Bulletin of the Department of Geology

Bulletin of the Department of Geology, Tribhuvan University, Kathmandu, Nepal, Vol. 11, 2008, pp. 51–60

Possible methods of preventing groundwater contamination at landfill sites; case studies from Nepal

Suman Panthee

Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, Nepal

ABSTRACT

Significant increase in municipal solid waste in Nepal has led to build up of few landfill sites in urban areas. Among several problems existing in the landfill sites, groundwater and soil contamination are the major problems. The major causes of contamination are generation of leachate, improper design and selection of materials in the landfill sites. Therefore, understanding on physical and chemical behavior of the leachate with the fill material, and the landfill site design parameters is required to solve the problem. Three landfill sites (Gokarna, Sisdol and Pokhara) were studied as case studied to identify leakage problems in view of controlling leachate migration. Hydraulic conductivity, particle size distribution and shape of basement material were studied. Gokarna Landfill Site did not have proper clay lining or other technology that prevents groundwater contamination. The Sisdol and the Pokhara landfill sites were improved sites but were devoid of clay lining. To control leachate migration, proper basement and other design is required. The slope of the basement clay liner should be adjusted properly according to the hydraulic conductivity of the clay to prevent leachate movement downward. Similarly, selection of shape and size of drainage material is important for aeration, and to prevent from leachate clogging and puncturing the basal clay or geo-membrane. The case studies suggested need of some improvements for basal design of landfill sites for future. Besides the basement design, design of leachate suction well and vegetative technology for leachate treatment are necessary. A basement design is proposed that will be economic and suitable for developing countries. This paper discusses about some drawbacks in technical practices in some landfill sites in Nepal and suggests possible methods that can be applied in constructing landfill sites for reducing contamination.

INTRODUCTION

There has been a significant increase in municipal solid waste generation in Nepal in the last few decades. This is largely becasue of rapid population growth, population migration towards cities and urban centres, and economic development in the country. Solid waste management has become a major environmental issue in Nepal. Among the several problems of landfill sites, groundwater and soil contamination are the major problems. The main causes of these problems are leachate and design parameters. To avoid soil and groundwater contamination, several techniques and practices have been introduced and implemented (CKV 2002). Techniques that have been practiced in developed countries are not practical because of high cost. In case of Nepal, the modified techniques have been gradually introdued (CKV 2002; CKV and JICA 2002; PEIP et al. 2002). Through some modified practices have been adopted, some improvement is still necessary.

This paper discusses about some lagging technical practices in some major landfill sites in Nepal and recommends techniques suitable in the context of Nepal and other developing and underdeveloped countries, based on case studies of landfill sites and

*Corresponding author:
E-mail address: panthisuman@gmail.com

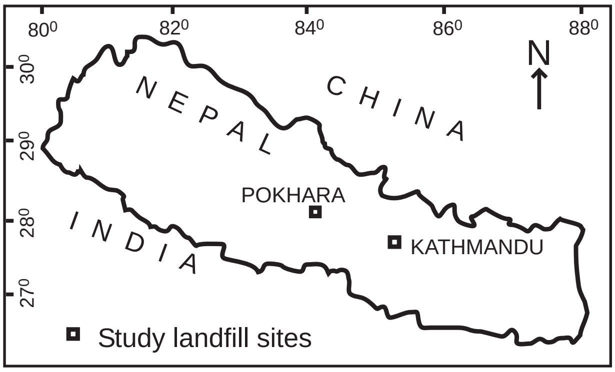

Fig. 1 Location map of the study area

lab analysis of materials used in the landfill sites. The main aims were to find drawbacks of the landfill sites in contaminating groundwater and soil in all starting, operating and reclamation phases. Finding the major drawbacks would be helpful to improve landfill site development in other areas in the future.

CASE STUDIES OF LANDFILL SITES

Three landfill sites; Gokarna landfill site, Sisdol landfill site and Pokhara municipal sanitary landfill site (Fig. 1) were selected for the case studies. These were selected because these are the only landfill sites which are technically designed landfill sites in Nepal. Among them, Gokarna landfill site is an abandoned site and the other two are currently operating landfill sites.

