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Impact of solid waste on water quality: a case study of Gokarna landfill site, Kathmandu

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ABSTRACT

The Gokarna landfill site (GLS) was in operation between 1986 and 1996. At present, there is a high risk of shallow aquifer contamination owing to the absence of a barrier layer and a high rate of leachate inflow from the landfill site. About 20 m thick sandy bed is transmitting pollutants to the shallow aquifer. The water quality analysis of shallow wells, dug wells, and springs around the GLS carried out between November 2003 and March 2004 revealed that they are polluted by the leachate. The heavy metal concentration, chlorides, iron as well as BOD and COD values depicted their increasing trend. Likewise, the microbial contamination was also high, and the water was unsuitable for domestic use. However, there is a low probability of contaminating the deep aquifer owing to the presence of impermeable layers of silt and clay above it. On the other hand, the amount of pollutants in the leachate has decreased significantly in recent years, especially after 1996.

INTRODUCTION

The Gokarna landfill site (GLS) is located in the north of the Kathmandu valley (Fig. 1). The site was developed under the support from German Technical Cooperation (GTZ) for the Kathmandu and Lalitpur (Patan) municipalities and came into operation in 1986. However, the GLS was closed down in 1996, when the local communities strongly opposed its operation and claimed that the solid waste threatened public health by deteriorating the environment and contaminating the shallow aquifers and springs. The GLS is surrounded by 20–30 m high hillocks (Fig. 2) of sand and silt. At present, landslides, gullies, and rills are developed on the slopes of the hillocks.

This paper deals with the hydrogeological situation of the GLS and attempts to evaluate the environmental impact of solid waste disposal at Gokarna. For this purpose, borehole data were collected from various reports and agencies. At the same time, the water quality of shallow wells and springs was tested in November 2003, March 2004, and August 2004.

PHYSIOGRAPHY AND CLIMATE

The Kathmandu valley is an oval-shaped intermontane basin exhibiting a centripetal drainage pattern. The valley extends about 30 km in the east–west and 25 km in the north–south directions. It occupies an area of about 650 sq km and ranges in altitude from 1220 to 1500 m. The GLS lies in a small valley (Fig. 1, 2), about 8 km (aerial distance) northeast of the Kathmandu metropolis, along the road to Sankhu. The valley is about 500 m long and 150 m wide, and is drained by a small tributary (called the Nagdaha) to the Bagmati River. The village of Mulpani is situated to the south of the GLS.

The study area lies in the subtropical zone, which is generally dry and hot between March and June (Fig. 3). The weather is punctuated by a few pre-monsoon thunderstorms with occasional hail. About 80% of the total annual rainfall occurs in the monsoon months of June to September (Fig. 4). The average annual rainfall varies from 1120 mm at Khumaltar (in the southern part of the valley) to 2740 mm at Kakani (in the northern extremity). The total annual rainfall also varies significantly – from 1000 to 2000 mm in the valley and from 1500 to 3300 mm in the mountains (JICA 1995).

GEOLOGY AND HYDROGEOLOGY

The sediments of the study area belong to fluvio-deltaic facies (Fujii and Sakai, 2002), and are exposed in road cuts and cliffs surrounding the GLS. Generally, they are covered by a topsoil layer comprising low plastic, light brown sandy silt with fibrous material. Black clayey silt, light brown cohesionless sandy silt, and reddish yellow to brown coarse sand are found respectively below the top soil. Rachana Consulting (1980) reported white micaceous medium sand from 170 m long lower reach (which was converted subsequently into the GLS) and black clayey silt from the upper reach of the Nagdaha Khola. Three lithological cross-

