seepage of leachate by the different researcher in a differentperspective[10].The dispersion and diffusion of leachate pollutant into the groundwater depends on physical and chemical properties of contaminants and groundwater flow pattern. Seasonal variations in groundwater quality, particularly during rainy seasons due to degradation of solid waste material, the waste components are infiltrated with precipitation into the groundwater [26]. Hydrogeological factors such as rainfall, mineral weathering, the topography of study area and biological activity involves an important role in leaching and contamination of groundwater from MSW and anthropogenic activities[32], [33]. Chakraborty and Kumar (2016)[9] reported that the assessment of water quality based on the distance from landfill site is positively influenced by landfill leachate. Fernández et al. (2014)[34]concluded the high concentration of leachate plume contains sulphate, nitrate, iron, manganese, chromium contaminants near the center of the landfill site area, reaching an extension of900 m. Pejman et al., (2017)[35] were ranked the risk of most common heavy metal in the following order Cd >Pb>Ni>Cr>Zn>Cu on the basis of their toxicity. Some water quality parameter such as hardness, total alkalinity, chloride,and COD appear to be proportional to one another in a scattered way around the landfill site [33].Tongesayi et al., (2017)[36]observed an actual existence of lead contamination in groundwater by uncontrolled leachates from the landfill.The contamination in the groundwater due to leaching of toxic species from the MSW depends on the processes that fix the pollutants in soil and transport the contaminants to groundwater. Most of the pollutants reduced in quantity, toxicity and concentration with respect to time and type of landfill site either operational and open or old and closed.Mostly organic matter and nitrogen from landfill leachates are dominant for groundwater pollution[37].

Various chemical and physical factors are responsible for mobilization of constituents from the inorganic waste into the leaching medium. Chemical factors comprise waste composition and mineralogy, temperature, pH and redox potential, while a physical factor is characterized by specific surface area, particle size, porosity, hydraulic gradient, hydraulic conductivity, advection and diffusion [38]. Leaching is kinetically controlled by the rate of pollutant release via diffusion which is measured by effective diffusion coefficient among the physical hindrance factor such as porosity, pore structure, the degree of compaction and tortuosity slow the rate of pollutants released. The heavy metals contamination in groundwater does not affect the wells found at far points from the landfill source in a short time interval but when the time intervals extended more than 1 year the heavy metal concentrations decrease with distance[39].In groundwater assessment, many investigators applied IDW (Inverse distance weighted) method for interpolation of unknown points in GIS environment because of its neighborhood approach and spherical function to prepare the distribution map of the water pollutants [9],[40], [14], 41]. Geographical information system (GIS) is used to identify the groundwater polluted area near to the landfill that is very key step of groundwater quality management.GISis avery useful effectivetool inselection of dumping site area for municipal solid waste disposal[42].Groundwater modeling also plays an important role in understanding the groundwater systems, estimation of aquifer properties; and forecasting the future [43].

1.5 Groundwater flow and transport modeling

The groundwater model isa computer programto make a prediction of future behavior of the aquifer system. Models are used when it is easier to work with a substitute than with the actual system. Wang and Andersion (1982)[44]defined a model as designed to represent a simplified version of reality. The geologic condition, hydrologic condition,hydraulic properties and water budget determined the input data for a groundwater modeling.Groundwater models give the information about natural process that affect the aquifer system. Spatial distribution of geological properties and temporal behavior of groundwater flow is determined by groundwater flow model.Generally, an analytical solution can be obtained under many simplifying assumptions, such as unidirectional velocity field, a set of uniform transport properties [45], a simple flow domain geometry and simple pattern of the sink andsource distributiongroundwater models can be used for three generalpurposes.

1 To predict the expected change in aquifer.
2 To describe the system in order to analyse various assumptions about its nature and dynamics.
3 To generate a hypothetical system that will be used tostudy principlesof groundwater flow associated with various general or more specific problems.

1.6 Background of the research problem

The threat to the groundwater from the unlined and uncontrolled landfills exists in many parts of the world, particularly in the underdeveloped and developing countries where the hazardous industrial waste is also co-disposed with municipal waste and no provision of separate hazardous landfills exists.

Today, contaminated groundwater has turned into a significant issue in India. Critical pollution has been identified in 839out of 5,723 groundwater blocks across the country by Central Ground Water Authority. Industries dispose of their waste extensively in landfills and garbage dumps, toxic waste from which repeatedly percolate into groundwater and contaminate them. According to Central Ground Water Board (Government of India) in the country more than millions of tonnes of garbage are left untreated, toxic waste is bound to go underground and affect aquifers. The impact of

MSW landfill leachate on the surface and groundwater has given rise to a number of studies in recent years and gained major importance due to a drastic increase in population.

MSW landfill leachate can cause severe health and environmental impacts represented by soil, groundwater and surface water contamination which implies the necessity for leachate treatment before its ultimate disposal.The adverse impact of landfill on the environment and human health can be reduce by advance MSW management approach that improve the quality of life and supports economic development.

Currently many of the major cities in India are struggling with the issue of finding appropriate landfill area for MSW dumping purpose[42]. MSW is dumped unscientifically in a non-engineered way in open low lying area.

At present the municipal solid waste management in Varanasi City is not satisfactory due to fast urbanization and lack of specialized waste management practices as per MSW (2000) management and handling rule [13].The city has non-engineered and low-lying open dump area namely Ramana and Karsara. Municipal solid waste collected from different localities of the city and brought to an open area and dumped in a rough manner. It is observed that the landfilling of MSW is not done in a systematic and scientific way. The solid waste and soil cover are irregular at the site. The bottom of the dumping site is not lined and there is no establishment for the collection of leachate. Open dumping areas are very prone to flooding especially during the post-monsoon period of every year. The open wells and bore wells are the main source of water supply for drinking and other purposes in village area around the dumping site. The open dumping sites have been getting thousands of tons of solid wastes without proper segregation and pre-treatment. Therefore there is a greater chance of groundwater contamination by percolation of MSW leachate in the nearest open wells of the village area. The present study may help a local authority in the protection of groundwater pollution risk from the MSW landfill and to active post-closure monitoring until the leachate production is stabilized and attained sustainability.

1.7 Objective of the research

1. The objective of this study is to calculate the Leachate Pollution Index (LPI) of the MSWdumping sites and to know the overall pollution potential of the MSW leachate.
2. To assess the groundwater quality around the MSW dumping sites by evaluating the Water Quality Index (WQI) in pre- and post-monsoon period.
3. To estimate the status of groundwater quality around the MSW dumping sites by spatial interpolation of WQI in Geographical Information System (GIS) environment.
4. To develop the groundwater model of study area for finding the relationship between LPI, WQI and groundwater flow path and to predict the contamination from the open uncontrolled dumping site.

The WQI and LPI play an important monitoring tool for landfill policymakers and the local authority to safeguard groundwater pollution risk from the MSW landfill. This study can be helpful to landfill strategy makers as a scientific method for spatial pollution monitoring program.

The developed groundwater flow and transport model takes in accounts for prediction of the fate of various chemical species, which is present in MSW dumping leachate.