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Assessment of Groundwater Pollution near Municipal Solid Waste Landfill

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Abstract: The leachate produced by waste disposal sites contains a large amount of contaminants which are likely to pollute ground water. The impact of such sites upon ground water can be judged by monitoring the concentration of potential contaminants at a number of specific monitoring points. In this study, the quality of ground water around a municipal solid waste dumping site was investigated. It is clearly evident from the ground water monitoring that the leachate generated from the landfill site is affecting the groundwater quality in the adjacent areas through percolation in the subsoil and with the passage of time the concentration of most of the parameters were found to be increased. Thus the study revealed that the ground water in and around the landfill site should not be used for drinking purpose unless it meets specific standards. Indiscriminate dumping of wastes in developed areas without proper solid waste management practices should be stopped.

Key words: Leachate, landfill, municipal solid waste, groundwater pollution.

Introduction

Groundwater contamination is a major concern in landfill operations because of pollution effects of landfill leachates and its potential health risks (Lee and Jones-Lee, 1993; Christensen et al., 2001; Stollenwerk and Colman, 2003). Waste disposal by landfill has led to the pollution of groundwater resources under a wide range of conditions around the globe (Sangodoyin, 1993; Ahel et al., 1998; Christensen et al., 1998; Afzal et al., 2000). The impact of landfill sites on groundwater has been attempted by different workers in different perspectives (Robinson et al., 1982; Newell et al., 1990; Gaily and Gorelick, 1993; Kjeldsen et al., 1993; Meju, 1993; Tejero et al., 1993; Flyhammar, 1995; Vendrame and Pinho, 1997). Landfills have been identified as one of the major threats to groundwater resources (Fatta et al., 1999). 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 (Christensen and Kjeldsen, 1989). The composition of landfill leachate, the amount generated and the extraction of potential pollutants from the waste depend upon several factors, including waste composition, degree of compaction, absorptive capacity of the waste and age of waste, the climate, levels of precipitation, landfill temperature, size, geology, engineering and operational factors of the landfill (Leckie and Pacey, 1979; Kouzeli-Katsiri et al., 1999). Many approaches have been used to assess the contamination of underground water. It can be assessed

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either by the experimental determination of the impurities or their estimation through mathematical modelling (Butow et al., 1989; Stoline et al., 1993; Hudak,1998; Moo-Young et al., 2004).

Groundwater Pollution—Indian Scenario

In India, open dumping of solid waste in low lying areas is practiced in most of the centres which are managed by municipal agencies. A number of incidents have been reported where leachates have contaminated the surrounding ground water and surface water. Jeevanrao and Shantaram (1995) found that total hardness, alkalinity, BOD and COD values were beyond the prescribed limit in the ground water at both Amberpet and Golkonda solid waste landfill sites at Hyderabad. In urban areas the ground water is contaminated due to leachate from municipal solid waste disposal site and in rural areas, leachate from fertilizers used for agricultural purposes has contaminated the ground water (Eldho, 2001). Gopal et al. (1991) investigated the extent of groundwater pollution by solid wastes in Kanpur city. Olaniya et al. (1998) studied groundwater pollution due to refuse leachate. Kumaraswamy et al. (2000) has conducted a study on the movement of ground water in and around a solid waste disposal site near Andhra Pradesh. Mor et al. (2006) has reported the effect of municipal solid waste disposal on ground water around a landfill site at Delhi.

Statutory Regulations

The State regulatory authorities, in almost all countries, have framed regulations to safeguard against the contamination of groundwater resources from leachate. In India, the Municipal Solid Waste (Management and Handling) Rules, 2000 were enacted in October 2000 under the Environment Protection Act (EPA), 1986. According to these rules municipal authorities are responsible for the implementation of the provisions of these rules. As per these rules, engineered or sanitary landfills with provision of construction of non-permeable lining system at the bottom and the sides of waste matrix are to be constructed. A minimum liner specification of a composite barrier having 1.5 mm high density polyethylene geomembrane or equivalent, overlying a 90 cm of soil (clay or amended soil) layer having permeability coefficient not greater than 1×10^{-7} cm/sec is specified. The highest level of water table should be at least 2 m below the base of clay or amended soil barrier layer. Final landfill cover is applied over the entire landfill surface after landfill operations are completed. Landfill covers consist of successive layers of compacted clay or geosynthetic material, pebbles and soil layer for vegetation. These are designed to prevent infiltration, migration of landfill gas and limit the entry of surface water into the landfill, blowing of waste materials, prevent rats, flies and other disease vectors from entering the landfill. Prior to the commencement of monsoon season, an intermediate cover of 40-65 cm thickness of soil with proper compaction and grading should be placed on the divert runoff away from the active cell. Leachate is to be prevented from percolating to the soil and contaminate underground water and must be treated to meet the prescribed standards (MSW Rules, 2000).

