Environ Monit Assess (2008) 143:227–238
DOI 10.1007/s10661-007-9971-0

# Impact of poor solid waste management on ground water

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Received: 24 May 2007 / Accepted: 27 August 2007 / Published online: 13 November 2007


**Abstract** The leachate produced by waste disposal sites contains a large amount of substances which are likely to contaminate 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 disposal site in Chennai was investigated. Chemical analyses were carried out on water samples collected at various radial distances from the boundary of the dumping yard, at intervals of 3 months and for a period of 3 years. The study has revealed that the ground water quality does not conform to the drinking water quality standards as per Bureau of Indian Standards. The effects of dumping activity on ground water appeared most clearly as high concentrations of total dissolved solids, electrical conductivity, total hardness, chlorides, chemical oxygen demand, nitrates and sulphates. Leachate collected from the site showed presence of heavy metals. The contaminant concentrations tend to decrease, during the post monsoon season and increase, during the pre monsoon season in most of the samples. The study clearly indicates that landfills in densely populated cities should have the ground water monitored on regular basis. Furthermore, ground water in and around the landfill sites shall not be used for drinking purposes unless it meets specific standards. Indiscriminate dumping of wastes in developed areas without proper solid waste management practices should be stopped.

**Keywords** Ground water contamination · Heavy metals · Leachate · Municipal solid waste · Open dumping yard

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## Introduction

In most of the developing countries, solid wastes are being dumped on land without adopting any acceptable sanitary land filling practices. Precipitation that infiltrates the solid wastes disposed on land mixes with the liquids already trapped in the crevices of the waste and leach compounds from the solid waste. The leachate thus formed contains dissolved inorganic and organic solutes. In course of time, the leachate formed diffuses into the soil and changes the physico-chemical characteristics of water.

Leachate from a solid waste disposal site is generally found to contain major elements like calcium, magnesium, potassium, nitrogen and ammonia, trace metals like iron, copper, manganese, chromium, nickel, lead and organic compounds like phenols, polyaromatic hydrocarbons, acetone, benzene, toluene, chloroform etc (Freeze and Cherry 1979). The concentration of these in the leachate and water depends on the composition of wastes (Alker et al. 1995). Some of the pollutants may be adsorbed on to the soil media during the flow of leachate through the soil.

The leachate migrates from unsaturated zone to ground water table. When leachate mixes with ground water it forms a plume that spreads in the direction of flowing ground water contaminating the ground water of the locality. The degree of contamination in the aquifers depends on the transport rate of contaminants and depository conditions at the site as the contaminants permeate through the soil media.

In the present study, the impact of leachate percolation on ground water quality was investigated around a municipal solid waste disposal site at Perungudi, Chennai. The effects of distance of ground water source from the dumping yard and temporal variations since dumping on the contamination levels were investigated.

## Ground water pollution – Indian scenario

In India, open dumping of solid waste in low lying areas is practiced in most of the centers which are managed by municipal agencies. A number of incidents have been reported where leachates have contaminated the surrounding ground water and surface water. In urban areas the groundwater 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 groundwater (Eldho 2001). Gopal et al. (1991) investigated the extent of ground water pollution by solid wastes in Kanpur city. Olaniya et al. (1998) studied ground water 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.

## Study area

Chennai is a major Indian city with a population of more than 6.98 million lying at latitude 13.04° N and longitude 80.17° E.There are two designated landfills, Perungudi in the south and Kodungaiyur in the north currently being used as open dumps for disposal of municipal solid waste from the Chennai city area. These sites are operated by the municipal corporation and accept wastes from Chennai only. The daily generation of waste in Chennai is 4,800 tons and is expected to reach 6,000 tons by the year 2010 (Table 1).

The Perungudi dump site is located towards the northern limit of a large topographic depression termed as the Pallikaranai Depression which stretches approximately 10 km north to south and is up to 3 km wide from west to east. The area is low lying, close to sea and is connected to the sea via the Buckingham canal and the Kovalam Estuary at the Southern end of the depression. The dump site lies between 2 and 3 km west of the Buckingham Canal and is at 3.5 to 4.5 km west of the Bay of Bengal coastline.

## Waste disposal activity at Perungudi dump site

The Perungudi dumping yard is in operation since 1987. The total area used for dumping is around 58 ha. The entire area is divided into several phases of dumping activity. The quantity of waste that is currently dumped in the yard is in the order of 2,450 tons per day. A variety of vehicles delivers the waste to the site resulting in a wide range of unloading procedures like end tipping, side tipping and manual unloading. Unloaded waste is tipped in conical piles and then spread out by bulldozers. No cover of any description is 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. Rag pickers and

**Table 1** Generation of municipal solid wastes in Chennai

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|
| Average tons per day | 2,724 | 2,887 | 3,316 | 3,312 | 3,761 | 4,200 | 4,600 | 4,800 |

**Table 2** Composition of waste

| Physical analysis | Values (%) | Chemical analysis | Values |
|---|---|---|---|
| Food waste | 8.00 | Moisture content | 27.60 |
| Green waste | 32.20 | pH value | 7.63 |
| Timber (wood) | 6.99 | Organic content (%) | 46.06 |
| Consumable plastic | 5.86 | Carbon content (%) | 21.53 |
| Industrial plastic | 1.80 | Nitrogen content (%) | 0.73 |
| Steel and material | 0.13 | Phosphorous (%) | 0.63 |
| Rags and textiles | 3.14 | Calorific value (in KJ/Kg) | 4,595 |
| Paper | 6.45 | Potassium (%) | 0.63 |
| Inerts | 33.98 | | |
| Rubber and Leather | 1.45 | | |

scavengers on site 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 land filled wastes, may proceed uninhibited. The refuse is dumped in low lying areas haphazardly. As a result, the adjoining land gets enriched in salts and trace metals. Dumped waste comes in contact with water causing pollution depending upon environmental conditions and solubility of metals. On the basis of the topographic survey, the thickness of deposited municipal solid waste is in the order of approximately 2m to 2.5 m spread over an area of 58 ha. Thus, the volume of solid wastes at present amounts to $1.31\times 10^7$ $m^3$.