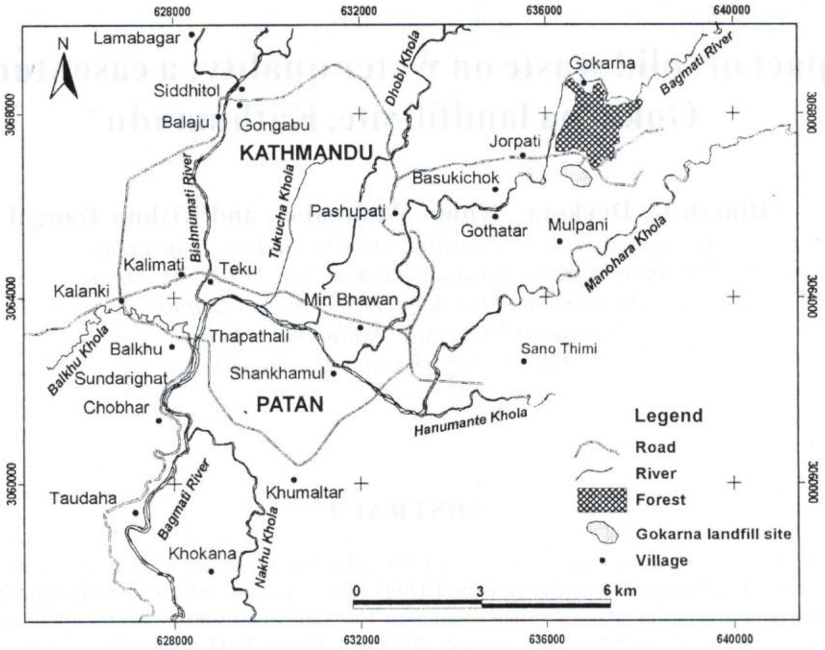

Fig. 1: Map showing the location of GLS

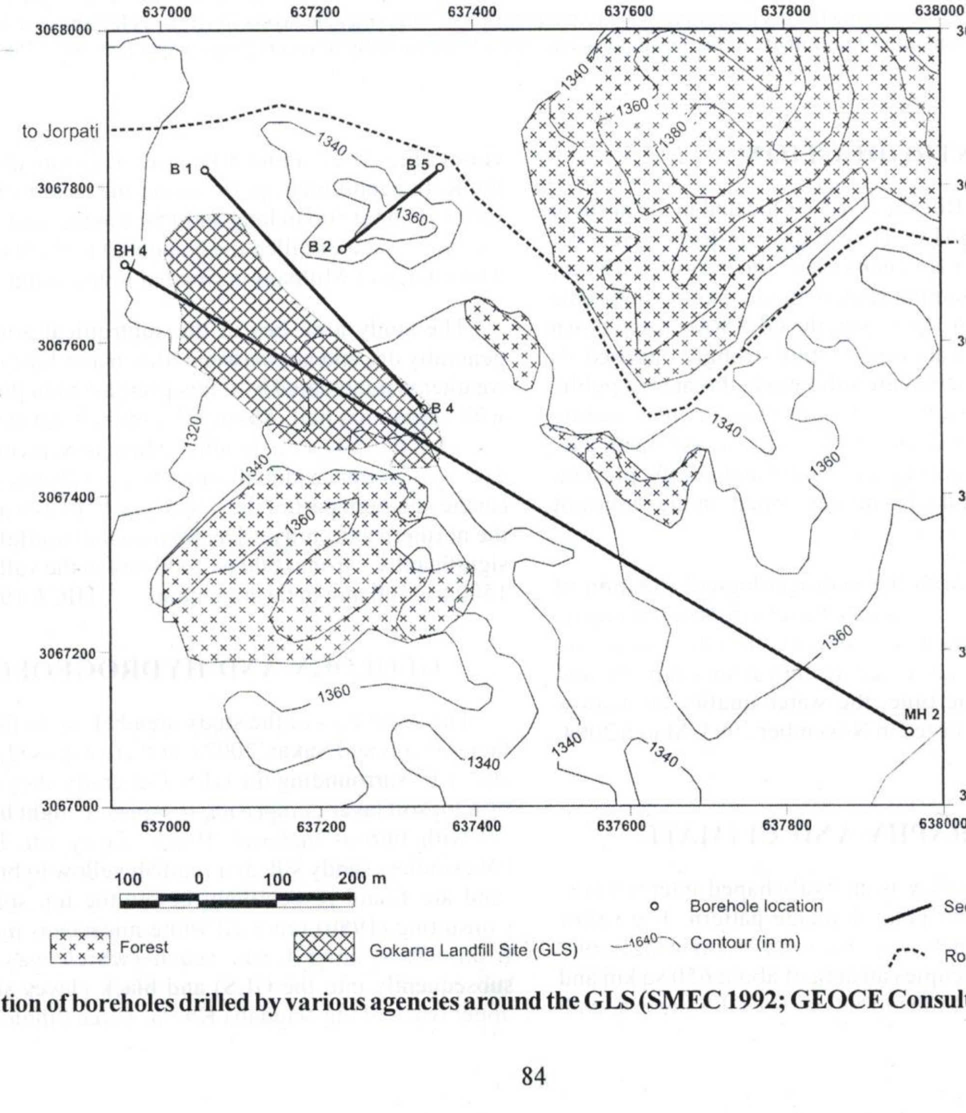

Fig. 2: Location of boreholes drilled by various agencies around the GLS (SMEC 1992; GEOCE Consultant Pvt. Ltd. 1990)

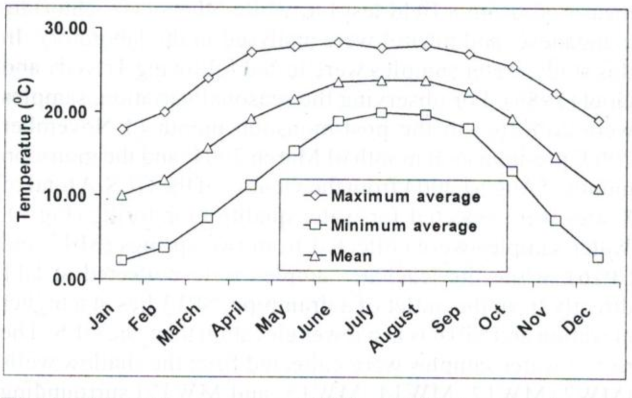

Fig 3: Monthly average (1971–1994) temperature at Kathmandu Airport (DHM 1977, 1982, 1984, 1986, 1988, 1995, 1997)

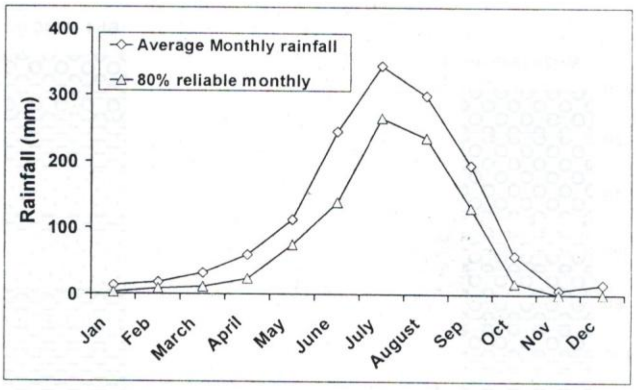

Fig. 4: Monthly average (1971–1994) rainfall at Kathmandu Airport (DHM 1977, 1982, 1984, 1986, 1988, 1995, 1997)