In the present study, the impact of leachate percolation around a municipal solid waste disposal site on groundwater quality was investigated. The effects of distance of groundwater source from the dumping yard, contamination level of ground water and with the passage of time whether the concentration of various physico-chemical parameters were increased or decreased were investigated.

Experiment

Leachate Sampling

Leachate sample for present study was collected from municipal solid waste dumping site at Suchi Village; district Jalandhar near National Highway No. 1 that spreads over 0.8 hectares of low lying land area. Jalandhar is a major city of India lying at latitude 31.33° N and

Table 1: Generation of Municipal Solid Waste (MSW) in major cities of Punjab

Corporation	*Population in 10^5*	*MSW in TPD*	*Per capita per day generation in grams*
Patiala	3.23	180	560
Ludhiana	13.95	850	610
Jalandhar	8.5	350	450
Amritsar	9.75	450	460
Total	33.94	1830	539

TPD: Tonnes per day

longitude 75.58°E with a population of more than 8,00,000 and the municipal solid waste generated is about 350 tonnes/day. Details of municipal solid waste generated in major cities of Punjab are shown in Table 1 as reported by Punjab Pollution Control Board (PPCB, 2007). Municipal solid waste dumping site was operational since 2004, receiving non-hazardous municipal waste. The site was non-engineered low lying open dump, looked like a huge heap of waste up to a height of 6-10 m. No cover, of any description, was placed over the spread waste to inhibit the ingress of surface water or to minimize litter blow and odours or to reduce the presence of vermin and insects. Since, there were 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.

Groundwater Sampling

Groundwater samples were collected from hand pumps near solid waste dumping site. The underground water of the studied area is used for domestic and other purposes. Six groundwater sampling points were chosen representing six hand pumps located at different distance GW-1 (5 m ±1), GW-2 (10 m ±1), GW-3 (20 m ±1), GW-4 (25 m ±1), GW-5 (30 m ±1) and GW-6 (50 m ±1) from the landfill location within an area of 50 metres from the periphery of landfill site as shown in Figure 1. Groundwater sampling was carried out in July 2007 during the rainy season when a rise in water table was expected. Again after a time period of two years (i.e. July 2009) groundwater samples were collected from the same locations to determine the effect of leachate discharge from solid waste dumping site on groundwater of the adjoining area with time. The parameters were selected based on their relative importance in municipal landfill leachate composition and their pollution potential on groundwater resources (Lee and Jones-Lee, 1993). Chloride was included in the groundwater quality assessment because of its measure of extent of dispersion of leachate in the groundwater body (Chapman, 1992). All the sampled hand pumps were protected sources of domestic water supply for private use. Groundwater samples were collected in plastic containers which were previously cleansed with nonionic detergent and finally rinsed with deionized water prior to usage. As part of the quality control measures, samples were rinsed with sampled groundwater before being filled.

Analytical Work

Analytical methods as specified by American Public Health Association (APHA, 1998) have been used in the present investigation. The pH was measured by electronic pH meter (4500-H^+.B of Standard Methods). Turbidity of samples was measured by Nephelometer by using optical properties of light (2130.B of Standard Methods).