As per water balance approach, the quantity of leachate generated is estimated based on the quantum of maximum rainfall intensity, run off coefficient of waste surface and evaporation losses. With the maximum monthly rainfall at 400 mm, runoff coefficient of 0.5 and evaporation losses of 150 mm, the quantity of leachate generated from the Perungudi dumping area is obtained as 348,000 $m^3$/year.

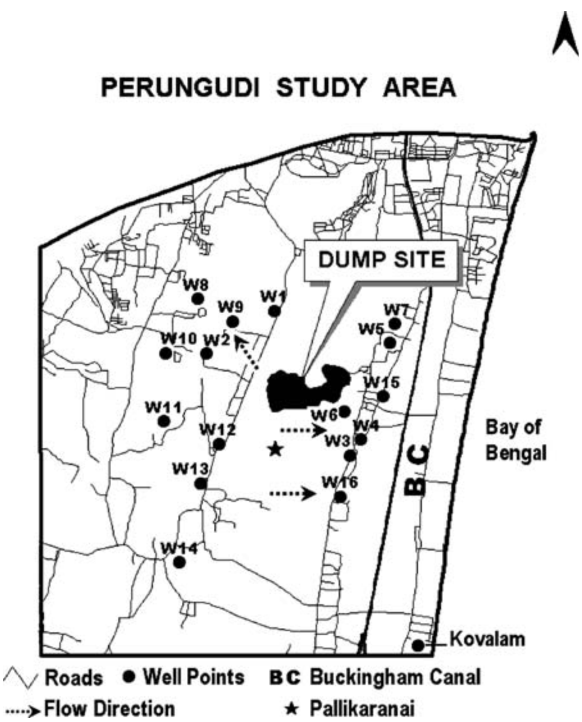


**Fig. 1** Study area with the location of sampling wells

**Table 3** Physical–chemical characteristics of leachate

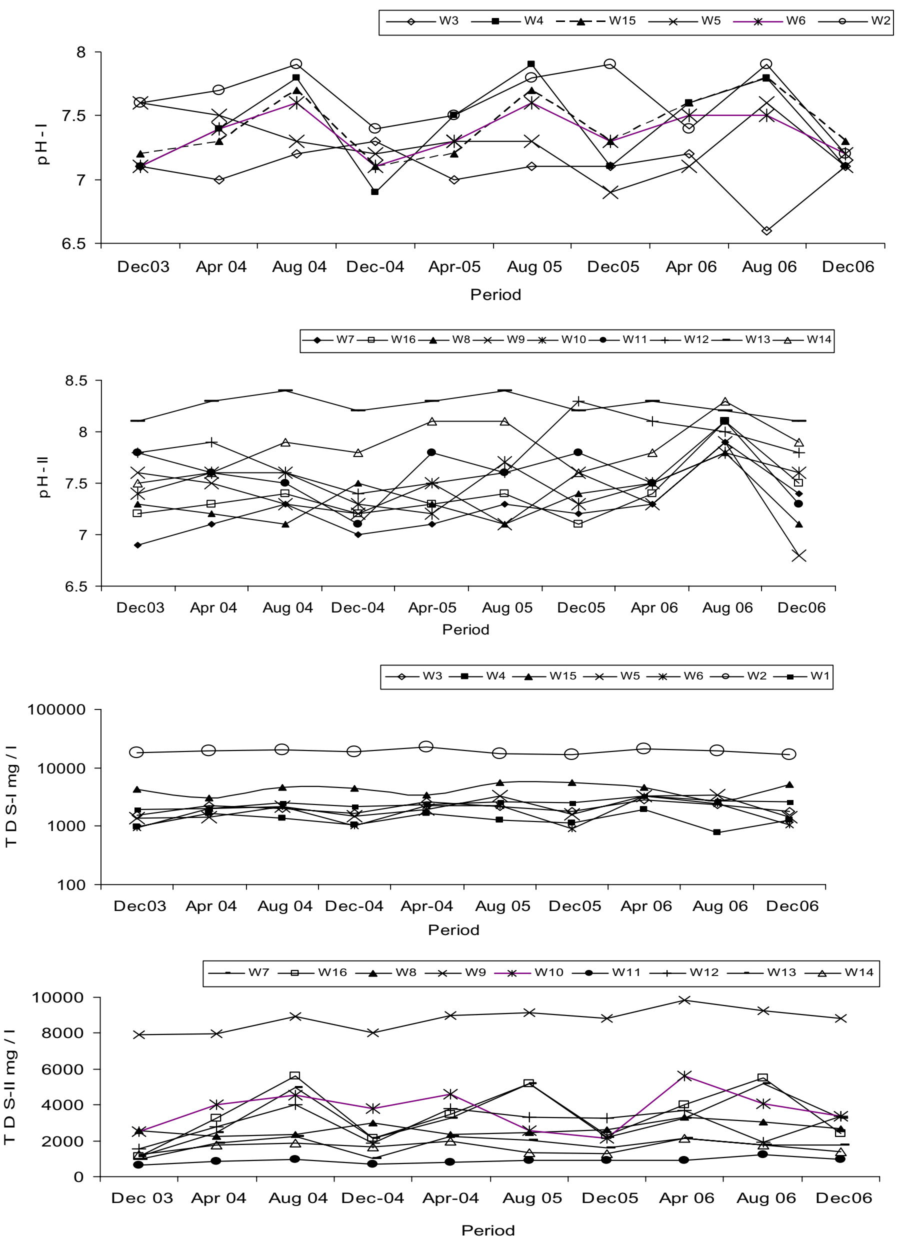
| Parameters | Concentrations (mg/l) |
|---|---|
| Physical examination | |
| Appearance | Blackish |
| Odour | Sewage smell |
| Turbidity, NTU | 182 |
| Total Dissolved Solids (TDS) | 26,212 |
| Electrical conductivity (EC; micro mho/cm) | 30,690 |
| Chemical examination | |
| pH | 7.83 |
| Total hardness as $CaCO_3$ | 1,475 |
| Calcium (Ca) | 400 |
| Magnesium (Mg) | 114 |
| Sodium (Na) | 1,850 |
| Potassium (K) | 1,325 |
| Iron (Fe) | 5.497 |
| Manganese (Mn) | 0.416 |
| Free ammonia | 189.28 |
| Chloride (Cl) | 1,731 |
| Sulphate ($SO_4$) | 552 |
| Phosphate ($PO_4$) | 83.3 |
| Silica | 256.98 |
| Arsenic | BDL |
| Lead (Pb) | 0.038 |
| Cadmium (Cd) | 0.021 |
| Copper (Cu) | 0.219 |
| Chromium (Cr) | 0.200 |
| Zinc (Zn) | 7.448 |
| Biological Oxygen Demand (BOD) | 17,800 |
| Chemical Oxygen Demand(COD) | 23,860 |