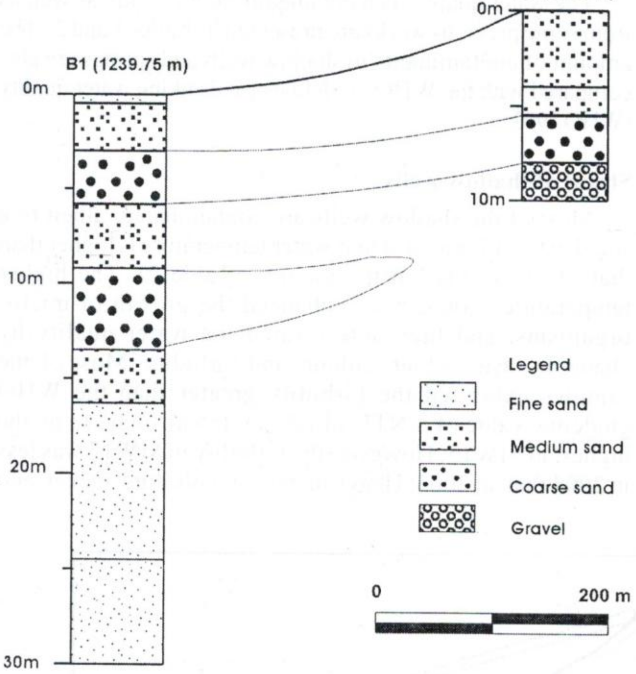

Fig. 5 Geological cross-section along B1 and B4 (GEOCE Consultant Pvt. Ltd. 1990)

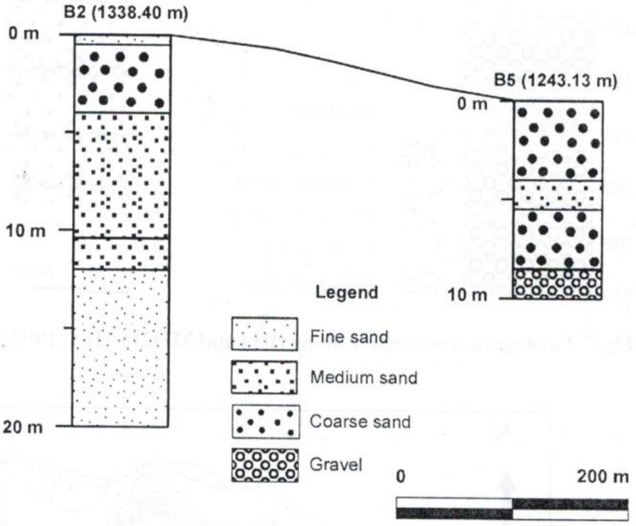

Fig. 6 Geological cross-section along B2 and B5 (GEOCE Consultant Pvt. Ltd. 1990)

sections (Fig. 2, 5, 6, 7) were prepared by extrapolating the borehole data collected from various agencies (BH4 and MH2: SMEC 1992, B1 and B4; B2 and B5: GEOCE Consultant Pvt. Ltd., 1990). The lithology is predominated by sand and gravel up to a depth of 20 m, except in borehole BH4 where some silt and clay lenses are also present.

The GLS lies in the northern foothills constituting the major groundwater recharge zone of the Kathmandu valley. There are shallow as well as deep aquifers around the GLS. The shallow aquifers are up to 20 m thick and comprise sandy layers, whereas the confined deep aquifers attain a thickness of tens of metres. Most of the neighbouring villagers on the downstream side of the GLS are using the water from many shallow (<10 m deep) dug wells and roar pumps. The aquifers in these sandy layers are prone to contamination by the leachates of the GLS. The solid waste dumped on the GLS is not covered properly and has no proper drainage system. Consequently, the runoff erodes the waste by making rills and gullies, and reaches the shallow aquifers through infiltration and percolation carrying dissolved contaminants with it (Fig. 8).

WATER QUALITY

The pollution status and its trend were assessed on the basis of present water quality study as well as the past reports. Some parameters (viz. pH, electrical conductivity, dissolved oxygen (DO), turbidity, and temperature) were

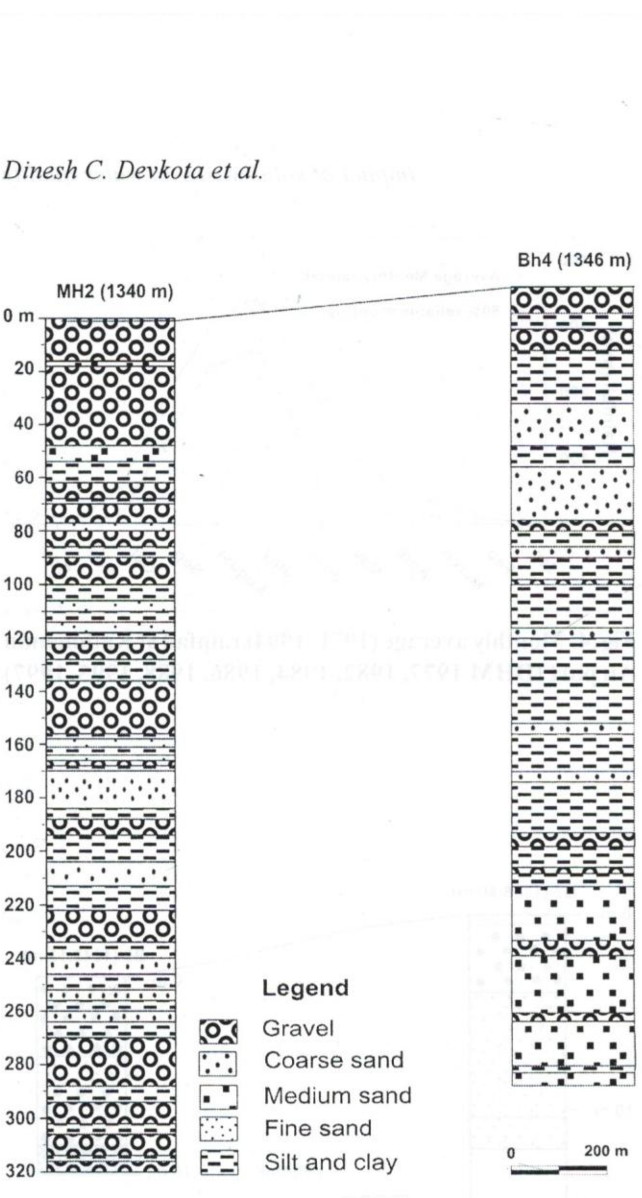

Fig. 7: Geological cross-section along BH4 and MH2 (SMEC 1992)