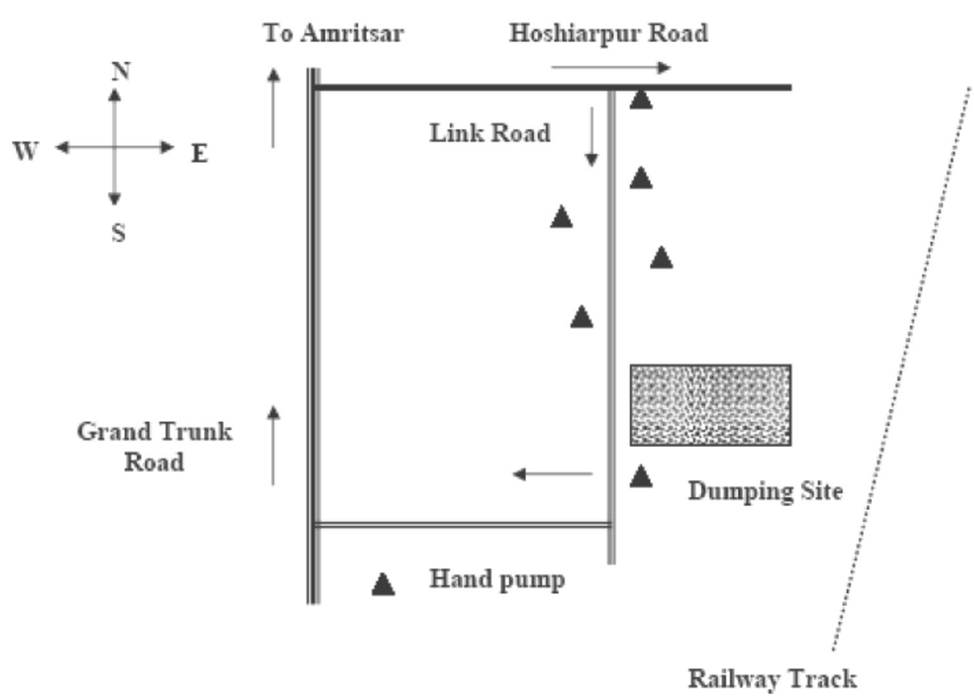


Figure 1: A sketch of the studied area with groundwater sampling points.

Properly shaken unfiltered sample was used and estimated by gravimetric method (2540.B of Standard Methods). Filtered sample through Whatman filter paper 44 enables to determine Total Dissolved Solids (2540.C of Standard Methods). Argentometric volumetric titration method in the presence of potassium chromate provides reliable results of chloride (4500-Cl^-.B of Standard Methods). Total Hardness-EDTA titration method with presence of Eriochrome Black T (EBT) indicator was adopted (2340.C of Standard Methods). Chemical Oxygen Demand (COD) refluxion of sample followed by titration with Ferrous Ammonium Sulphate (FAS) was adopted (5220-C of Standard methods). Biological Oxygen Demand (BOD) was determined by estimating initial and final DO in the sample (5210-B of Standard methods). Ammonical nitrogen, phosphate, iron, lead, chromium hexavalent and cadmium were estimated using spectrophotometer (UV-VIS Smart Spectrophotometer, 2000).

Results and Discussions

Leachate Quality

The results of leachate sample analyzed for various physico-chemical characteristics viz pH, Total Solids (TS), Total Dissolved Solids (TDS), hardness, turbidity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), chloride (Cl^-), ammonical-nitrogen (NH_3-N), phosphate (PO^-_4), iron (Fe), lead (Pb), chromium hexavalent (Cr^{6+}) and cadmium (Cd) of the landfilling site and also the standards for the discharge of leachate sample on inland surface water, public sewers and land disposal are shown in Table 2. The results indicated that physico-chemical characteristics of the leachate sample were beyond the permissible limits.

Groundwater Quality

The desirable and maximum permissible limit for groundwater quality standards recommended by Bureau of Indian Standard (BIS, 1991) and World Health Organization (WHO, 1997) are shown in Table 3. Various physico-chemical parameters viz pH, TS, TDS, hardness, turbidity, BOD, COD, Cl^-, NH_3-N, PO^-_4, Fe, Pb, Cr^{6+} and Cd were analyzed to determine pollution potential of leachate discharge from solid waste dumping site on ground water of the adjoining area. The results of groundwater samples analyzed for various physico-chemical characteristics are shown in Figure 2 (a-n).