## Present investigation

*Sample collection and analysis* Relevant properties of waste, leachate and soils must be known for water contamination analysis. A drill rig with hollow stem augers was used to drill holes for solid waste sample recovery. The auger cuttings recovered were sealed in plastic bags and transported to the laboratory for analysis. A total of nine representative solid waste samples were collected for characterization. Table 2 shows the Physical and Chemical Composition of Perungudi Municipal Solid Waste.

Perforated PVC pipes of 10 cm diameter were inserted at points within the disposal area and leachate samples were collected for analysis. These leachates were filtered and preserved with a drop of concentrated nitric acid for soluble heavy metal analysis.

**Fig. 2** Concentration of pH, TDS at various sampling locations during different periods (*I* – wells within 1.25 km, *II* – wells beyond 1.25 km)



Ground water samples were collected from 30 open wells at various locations surrounding the dumping yard. On account of similar levels of contamination in some adjacent wells, data from 16 wells only are reported. The samples were immediately transferred to the laboratory and carefully stored for analysis. The samples were tested for relevant physico-chemical parameters pH, total dissolved solids, electrical conductivity, total hardness, chemical oxygen demand, chlorides, fluorides, nitrates, sulphates and heavy metals iron, copper, zinc, chromium, cadmium and lead. pH was measured in the field immediately after collection using water test meter. The other parameters were analyzed following the procedure specified in APHA (1994).

Figure 1 shows the study area and locations of the 16 sampling wells. To understand the effect of seasonal variation on the ground water quality, the samples were collected at intervals of 3 months for a period of 3 years (December 2003 to December 2006).

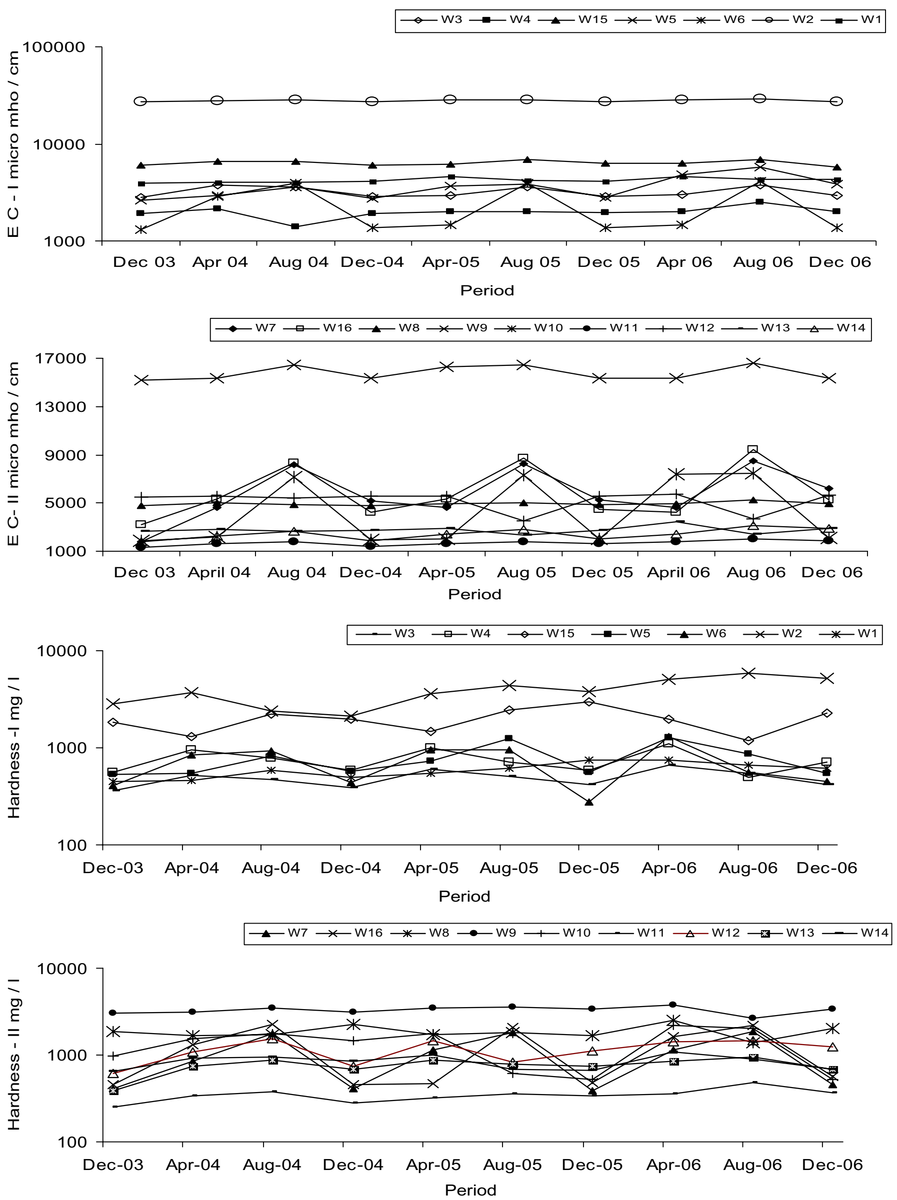



**Fig. 3** Concentration of EC, Hardness at various sampling locations during different periods (*I* – wells within 1.25 km, *II* – wells beyond 1.25 km)

## Results and discussion

Leachate is generated by different sources of moisture entering the waste like precipitation over uncovered waste, liquids present in the refuse, moisture resulting from decomposition and intrusion of ground water into the fill. The amount and production rates of contaminants depend on the type of waste and moisture content. Table 3, gives the characteristics of Perungudi leachate and indicates high values of total dissolved solids, electrical conductivity and chemical oxygen demand. pH values of the leachate varies from 6.8 to 8. Leachate samples indicate presence of heavy metals like Cd, Cr, Cu, Zn, Pb and Fe. The presence of metals in the leachate shows the effect of unsegregated solid waste containing steel scrap, lead batteries, tins, cans etc.To avoid such heavy metal contamination source segregation of waste is a must.