measured using a field test kit, while others (viz. chloride, manganese, and nitrite) were analysed in the laboratory. In this study, water samples were tested following Trivedy and Goel (1986). For observing the seasonal variation, samples were collected in the post-monsoon month of November 2003, pre-monsoon month of March 2004, and the monsoon month of August 2004 from the vicinity of the GLS. A total of 8 sites were selected for water quality monitoring (Fig 9). Water samples were collected from two springs (SP13 and SP16), while the leachate samples were collected at L11 directly from the outlet of a drainpipe. SP13 lies at a higher elevation and SP16 is at a lower elevation than the GLS. The rest of water samples were collected from the shallow wells (MW2, MW12, MW14, MW15, and MW17) surrounding the landfill site and lying at lower elevations. The depth of water samples in the shallow wells varied from 3 to 7 m.

The water quality data obtained from this study as well as from some previous works are presented in Tables 1 and 2. The amount of contaminants in shallow wells and springs are also compared with the WHO guidelines for drinking water quality (WHO 1993).

Status of shallow wells

Most of the shallow wells are contaminated, albeit to a small extent (Table 1). Their water temperature is higher than that of the springs in the vicinity (Table 2). The higher temperatures could have enhanced the growth of micro-organisms, and thus deteriorated the water quality by changing taste, odour, colour, and turbidity. Most of the samples exhibited the turbidity greater than the WHO guideline value of 5 NTU (Table 1). It was found to be the highest in MW15. However, the turbidity in MW17 was less in 2004 than in 2003. Heavy metals (mainly zinc, nickel, and