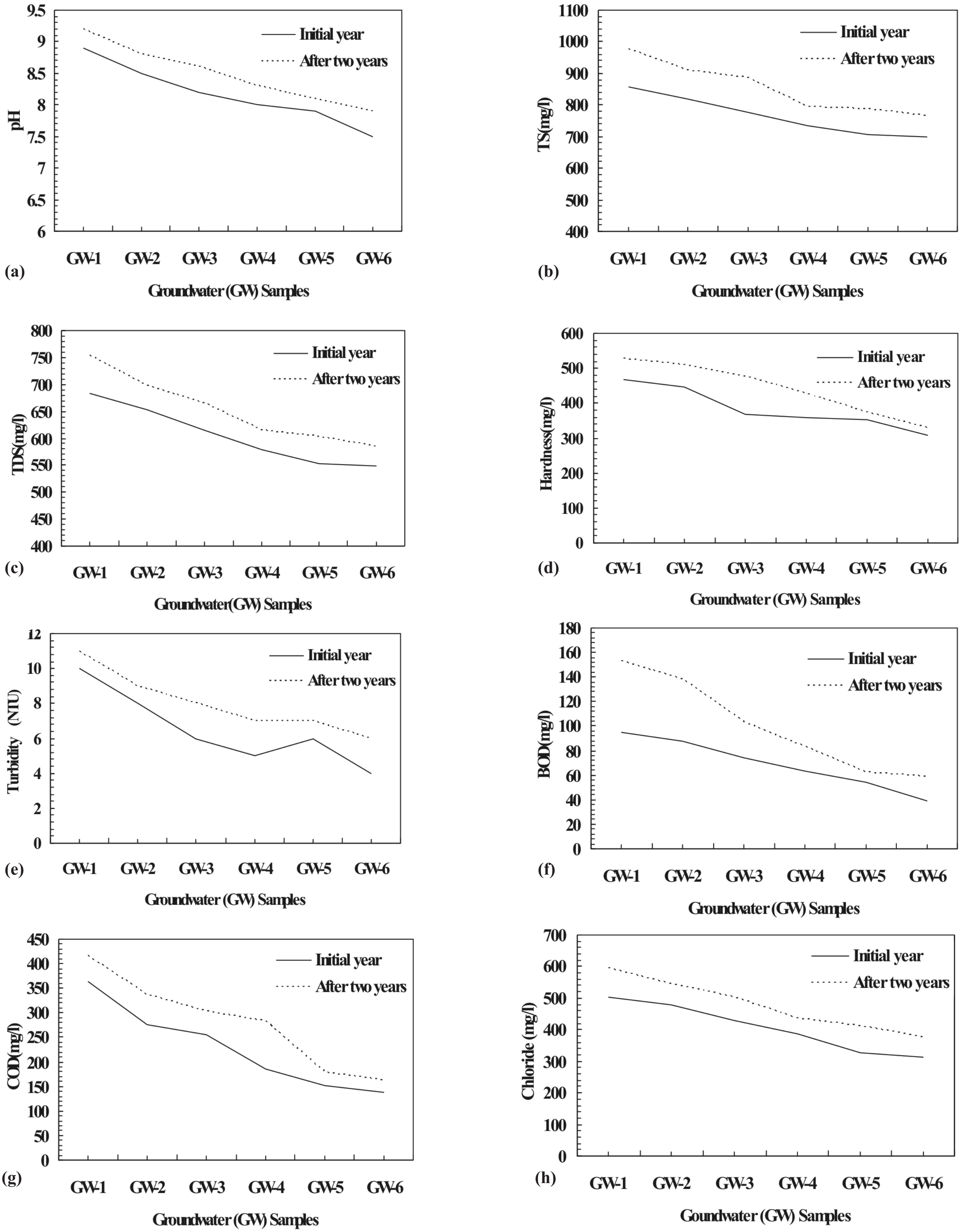
pH values of the groundwater samples initially were 8.9, 8.5, 8.2, 8.0, 7.9 and 7.5 and after a time period of two years were 9.2, 8.8, 8.6, 8.3, 8.1 and 7.9 as shown in Figure 2(a). It has been observed that the pH values of the groundwater samples were found to be increased with the passage of time; reason being with time the solid

Table 2: Physico-chemical characteristics of the leachate

*Parameters**	*Results*	*Standards (Mode of Disposal)***		
		Inland surface water	*Public sewers*	*Land disposal*
pH	10.3	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
TS	8600	-	-	-
SS	1800	100	600	200
TDS	6800	2100	2100	2100
Hardness	638	300	-	-
Turbidity (NTU)	30	5	10	10
BOD (3 days at 27° C) max.	809	30	350	100
COD	1690	250	-	-
Chloride	853	1000	1000	600
Amm-Nitrogen	83	50	50	-
Phosphate	78	-	-	-
Iron	6.6	0.01	0.01	-
Lead	0.9	0.1	1.0	-
Chromium hexavalent	1.5	2.0	2.0	-
Cadmium	3.2	2.0	1.0	-

* All values in mg/l except for pH and turbidity.