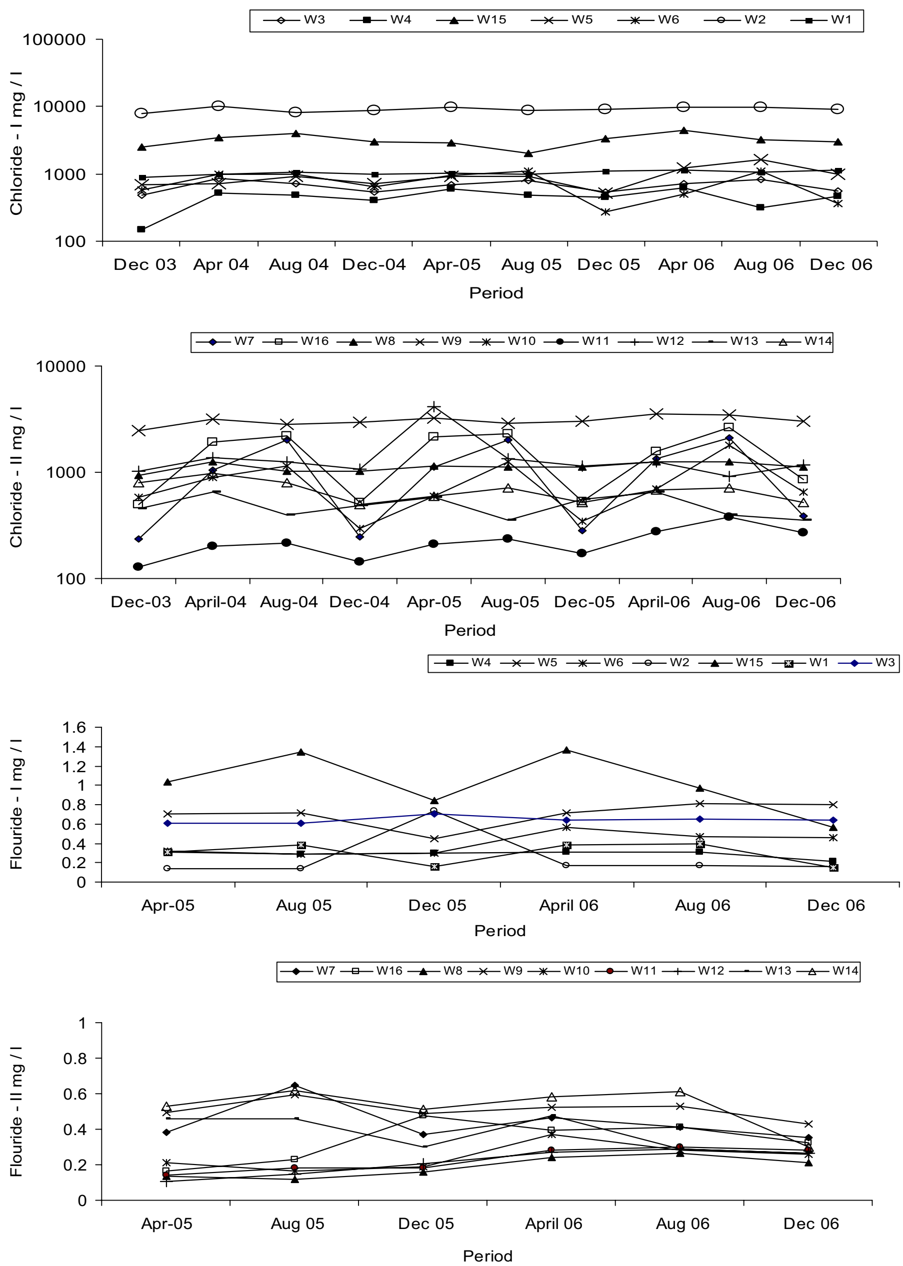



**Fig. 4** Concentration of Chlorides, Flourides at various sampling locations during different periods (*I* – wells within 1.25 km, *II* – wells beyond 1.25 km)

Figures 2, 3, 4, 5, 6, 7, and 8 present typical variations in contaminant concentrations with time for pH, total dissolved solids, electrical conductivity, hardness, chlorides, fluorides, nitrates, sulphates, chemical oxygen demand, Fe, Zn, Cu and Pb in the water samples collected.

Most of the water samples present high contaminant concentrations caused by the leachate. pH of the samples varies from 6.5 to 8.0. Wells located close to the disposal area is found to have high concentrations of electric conductivity, total dissolved solids, total hardness, chlorides and sulphates. Total dissolved solids are found to be in the range of 630 to 22,542 mg/l. During the post monsoon period, the total dissolved solids concentration was reduced but is still found to be at levels higher than the permissible limit. This high concentration is probably due to contamination by leachates that has in filtered the ground water from the disposal site. The high value of total dissolved solids is due to the high amount of inorganic material that has leached from the landfill. The high value of chemical oxygen demand indicates the presence of organic matter. The amount of chlorides is found to be greater than permissible