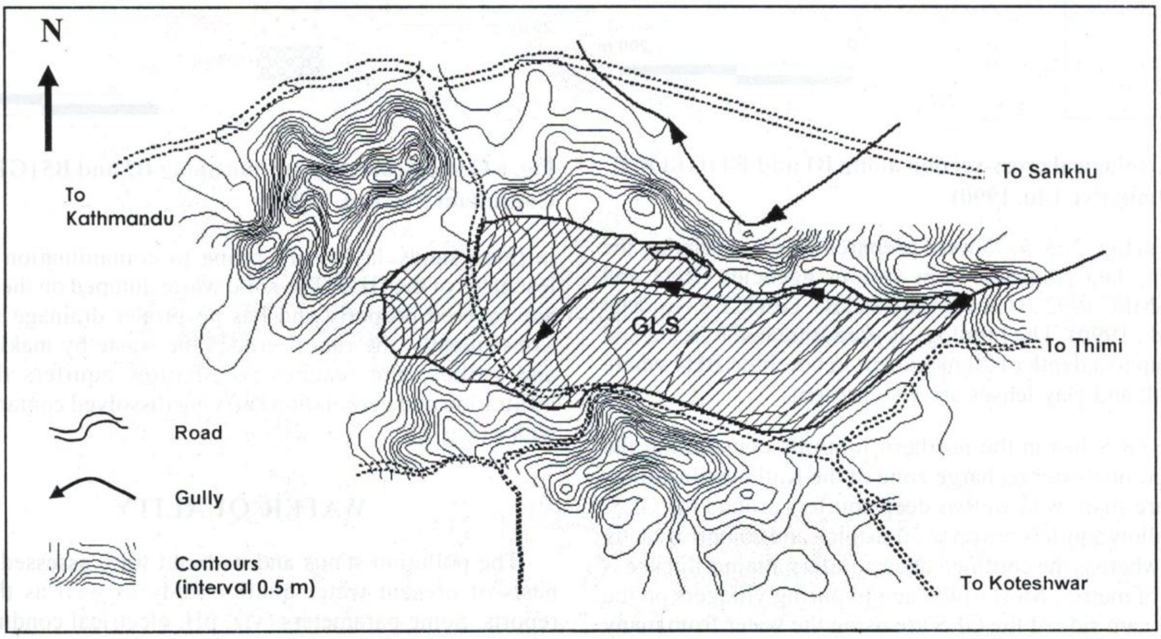

Fig. 8: Topographic map of the GLS

Table 1: Water quality analysis data of shallow wells at the GLS

Sampled Location	Shallow well MW2				Shallow well MW 12					Shallow well MW 14			Shallow well MW 15			Shallow well MW 17		
Sampled depth (m)	4.57				3.05					4.88			4.57			4.57		
Sampled date	Mar-96	Nov-03	Mar-04	Aug-04	1989	Mar-96	Nov-03	Mar-04	Aug-04	Nov-03	Mar-04	Aug-04	Nov-03	Mar-04	Aug-04	Nov-03	Mar-04	Aug-04
Parameters/Samples	NA	G1	G9	G17	NA	NA	G2	G10	G18	G3	G11	G19	G4	G12	G20	G5	G13	G21
Temperature (^{0}C)	NA	21.5	21.9	22	NA	NA	23.8	21.9	22.3	22.1	20.1	23	20.9	21.9	22.9	20.5	21.9	22.2
PH	6.36	6.86	6.15	6.14	7.1	5.95	6.75	6.5	6.24	6.86	6.7	6.35	6.81	6.9	6.24	6.86	6.9	6.42
Electrical conductivity (µS/cm)	560	589	375	77	295	160	941	756	58.1	416	210	200	574	188	286	630	557	86.7
Turbidity (NTU)	1	8.1	ND	15	NA	1	34	25	61	80		175	480	2.4	380	390	140	434
Total alkalinity as $CaCO_3$ (mg/l)	169	300	320	90	NA	94	600	640	100	300	31.5	234	400	640	500	400	220	100
Total hardness as $CaCO_3$ (mg/l)	288	160.8	220	190	2.3	102	246	200	160	184	44.4	205	170	120	235	200	200	640
Calcium (mg/l)	65.6	32	88.176	420	13	19.2	72	56.112	19	56	16.1	30	52	40.08	44	66	176.3	320
Magnesium (mg/l)	30.1	19.4	32.16	50.7	1.9	13.1	15.8	35.1	9.7	10.6	28.3	21	9.6	19.5	24	8.4	5.7	156.2
Chloride (mg/l)	122.6	56.8	56.8	35.89	14	13.2	71	100.14	42.6	17.04		11.34	46.86		18	61.06	56.8	285.2
Phosphate (mg/l)	0.098	0.5	<0.01	0.01	1.8	0.098	0.25	0.19	0.75	0.25	0.05	0.15	>3	0.14	2	0.75	0.23	0.25
Nitrite–N (mg/l)	0.003	0.025	<0.02	<0.02	2.6	0.007	ND	<0.02	<0.02	ND	<0.02	<0.02	ND	<0.02	<0.02	0.025	<0.02	0.1
Nitrate–N (mg/l)	3.91	2	2.5	17	<0.5	0.028	1	4.6	30	ND	0.14	1	1	<0.01	0.5	1	0.4	ND
Iron (mg/l)	0.2	0.1	0.2	1	0.17	1.93	2.64	0.8	1.49	40.5	NA	9	40.9	0.3	8	32.7	6.9	4.9
Manganese mg/l	NA	NA	NA	NA	NA	NA	1.13	NA	NA	1.7	0.04	NA	6.5	NA	NA	2.7	NA	NA
Lead mg/l	0.03	NA	<0.01	0.1	<0.002	<0.01	NA	0.02	0.25	NA	<0.01	<0.01	NA	<0.01	<0.01	NA	0.02	0.61
Copper (mg/l)	0.007	ND	<0.01	0.01	0.1	<0.002	0.012	<0.01	0.03	0.208	<0.01	0.16	0.043	<0.01	0.102	0.036	0.023	0.03
Zinc (mg/l)	0.011	0.029	0.041	0.035	0.33	0.007	0.205	0.14	0.14	0.436	0.13	0.21	0.442	0.037	0.39	0.223	0.14	0.15
Nickel mg/l	0.016	<0.01	<0.02	0.01	<0.01	0.012	<0.01	<0.02	0.01	0.26	<0.02	0.21	0.051	<0.02	0.043	0.02	<0.02	0.09
Cadmium mg/l	0.002	NA	<0.001	0.02	<0.0002	<0.001	NA	<0.001	0.003	NA	<0.001	0.003	NA	<0.001	<0.001	NA	0.003	0.002
Chromium mg/l	<0.005	0.005	<0.02	<0.01	0.011	<0.005	0.01	<0.02	<0.01	0.26	<0.02	0.15	0.083	<0.02	0.061	0.04	0.012	0.02
DO (mg/l)	0.48	2.02		1	7	0.57	0.4	NA	0	0.81	NA	0.6	2.43	NA	0.92	0.4	NA	1.6
BOD-5 (mg/l)	0.98	1.21	1.3	NA	3	0.74	0.2	2	NA	0.81	1.7	NA	2.03	1.9	NA	0.2	4.1	NA
COD (mg/l)	16	NA	18.5	NA	20	11	NA	21.5	NA	NA	17.6	NA	NA	18.7	NA	NA	30	NA
Coliform/ Bacteria	NA	70 in 100ml	100 in 100ml	300	-	-	>300 in 100ml	1250	7500	>300 in 100ml	23	700	>300 in 10 ml	20 in 100 ml	800	>300 in 50 ml	2000 in 100 ml	7500

NA: Not analysed, ND: Not detected. Source: Hartman (1990), NESS (1996), Devkota et al. (2003), and present study in 2003 and 2004