** Municipal Solid Wastes (Management and Handling) Rules, 2000


9.5
9
8.5
8
7.5
7
6.5
6
pH
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(a)
Groundwater (GW) Samples
1100
1000
900
800
700
600
500
400
TS(mg/l)
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(b)
Groundwater (GW) Samples
800
750
700
650
600
550
500
450
400
TDS(mg/l)
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(c)
Groundwater(GW) Samples
600
500
400
300
200
100
0
Hardness(mg/l)
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(d)
Groundwater (GW) Samples
12
10
8
6
4
2
0
Turbidity (NTU)
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(e)
Groundwater (GW) Samples
180
160
140
120
100
80
60
40
20
0
BOD(mg/l)
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(f)
Groundwater (GW) Samples
450
400
350
300
250
200
150
100
50
0
COD(mg/l)
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(g)
Groundwater (GW) Samples
700
600
500
400
300
200
100
0
Chloride (mg/l)
Initial year
After two years
GW-1
GW-2
GW-3
GW-4
GW-5
GW-6
(h)
Goundwater (GW) Samples

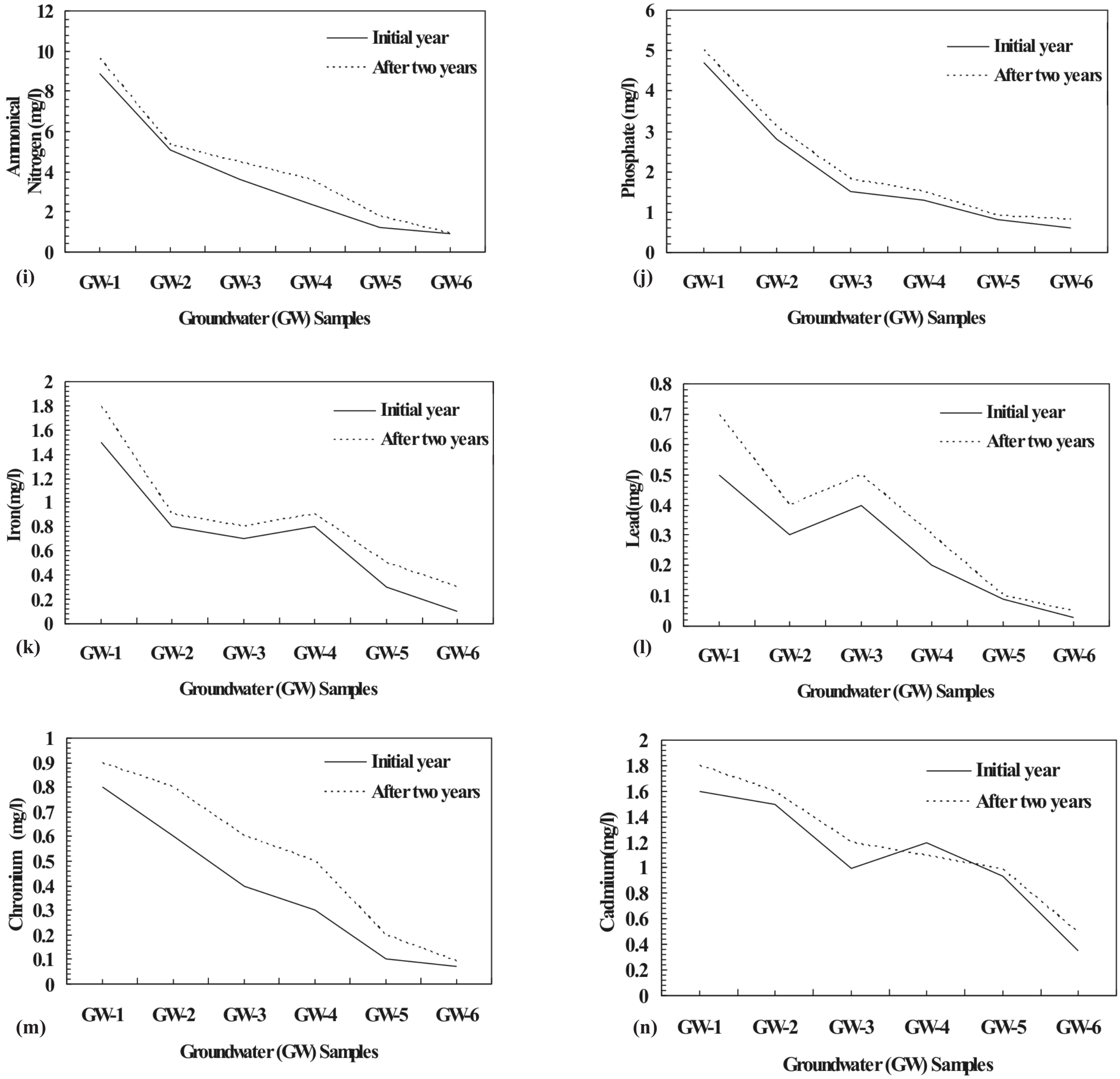


Figure 2: (a-n) Physico-chemical characteristics of groundwater samples.