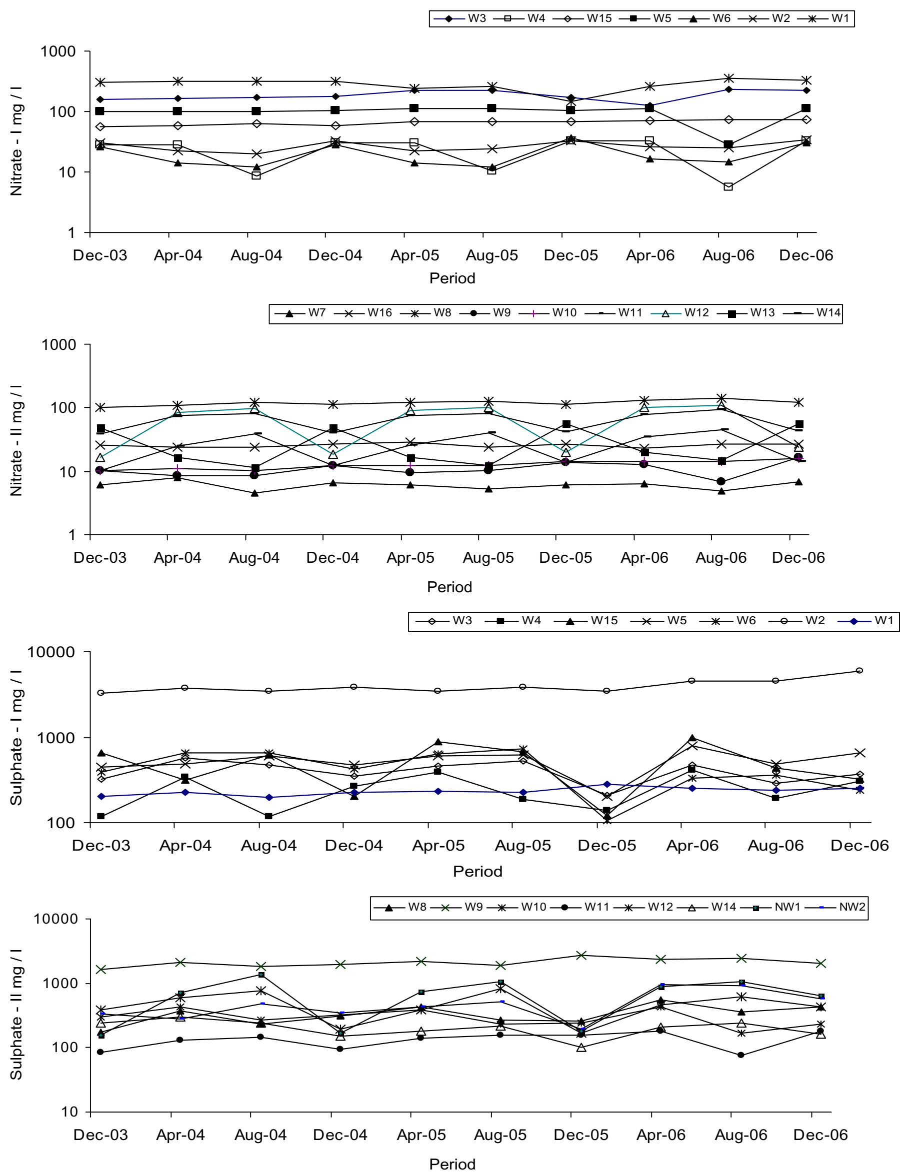



**Fig. 5** Concentration of Nitrates, Sulphates at various sampling locations during different periods. (*I* – wells within 1.25 km, *II* – wells beyond 1.25 km)

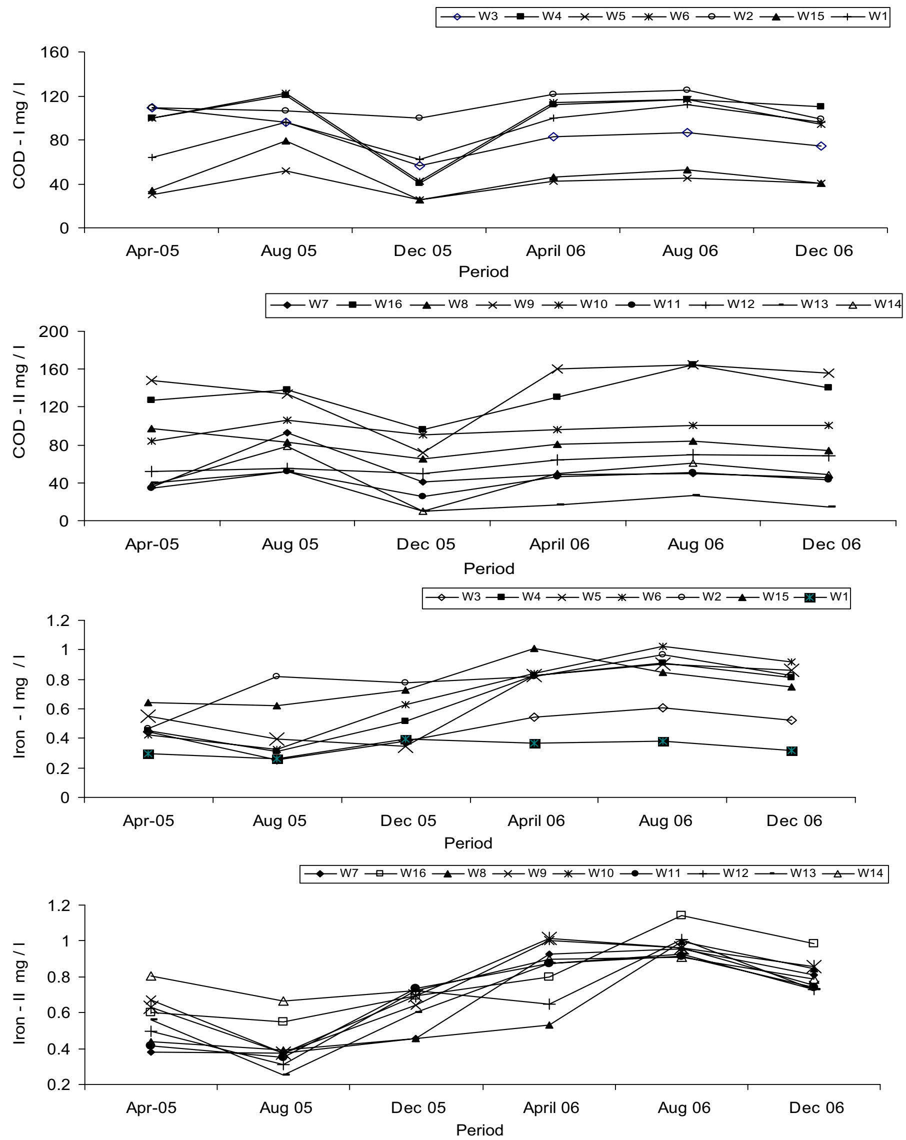



**Fig. 6** Concentration of COD, Iron at various sampling locations during different periods. (*I* – wells within 1.25 km, *II* – wells beyond 1.25 km)