Table 2: Water quality analysis data of springs and leachate at the GLS

Parameters	**Leachate L11**					**Parameters**	**Spring SP13**				**Spring SP16**				
Sampled depth (m)	Surface drain					Sampled depth (m)	Surface				Surface				
Sampled date	1988	Mar-96	Nov-03	Mar-04	Aug-04	Sampled date	Mar-96	Nov-03	Mar-04	Aug-04	1989	Mar-96	Nov-03	Mar-04	Aug-04
Parameters/ Samples No	NA	NA	G6	G14	G22	**Parameters/ Samples No**	NA	G7	G15	G23	NA	NA	G8	G16	G24
Temperature (°C)	NA	NA	23.3	27.9	26	Temp (°C)	NA	15.6	19	24.9	NA	NA	19.5	19.7	22.1
pH	7..32	6.75	8.65	7.6	7.13	pH	6..3	7..95	7.7	6.46	6..9	6..95	6.65	6.8	6.19
Electrical conductivity (μS/cm)	12830	13500	19000	12180	999	Electrical conductivity (μS/cm)	540	140	144	17.8	203	110	781	1281	95.5
Turbidity (NTU)	NA	640	120	138	33	Turbidity (NTU)	4	35	100	12	NA	32	160	350	128
Total alkalinity as $CaCO_3$ (mg/l)	NA	8798	11500	500	18000	Total alkalinity as CaCO3 (mg/l)	47	50	120	100	NA	84	400	680	700
Total hardness as $CaCO_3$ (mg/l)	NA	9500	980	2040	880	Total hardness as CaCO3 (mg/l)	29	60	92	40	3.8	74	180	240	600
Calcium (mg/l)	512	2700	280	801.6	419	Calcium (mg/l)	6.4	18	32	95.2	15	15.2	56	56.11	176.1
Magnesium (mg/l)	166.4	656.1	67.2	302.16	214.6	Magnesium (mg/l)	3.2	3.6	14	50	7.5	8.8	9.6	44.86	139
Chloride (mg/l)	2079	24046	2613	1761.2	827.8	Chloride (mg/l)	-	7.1	14.2	7.1	14	7.5	130.6	313.6	399.4
Phosphate (mg/l)	3	0.76	15.3	2.5	2	Phosphate (mg/l)	0.12	0.25	<0.01	0.25	0.25	0.05	2	0.14	0.25
Nitrite–N (mg/l)	ND	0.98	ND	<0.02	0.025	Nitrite–N (mg/l)	ND	ND	<0.02	<0.02	0.04	0.002	ND	<0.02	0.05
Nitrate–N (mg/l)	ND	2.73	ND	37.0	ND	Nitrate–N (mg/l)	0.07	ND	<0.01	ND	<0.5	0.06	1	<0.01	ND
Iron (mg/l)	2.6	323.11	6.87	3.4	7.1	Iron (mg/l)	<0.01	3.7	3	0	<0.1	4.6	18.86	4.7	3.49
Manganese mg/l	NA	NA	0.33	NA	NA	Manganese mg/l	NA	0.37	NA	NA	NA	NA	3.1	NA	NA
Lead mg/l	0.1	0..32	0.06	0.13	0.51	Lead mg/l	<0.01	NA	<0.01	<0.01	<0.002	0.01	NA	0.13	0.32
Copper (mg/l)	0.1	0.07	0.017	0.071	0.03	Copper (mg/l)	<0.002	0.008	<0.01	<0.01	0.28	<0.002	0.004	0.071	0.04
Zinc (mg/l)	0.31	0.26	0.065	0.12	0.33	Zinc (mg/l)	<0.001	0.031	0.071	<0.01	0.16	0.015	0.036	0.23	0.02
Nickel mg/l	3.7	0.55	0.05	0.11	0.19	Nickel mg/l	0.005	0.02	<0.02	<0.01	<0.01	<0.005	0.02	0.11	0.13
Cadmium mg/l	0.3	0.002	0.004	0.001	0.007	Cadmium mg/l	<0.001	NA	<0.001	<0.001	<0.002	<0.001	NA	0.001	0.005
Chromium mg/l	0.6	<0.05	0.05	0.013	0.03	Chromium mg/l	<0.005	0.007	<0.02	<0.01	0.005	<.005	0.015	0.013	0.03
DO (mg/l)	NA	ND	0	NA	0.9	DO (mg/l)	4.46	9.31	NA	5.9	2.5	8.43	0.81	NA	6.6
BOD-5 (mg/l)	9400	3500	3000	1412.0	NA	BOD-5 (mg/l)	0.31	3.24	49.2	NA	1.1	7..95	0.61	270.0	NA
COD (mg/l)	13305	45500	9000	1527.0	NA	COD (mg/l)	8	NA	59.3	NA	7	80	NA	412.0	NA
Coliform/ Bacteria	NA	NA	>300 in 5ml	5800 in 100 ml	30000	Coliform/ Bacteria	NA	>300 in 100ml	2000 in 100 ml	1200	NA	NA	>300 in 50 ml	2500 in 100 ml	8000

NA: Not analysed, ND: Not detected. Source: Hartman (1990), NESS (1996), Devkota et al. (2003), and present study in 2003 and 2004

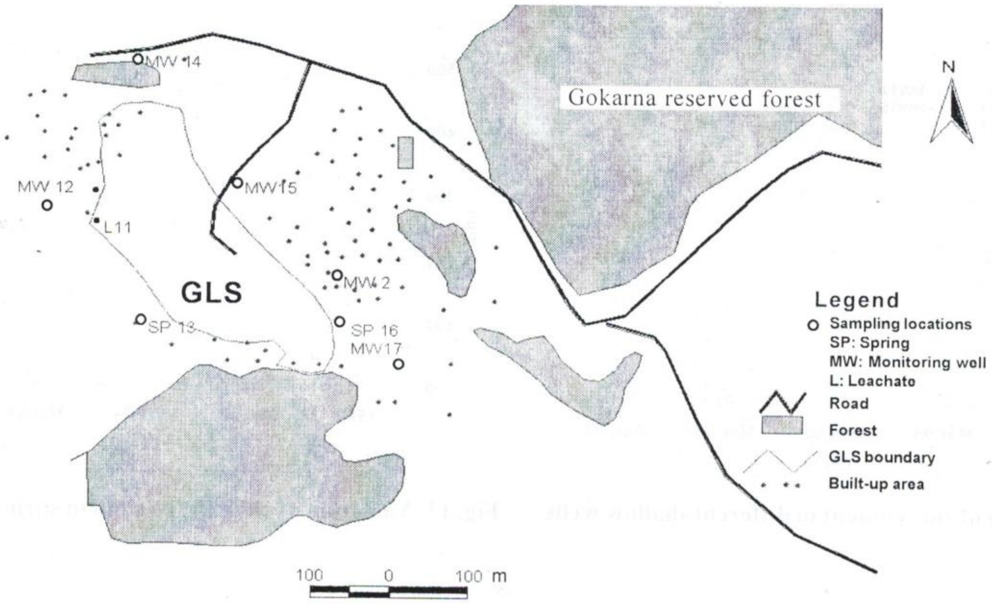

Fig. 9: Samples locations around GLS

chromium) were traced in most of the shallow wells (Table 1). For example, the concentration of zinc in the shallow wells increased significantly in the post monsoon month of November 2003 (Fig. 10, Table 1). The heavy metal content in most of the wells was significantly higher than in the groundwater from the central part of Kathmandu valley (Joshi 2002). Some of the shallow aquifers were also found to be highly contaminated by iron and manganese.