waste material gets degraded and the waste constituents percolate down along with rainwater thus polluting groundwater near solid waste dumping site.

TS values of the groundwater samples initially were 857 mg/l, 818 mg/l, 776 mg/l, 733 mg/l, 705 mg/l and 699 mg/l and the TS values of groundwater samples after a time period of two years were 978 mg/l, 910 mg/l, 885 mg/l, 793 mg/l, 786 mg/l and 765 mg/l as shown in Figure 2(b). The TDS values of the groundwater samples initially were 683 mg/l, 654 mg/l, 616 mg/l, 578 mg/l, 553 mg/l and 549 mg/l and the TDS values of groundwater samples after a time period of two years were 754 mg/l, 698 mg/l, 665 mg/l, 615 mg/l, 603 mg/l and 585 mg/l as shown in Figure 2(c). This high value of TDS may be due to the leaching of various pollutants into the groundwater. The high concentrations of TDS decrease the palatability and may cause gastro-intestinal irritation in human and may also have laxative effect particularly upon transits (WHO, 1997). As per the classification of Rabinove et al. (1958) based on TDS, all the twelve samples were non-saline as shown in Table 4.

Hardness is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} in mg/l, equivalent $CaCO_3$. Hardness values of the groundwater samples initially

Table 3: Drinking water quality standards

*Parameters**	*BIS standards (IS 10500:1991)*		*WHO standards*
	Desirable limit	*Max. permissible*	
pH	6.5-8.5	6.5-8.5	6.5-9.2
TS	-	-	-
SS	-	-	-
TDS	300	1500	250
Hardness	300	600	300
Turbidity (NTU)	-	-	5
BOD	30	-	-
COD	250	-	-
Chloride	250	1000	200
Amm-N	-	-	-
Phosphate	-	-	-
Iron	0.3	1.0	0.3
Lead	0.05	-	-
Chromium hexavalent	0.05	-	-
Cadmium	0.01	-	-

* All values in mg/l except for pH and turbidity.

Table 4: Classification of groundwater samples on the basis of TDS concentration

Type of groundwater	*TDS (mg/l)*	*Samples*
Non-saline	<1000	12
Slightly saline	1000–3000	Nil
Moderately saline	3000–10,000	Nil
Very saline	>10,000	Nil

Table 5: Classification of groundwater samples on the basis of hardness

Hardness (mg/l)	*Descriptions*	*Samples*
0–60	Soft	Nil
61–120	Moderately hard	Nil
121–180	Hard	Nil
>180	Very hard	12

were 468 mg/l, 445 mg/l, 368 mg/l, 359 mg/l, 354 mg/l and 309 mg/l and the hardness values of the groundwater samples after a time period of two years were 528 mg/l, 509 mg/l, 476 mg/l, 428 mg/l, 375 mg/l and 329 mg/l as shown in Figure 2(d). Multivalent cations, particularly Mg^{2+} and Ca^{2+} are often present at a significant concentration in natural waters. These ions are easily precipitated and in particular react with soap to make it difficult to remove scum. Ca^{2+} often comes from carbonate-based minerals, such as calcite and dolomite. The excess of Ca^{2+} causes kidney or bladder stones and irritation in urinary passages. Mg^{2+} salts are cathartic and diuretic and high concentration may cause laxative effect, while deficiency may cause structural and functional changes. It is essential as an activator of many enzyme systems (WHO, 1997). According to the classification of Durfor and Becker (1964) for hardness, a very hard groundwater is dominantly distributed in the studied area as shown in Table 5.