amounts in most of the samples, both during post monsoon and pre monsoon periods. Total hardness is in the range of 250 to 5,800 mg/l and exceeds the permissible limit in most of the locations. The amount of nitrates and sulphates is found to be greater than the permissible at certain locations. The series of dominant cations and anions in the groundwater around the dumping site is found to be in the order of $Na^{+} > Mg^{++} > Ca^{++} > K^{+}$ and $Cl^{-} > HCO_3^{-} > SO_4^{2} > NO_3^{-}$.

The concentrations of Fe and Cu are found to be greater than desirable limits. The heavy metals Fe, Cu, Zn and Pb though are now less than the permissible they are found to be increasing with time. The heavy metals in water are less compared to that in the leachates. This can be due to the natural attenuation as pollutants move away from the source. The concentration of chromium and cadmium in the water samples were below detectable limits. It is inferred that if dumping continues above the life expectancy of the landfill, (20 years since dumping) level of contamination of the heavy metals Fe, Zn, Cu and Pb can exceed the permissible limits.

Table 4 gives the concentration range of contaminants in the wells at various distances. The contamination level is found to be high at most of the points within 1.25 km indicating the spread of the contaminant plume surrounding the dumping yard. The base

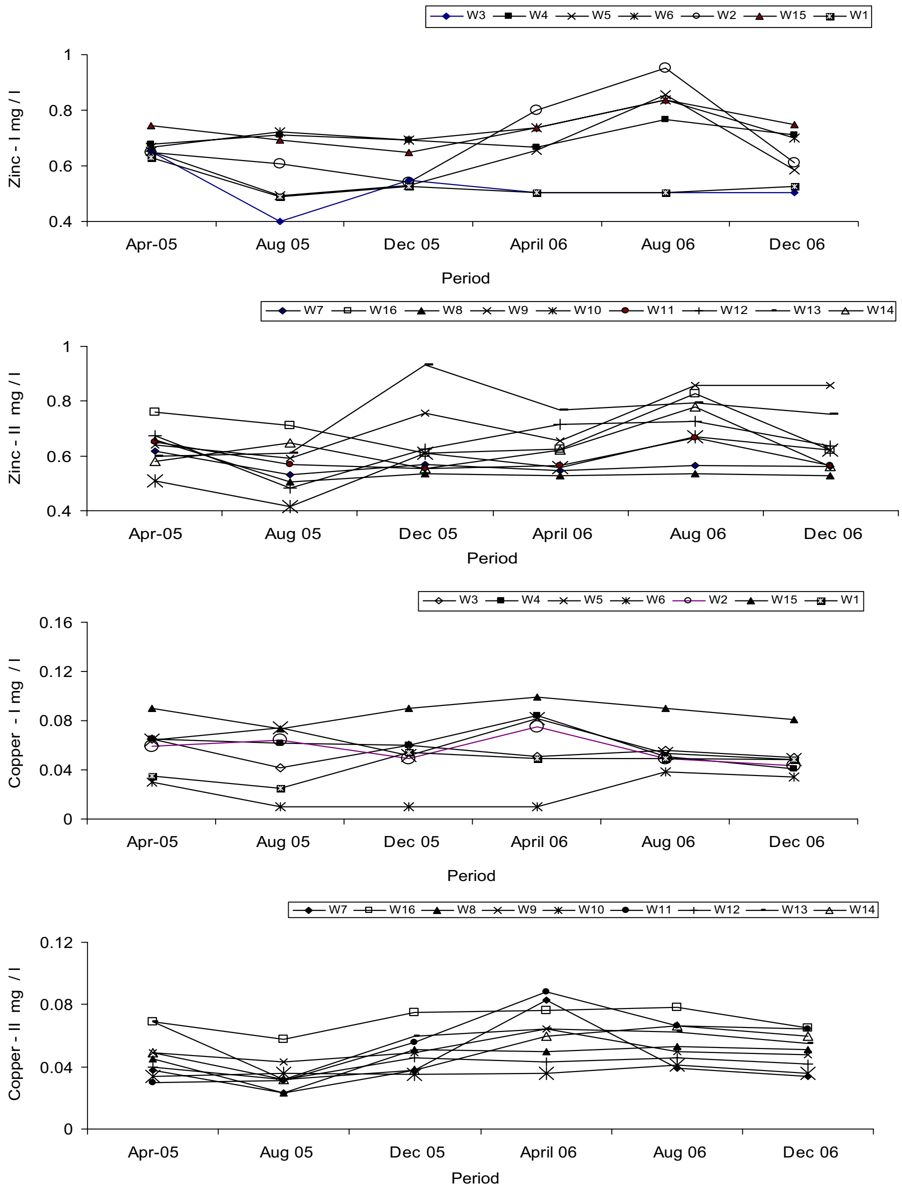


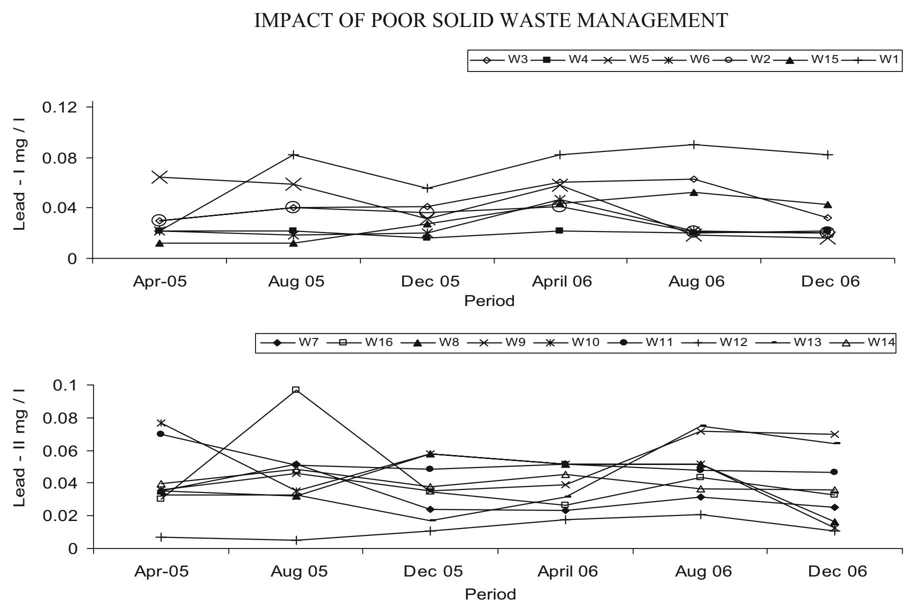

**Fig. 7** Concentration of Zinc, Copper at various sampling locations during different periods (*I* – wells within 1.25 km, *II* – wells beyond 1.25 km)

of the deposited waste is mostly inundated and significant thickness of waste may be submerged and hence quantity of leachate released will be substantially high causing the contamination level to increase in the surrounding area. Measured levels of contaminants are found to decrease progressively with increasing distance from the site.

The exceptionally high concentration of total dissolved solids, chlorides and hardness in certain wells may be attributed to some local geological variations like presence of fissured soil layer up to the point of well and absence of such fissures beyond the well zones. The contaminants being unable to spread through un-fissured layer get trapped and concentrated in these spots.