The observed value of bacterial coliform in the water of shallow wells was also higher than the WHO value of 0 counts, proving its unsuitability for drinking and daily use without further treatment. However, it is difficult to assess whether the observed value is attributable to the solid waste disposal alone. In view of the presence of the sandy soil at a shallow depth (Fig. 4, 5, 6), the waste disposal could be the main source of bacterial pollution in the shallow aquifers.

Status of springs

The water from springs in the area is severely affected by the solid waste disposal (Table 2). The water samples from SP13 and SP16 tended to be acidic and alkaline, respectively. The turbidity and conductivity of both the springs was also high. During the study period, a maximum iron concentration was observed in 2003. SP16 had a high concentration of iron, chloride, hardness, ammonia, zinc, heavy metals as well as microbial content, exceeding the WHO values. Very high heavy metal content, particularly lead and nickel, was detected in the spring samples.

Status of leachate

The leachate (Table 2) exhibited a high concentration of physical, chemical, and biological contaminants. Its high pH value indicated that the landfill was already under the methanogenic process. Both the BOD and COD values were very high. The other parameters such as chloride, dissolved solid, hardness, and alkalinity level also were comparatively higher. The heavy metal concentration was higher in the rainy season (August 2004) than in any other period.

A comparison of the water quality data of different seasons (i.e., pre-monsoon, monsoon, and post-monsoon) revealed that a number of physico-chemical parameters (such as conductivity, alkalinity, hardness, dissolved solid, and chloride content) had a lower concentration in the rainy season. But, the heavy metal content and microbial count increased in the rainy season in almost all samples. Hence, rainfall could be the major factor controlling the seasonal variation of concentration.

TREND MONITORING

A long-term water quality variation in the shallow wells, springs as well as leachate was studied by comparing the data of present study with those of 1988 (Hartman), 1996 (NESS), and 2003 (present study). The results are briefly described below.

Shallow Wells

The study of earlier (1989 and 1996) as well as recent (2003 and 2004) data reveals that there is a continuous deterioration of water quality in the area. This is more evident in case of iron (Fig. 11), chloride, and heavy metal content as well as conductivity (Table 1). The monitored wells exhibited a conductivity value higher (up to 941 μS/cm) than the tubewells from the central part of the Kathmandu valley (209.1–590.6 μS/cm; Joshi 2002).

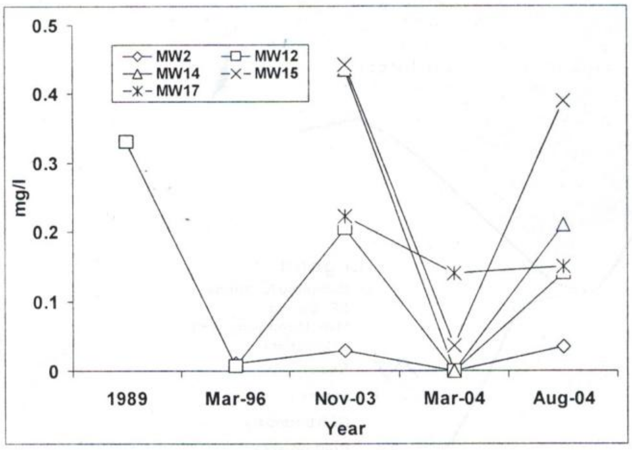

Fig. 10: Variation of zinc content in different shallow wells at Gokarna

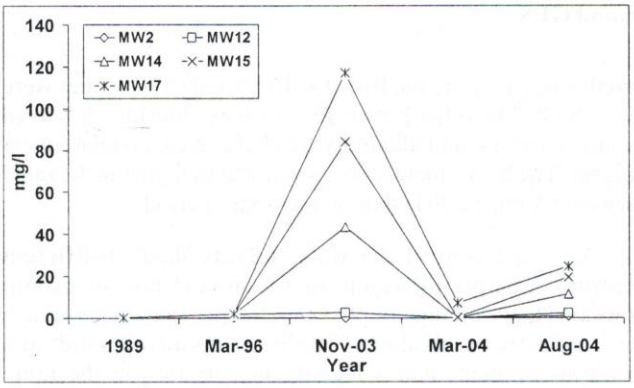

Fig. 11: Variation of iron in shallow wells

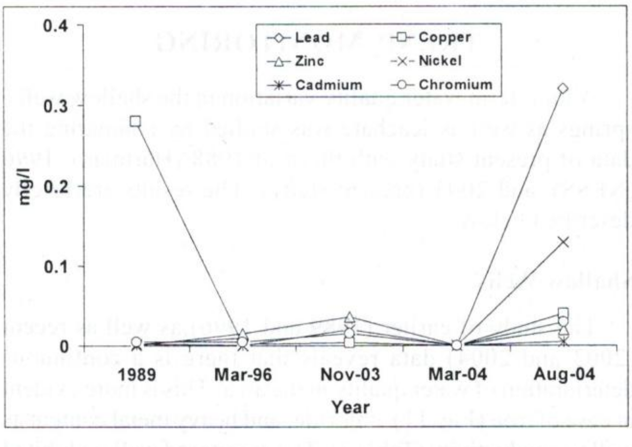

Fig. 12: Variation of heavy metal concentration in spring (SP16)

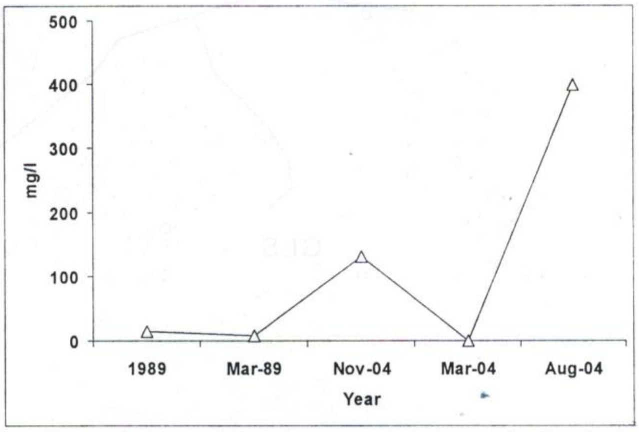

Fig. 13: Variation of chloride content in spring (SP16)