Turbidity is a measure of the degree to which the water looses its transparency due to the presence of suspended particulates. The turbidity is expressed in NTU (Nephelometric Turbidity Unit). The turbidity of groundwater samples initially were 10 NTU, 8 NTU, 6 NTU, 5 NTU, 6 NTU and 4 NTU and the turbidity values of the groundwater samples after a time period of two years were 11 NTU, 9 NTU, 8 NTU, 7 NTU, 7 NTU and 6 NTU as shown in Figure 2(e). According to World Health Organization (WHO) standards, the turbidity of drinking water shouldn't be more than 5 NTU, and should ideally be below 1 NTU. At sampling sites, the turbidity of groundwater samples was found to be comparatively higher than standard limit.

BOD is one of the most common measures of pollutant organic material in water. BOD indicates the amount of putrescible organic matter present in water. The BOD values of the groundwater samples initially were 95 mg/l, 88 mg/l, 74 mg/l, 63 mg/l, 54 mg/l and 39 mg/l and the BOD values of the groundwater samples after a time period of two years were 153 mg/l, 138 mg/l, 103 mg/l, 83 mg/l, 62 mg/l and 59 mg/l as shown in Figure 2(f). The BOD values recorded for the groundwater samples were above the permissible standard limit. This may be due to the reason that with time the solid waste material gets degraded and the waste constituents percolate down along with rainwater thus polluting groundwater near solid waste dumping site.

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. The COD values of the groundwater samples initially were 365 mg/l, 276 mg/l, 255 mg/l, 185 mg/l, 152 mg/l and 138 mg/l and the COD values of the groundwater samples after a time period of two years were 415 mg/l, 338 mg/l, 303 mg/l, 283 mg/l, 179 mg/l and 163 mg/l as shown in Figure 2(g). The COD values recorded for the groundwater samples were above the permissible standard limit. This may be due to the reason that with time the solid waste material gets degraded and the waste constituents percolate down along with rainwater thus polluting groundwater near solid waste dumping site.

An excess of Cl^- in water is usually taken as an index of pollution and considered as tracer for groundwater contamination (Loizidou and Kapetanios, 1993). The Cl^- values of the groundwater samples initially were 504 mg/l, 480 mg/l, 428 mg/l, 388 mg/l, 326 mg/l and 314 mg/l and the Cl^- values of the groundwater samples after a time period of two years were 596 mg/l, 545 mg/l, 503 mg/l, 436 mg/l, 413 mg/l and 375 mg/l as shown in Figure 2(h). High Cl^- content of groundwater is likely to originate from pollution sources such as domestic effluents, fertilizers, and septic tanks, and from natural sources such as rainfall, the dissolution of fluid inclusions. Increase in Cl^- level is injurious to people suffering from diseases of heart or kidney (WHO, 1997).

Nitrogen is an essential nutrient for the growth of microorganisms, plants and animals. It is an essential building block for the synthesis of protein and therefore nitrogen data is required for the treatability of waste-water by biological processes (Metcalf and Eddy, 2003). NH_3-N accounts for nitrogen in the form of ammonium ion and ammonia gas. NH_3-N values of the groundwater samples initially were 8.9 mg/l, 5.1 mg/l, 3.6 mg/l, 2.4 mg/l, 1.2 mg/l and 0.9 mg/l and the NH_3-N values of the groundwater samples after a time period of two years were 9.6 mg/l, 5.3 mg/l, 4.5 mg/l, 3.6 mg/l, 1.8 mg/l and 0.9 mg/l as shown in Figure 2(i).

PO^-_4 values of the groundwater samples initially was 4.7 mg/l, 2.8 mg/l, 1.5 mg/l, 1.3 mg/l, 0.8 mg/l and 0.6 mg/l and the PO^-_4 values of the groundwater samples after a time period of two years was 5.0 mg/l, 3.1 mg/l, 1.8 mg/l, 1.5 mg/l, 0.9 mg/l and 0.8 mg/l as shown in Figure 2(j). PO^-_4 is one of the key elements necessary for growth of plants and animals and in lake ecosystems it tends to be the growth limiting nutrient and is a backbone of the Kreb's Cycle and Deoxyribonucleic acid (DNA). Algal blooms are the result of an excess of nutrients, particularly phosphorus.

Heavy metals concentration would account for a certain portion of toxicity in the leachate. Landfill leachate is one of the major sources of heavy metals discharged to surrounding environment. Heavy metals were reported at excessive levels in groundwater due to landfills operations (Lee et al., 1986; Stollenwerk and Coleman, 2003). The concentrations of heavy metals such as cadmium, iron, chromium and lead were analyzed using UV-VIS Smart Spectrophotometer.