Chennai experiences two monsoons, namely, south west monsoon (June to September) and northeast monsoon (October to December) and the maximum rainfall occurs during the latter monsoon. The contaminant concentrations tend to decrease during the post monsoon seasons and increase during the premonsoon seasons in most of the samples. The samples were collected from open wells where water is used for domestic purposes. The less concentration

Fig. 8 Concentration of Lead at various sampling locations during different periods (I – within 1.25 km, II – beyond 1.25 km)




of total dissolved solids, chlorides and total hardness during the post monsoon period is due to dilution resulting from rainfall and the rain water harvesting scheme strictly implemented in this area. Especially during the monitoring period, Chennai experienced more than normal rainfall. This can be the reason for dilution of contaminants during the period. Table 5 gives the well-wise variation of few dominant chemical parameters during pre monsoon and post monsoon periods in 2006.

Ground water flow in the area is generally towards the east. A part of the flow is also towards the north west direction following the natural slope. The flow directions explain the larger contamination in the wells in the east and northwestern parts of the dump site. Once water enters the Buckingham Canal water quality parameters will be relatively constant due to dilution of contaminants in a relatively large body of water. In majority of the cases, the contaminant concentrations seem to be reasonably stable within a

**Table 4** Concentration range of contaminants in the wells at various distances

| Contaminants | Concentrations in wells within 1.25 km (mg/l) | Concentrations in wells beyond 1.25 km (mg/l) | Required[a] desirable limit (mg/l) | Maximum[a] permissible limit (mg/l) |
|---|---|---|---|---|
| PH | 6.6 to 7.9 | 6.8 to 8.4 | 6.5 –8.5 | 9.2 |
| TDS | 781 to 22542 | 631 to 9864 | 300 | 1500 |
| EC(micro mho/cm) | 1320 to 28600 | 1320 to 16600 | – | – |
| Total Hardness | 280 to 5800 | 250 to 3820 | 300 | 600 |
| Fluorides | 0.135 to 1.362 | 0.107 to 0.646 | 0.6 | 1.2 |
| Chlorides | 150.6 to 9800.25 | 129.20 to 4125.37 | 250 | 1,000 |
| COD | 25.58 to 122.40 | 10.221 to 164.21 | 20 | 20 |
| Nitrates | 5.58 to 353.40 | 4.5 to 142.60 | 45 | 45 |
| Sulphates | 105.60 to 5970.42 | 76.8 to 2678.40 | 150 | 400 |
| Fe | 0.258 to 1.024 | 0.251 to 1.142 | 0.3 | 1.0 |
| Zn | 0.39 to 0.953 | 0.416 to 0.931 | 5.0 | 10.0 |
| Cu | 0.01 to 0.099 | 0.023 to 0.088 | 0.05 | 1.5 |
| Pb | 0.0123 to 0.09 | 0.005 to 0.097 | 0.1 | 0.1 |