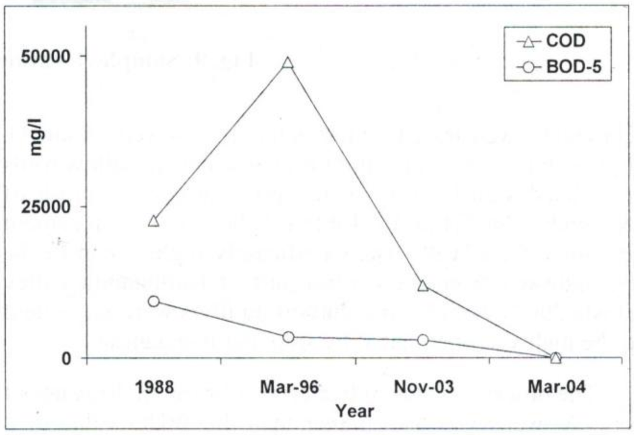

Fig. 14: Variation of BOD-5 and COD in leachate (L11)

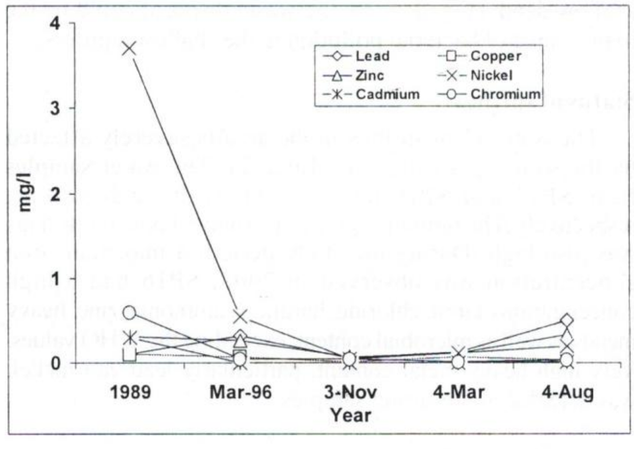

Fig. 15: Variation of heavy metal concentration in leachate

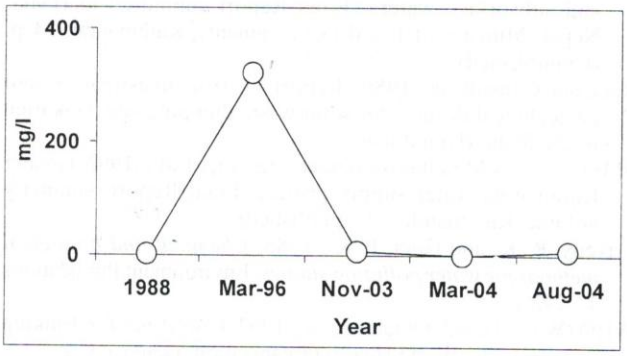

Fig. 16: Variation of iron in leachate (L11)

Springs

The heavy metal concentration (Fig. 12), chlorides (Fig. 13), iron as well as BOD and COD values depicted their increasing trend during 2003 and 2004 (Table 2). Likewise, the microbial contamination in both the springs had increased, and they were unsuitable for domestic use. Further, the contamination was more prominent in SP16 than in SP13.

Leachate

The data of 1988, 1996, and current observations (Table 2) are considered for the trend analysis of leachate quality. The concentration of pollutants was quite high in the leachate till 1996. Subsequently, the pollution level gradually decreased and attained a comparatively lower value by 2004. The pH of leachate also progressively changed from almost neutral (7.3) in 1988 to slightly acidic (6.75) by 1996, and to slightly alkaline (give the value) by 2004; indicating the initiation of methanogenic process by 1996 and its completion by 2004.

There is a close relationship between the total suspended solids and turbidity, which in turn is related to the biological oxygen demand (BOD). The leachate exhibited a maximum turbidity of 640 NTU in 1996, and it decreased drastically to 138 NTU by 2004.

The chemical oxygen demand (COD) values were found to be higher (45500 mg/l) than the BOD (3500 mg/l) values in 1996. High BOD values (9400 mg/l) were also observed in 1988. The peak value of COD is corresponding to the year 1996 of highest solid waste load to the landfill site. The amount of solid waste gradually decreased afterwards. However, the BOD values show the overall decreasing trend between 1988 and 2004 (Fig 14).

The heavy metal concentration does not show much variation. However, the concentration of nickel has drastically decreased since 1989 (Fig. 15).

The conductivity of leachate increased from 12830 μS/cm to 19000 μS/cm between 1988 and 2003, which decreased to 12180 μS/cm in 2004. The total alkalinity also had a similar trend. This trend suggests that the electrical conductivity of the leachate increases with the degradation of the solid waste. The values of total hardness, chloride, calcium, magnesium, and iron (Fig. 16) are gradually decreasing after 1988 (Table 2). The analysis of leachate indicates that its pollution level has decreased in recent years in comparison with the previous years, especially after 1996 when it was the worst.

CONCLUSIONS

About 20 m thick, shallow, unconfined aquifer is found beneath the GLS. The aquifer is contaminated by the leachate generated at the landfill site. The water quality analysis of shallow tubewells, dug wells, and springs around the GLS carried out between November 2003 and March 2004 revealed that they are polluted by the leachate. The heavy metal concentration, chlorides, iron as well as BOD and COD values depicted their increasing trend. Likewise, the microbial contamination was also high, and the water was unsuitable for domestic use. However, there is a less possibility of contaminating the deep confined aquifer. On the other hand, the present study also shows that the amount of pollutants in the leachate has decreased significantly in recent years, especially after 1996.

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