Fe concentration in groundwater needs to be monitored because it becomes harmful above certain levels. Fe values of the groundwater samples initially were 1.5 mg/l, 0.8 mg/l, 0.7 mg/l, 0.8 mg/l, 0.3 mg/l and 0.1 mg/l and the Fe values of the groundwater samples after a time period of two years were 1.8 mg/l, 0.9 mg/l, 0.8 mg/l, 0.9 mg/l, 0.5 mg/l and 0.3 mg/l as shown in Figure 2(k). High levels of iron can cause discolouration of the water, and can impart an unpleasant taste (USEPA, 2002).

Pb values of the groundwater samples initially were 0.5 mg/l, 0.3 mg/l, 0.4 mg/l, 0.2 mg/l, 0.09 mg/l and 0.03 mg/l and the Pb values of the groundwater samples after a time period of two years were 0.7 mg/l, 0.4 mg/l, 0.5 mg/l, 0.3 mg/l, 0.10 mg/l and 0.05 mg/l as shown in Figure 2(l). Pb potentially effects human health causing serious damage to the brain, kidneys, nervous system and red blood cells (USEPA, 2002).

Cr^{6+} values of the groundwater samples initially were 0.8 mg/l, 0.6 mg/l, 0.4 mg/l, 0.3 mg/l, 0.1 mg/l and 0.07 mg/l and the Cr^{6+} values of the groundwater samples after a time period of two years were 0.9 mg/l, 0.8 mg/l, 0.6 mg/l, 0.5 mg/l, 0.2 mg/l and 0.09 mg/l as shown in Figure 2(m). Cr^{6+} potentially effects human health causing damage to liver, kidney, circulatory and nerve tissues; skin irritation (USEPA, 2002).

Cd values of the groundwater samples initially were 1.6 mg/l, 1.5 mg/l, 1.0 mg/l, 1.2 mg/l, 0.93 mg/l and 0.35 mg/l and the Cd values of the groundwater samples after a time period of two years were 1.8 mg/l, 1.6 mg/l, 1.2 mg/l, 1.1 mg/l, 0.98 mg/l and 0.49 mg/l. At all the six sites, the cadmium concentration were found to be comparatively higher than standard limit as shown in Figure 2(n). Cd potentially effects human health causing nausea, vomiting, diarrhea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure (USEPA, 2002).

It has been observed that the concentration of most of the physico-chemical parameters of the groundwater samples were found to be more than permissible limits and with the passage of time values of various parameters like BOD, COD and heavy metals increased, reason being with time the solid waste material gets degraded and the waste constituents percolate down along with rainwater thus polluting groundwater near solid waste dumping site.

Conclusions

It has been concluded that groundwater samples contain high concentrations of organic and inorganic constituents, including heavy metals; liners must be used at the landfill site. The presence of hand pumps near the landfill sites to draw groundwater threatens to contaminate the groundwater and immediate remediation steps should be taken at landfill site. It is clearly evident from the groundwater monitoring that the leachate generated from the landfill site is affecting the groundwater quality in the adjacent areas through percolation in the subsoil and with the passage of time the concentration of most of the physico-chemical parameters were found to be increased. Therefore, some remedial measures are required to prevent further contamination.

Remedial Measures

This can be achieved by the management of the leachate generated within the landfill. Leachate management can be achieved through effective control of leachate generation, its treatment and subsequent recycling throughout the waste. Engineered landfill sites are generally 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 (Mor et al., 2006). This 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. Techno-economic feasibility studies should be carried out for choosing the options for a landfill site.

Suchi Village site is a non-engineered landfill. It is neither having any bottom liner nor any leachate collection and treatment system. Therefore, all the leachate generated finds its paths into the surrounding environment. In such conditions some feasible options that could be followed are:

(i) Increasing the evapo-transpiration rate by providing vegetation cover over the landfill can reduce leachate production.

(ii) Extraction of the leachate collected at the base can be done and it can be recycled, so that less amount will enter the aquifer lying below.

(iii) Limiting the infiltration of the water through the landfill cover by providing impermeable clay cover. Due to this, less water will enter and subsequently less leachate will be generated, thereby reducing the amount of leachate reaching the landfill base.

(iv) Use of geo-synthetic clay liner (GCL) should be included in the barrier system to reduce/limit the flow of liquid.

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