[a] Bureau of Indian Standards

**Table 5** Water qualities in the wells during premonsoon and postmonsoon period in 2006

| Well number | Chlorides (mg/l) | | Total hardness (mg/l) | | COD (mg/l) | | Nitrates (mg/l) | | Sulphates (mg/l) | | Flourides (mg/l) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | APR 2006 | DEC 2006 | APR 2006 | DEC 2006 | APR 2006 | DEC 2006 | APR 2006 | DEC 2006 | APR 2006 | DEC 2006 | APR 2006 | DEC 2006 |
| W1 | 1,120.25 | 1,125 | 750 | 610 | 100.20 | 96.21 | 262.24 | 324.24 | 254.60 | 255.68 | 0.382 | 0.154 |
| W2 | 9,826.24 | 9,015.34 | 5,040 | 5,140 | 121.45 | 98.76 | 26.24 | 34.26 | 4,507.44 | 5,970.42 | 0.173 | 0.164 |
| W3 | 715.34 | 560.80 | 670 | 420 | 82.41 | 74.42 | 124.60 | 224.60 | 473.73 | 371.39 | 0.641 | 0.641 |
| W4 | 624.21 | 460.24 | 1,100 | 710 | 112.24 | 110.21 | 32.24 | 32.48 | 413.38 | 304.79 | 0.313 | 0.21 |
| W5 | 1,213 | 984 | 1,260 | 550 | 42.23 | 40.12 | 110.46 | 112.48 | 803.31 | 651.65 | 0.714 | 0.80 |
| W6 | 500.12 | 365.21 | 1,320 | 450 | 113.44 | 94.21 | 16.24 | 30.24 | 331.20 | 241.80 | 0.566 | 0.456 |
| W7 | 1,350 | 383.60 | 1,160 | 460 | 48.14 | 45.16 | 6.4 | 6.8 | 894 | 644.03 | 0.466 | 0.352 |
| W8 | 1,256.11 | 1,125.13 | 2480 | 2010 | 80.12 | 74.26 | 132.24 | 120.49 | 561.38 | 425.26 | 0.240 | 0.21 |
| W9 | 3,560.12 | 3,025.21 | 3,820 | 3420 | 160.21 | 156.24 | 12.67 | 16.45 | 2,357.69 | 2,003.45 | 0.521 | 0.43 |
| W10 | 690.12 | 657.21 | 2,220 | 520 | 96.32 | 100.12 | 14.48 | 16.26 | 457.03 | 435.23 | 0.372 | 0.26 |
| W11 | 273.57 | 271 | 360 | 370 | 46.40 | 43.20 | 34.48 | 14.26 | 181.17 | 179.47 | 0.280 | 0.28 |
| W12 | 1,256.20 | 1,165.21 | 1,430 | 1,230 | 64.54 | 68.24 | 100.24 | 24.26 | 432.89 | 234.60 | 0.273 | 0.263 |
| W13 | 653.21 | 354.25 | 840 | 680 | 16.31 | 14.21 | 20.28 | 56.24 | 264.21 | 112.24 | 0.477 | 0.264 |
| W14 | 682.20 | 525.12 | 1,080 | 690 | 50.24 | 48.46 | 78.64 | 43.54 | 206.72 | 159.12 | 0.584 | 0.30 |
| W15 | 4,500.10 | 3,027.12 | 1,980 | 2,260 | 46.20 | 40.12 | 71.26 | 74.68 | 980.19 | 324.71 | 1.362 | 0.566 |
| W16 | 1,586.70 | 853.50 | 1,610 | 560 | 130.24 | 140.26 | 23.45 | 26.84 | 950.01 | 565.23 | 0.394 | 0.321 |

range (not rising over the years) during the 3-year study period. It is possible that contaminant plume might be spreading outwards from the dumping site. Additional analysis of water quality in the outer wells may yield more information regarding the spread of contaminants.

## Suggestions and remedial measures

Since it is found that the ground water surrounding the Perungudi dumping site is contaminated it is recommended that further dumping of wastes should be strictly prohibited in the area. This will help to reduce further flow of contaminants.

To prevent mixing of the leachate at the bottom of the Perungudi yard with the ground water source, number of bore wells should be drilled vertically over the entire dumping yard. The wells could be constructed and installed with slurry pump set for pumping of leachate. The leachate at the bottom of the yard could be pumped out either for recirculation or for collection and treatment. The leachate samples should be collected during pumping and analyzed to look into the permissible limits of standards prescribed in the regulations and then discharged into municipal drains. In order to prevent accumulation of storm water and rain water over the landfill an appropriate peripheral drain should be provided.

For designing of new disposal site, the bottom and sides of landfill should be provided with liners along with leachate collection and treatment facility so that the leachate generated would have minimum impact on water sources.

### Integrated waste management

In order to handle growing volumes of wastes in developing countries and to prevent environmental pollution, proper policies need to be enacted and implemented. Integrated waste management approach consisting of a hierarchical and coordinated set of actions that reduces pollution has to be enforced (Martin Medina 2002). Integrated waste management consists of the waste minimization techniques, waste prevention, reuse and recycling. Waste prevention seeks to reduce the amount of waste that individuals, businesses and other organizations generate. Once the waste prevention program has been implemented, the next priority in an integrated waste management approach, is promoting the reuse of products and materials. After the reuse of materials and products, recycling comes next in the integrated waste management hierarchy. Recycling is the recovery of materials for melting them, repulping them and reincorporating them as raw materials. It is technically feasible to recycle a large amount of materials, such as plastics, wood, metals, glass, textiles, paper, cardboard, rubber, ceramics, and leather. These waste minimization techniques would reduce the load in the landfills and also extend the life of the landfills.

### Composting, incineration

Considering the high proportion of organic matter in the waste generated in third world cities composting can also be an option to reduce the amount of wastes that are land filled, thus extending their lifespan. In an Integrated waste management approach, incineration occupies the next to last priority, after waste prevention, reuse, recycling and composting have been undertaken.

### Sanitary land filling

Sanitary landfills require significant investments and they often present political obstacles for their construction due to local opposition. Extending the life of landfills and diverting as much as possible by waste prevention, reuse, recycling and composting can make economic sense. Diverting materials from landfills can also create jobs, reduce poverty, improve economic competitiveness, reduce pollution and conserve natural resources. Sanitary landfills are necessary for final disposal of the wastes that could not be prevented, reused, recycled or composted. Ideally, sanitary landfills should be used primarily for non-reusable, non-recyclable and non-compostable residues. Sanitary landfills constitute a dramatic improvement over disposal of wastes in open dumps. Sanitary landfills greatly reduce pollution, risks to human health and the environment compared to open dumping.

## Conclusion

The high concentration of Total Dissolved Solids, Electrical Conductivity, Hardness, Nitrates, Chlorides, Sulphates, in ground water near landfill deteriorates the quality of water.

The principal threat to groundwater comes from inadequately controlled landfills where leachate generated from the fill is allowed to escape to the surrounding and underlying ground.

To minimize the impact of such landfills on ground water quality and the environment in general, it is necessary to properly design and build these facilities to prevent pollution.

Regular monitoring must be carried out over a large period, in order to verify the influence of seasonal variations on the contaminant concentrations with time.

Developing countries should strictly implement integrated waste management approach to handle large volume of wastes and protect environment.

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