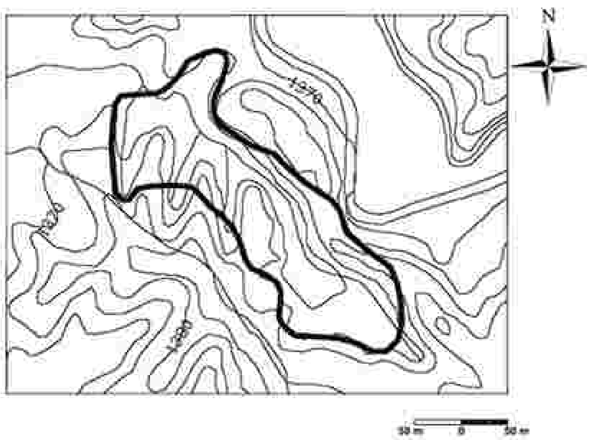

Fig. 2 Location map of Gokarna landfill site

Gokarna landfill site

Gokarna landfill site is the first site where technical consideration was brought in practice in Nepal. The landfill site is located in the Nagdaha valley that lies at NE of Kathmandu along the road from Gokarna to Sankhu and at about 4 km from Ring Road of Kathmandu (Fig. 2). The landfill site is developed at the upper part of a small catchment surrounded by hills (1342 a.m.s.l.). The main stream of the catchment is a tributary of the Bagmati River. The landfill site is about 500 m long and 200 m wide, and is more or less a closed valley. The nearest village to the south of the site is Mulpani.

Structures of landfill site

The landfill site was operated for 14 years from November 1985 to June 2000, and was abandoned due to social causes. The land filling was begun from outlet of the valley and developed towards the upstream. Initially concrete pipes supported by concrete walls at both sides of the valley were built in order to bypass the runoff water from the upper part of the catchment. At the base, clay was lined but lateral lining was not used. Sandwich and trench land filling techniques were used. The soil from excavation of suronding hills were used for covering the solid waste material.

In the landfill site several structures were designed, e.g., drainage pipes, groundwater monitoring wells, leachate collection pond, etc. The it was technically designed, several important paramters were not considered. Also the groundwater monitoring wells which were functioning up to the mid of the operation, were covered by the dumped waste. Similarly, a leachate collection pond was constructed around the mid of the period but later on it was also covered by the waste. In fact, it was not a proper leachate collection pond but was a pond to collect leachate which was coming from several sides and draining from the drain pipe which was initially constructed to drain the upstream water.

The landfill site area comprises thick alternating layers of sand, silt and mud of the Gokarna Formation (Yoshida and Igarashi 1984), and are interpreted as fluvio-deltaic deposit (Sakai 2001). Thickness of the individual layer is variable both vertically and laterally, and beds are slgihtly tilted 7° due S72°W. The drill

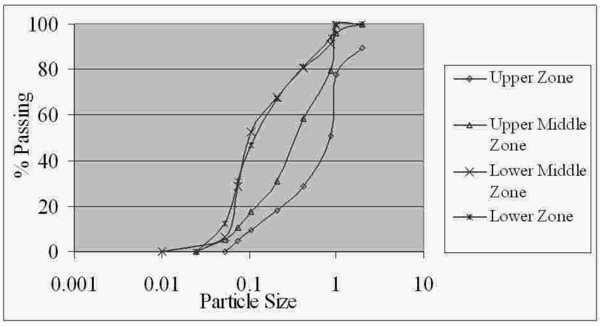

Fig. 3 Parcicle size distribution of Gokarna landfill site area

core data indicate that sand silt beds are thin below the surface level, whereas mud beds are thick and are more frequent. At the NW portion, the subsurface soil comprises more sand beds than in other portion, and sand is also coarse-grained.

Grain size coefficient of soil

Texture of all the soil layers were analysed using standard sieves and mechanical shaker. Fine grade of soil was analysed using ASTM 152-H type hydrometer. The sand of the upper part of the deposit was coarser compared to that from the lower part. The curvature coefficient (Cc) and the uniformity coefficient (Cu) which were calculated from the grain size plot for coarse sand were 2.8 and 0.8, and thus sand was poorly graded. Similarly the fine sand, silt and mud have Cu and Cc, respectively of 1.8 and 0.7, 2.6 amd 2.2, and 4.2 and 3.2. The curves of fine sand and mud layer indicate that both soils have gap graded nature (Fig 3).

Hydraulic conductivity of soil layers

Hydraulic conductivity (K) of representative soil layers was determined using the relationship after Masch and Denny (1966): $K = f_s f_a d^2$, where f_s is a pore shape factor, f_a is porosity factor and d is the grain diameter. The laboratory analysis was carried out using 'Constant Head Method' based on Darcy's law; K = Ql/tAh, where Q = discharge, l = length, A = area, h = head loss and t = time. The K within the layer varies.

Results observed from both methods are almost similar. Each layer has different hydraulic conductivity and it is also observed that the hydraulic conductivity within a layer also varies. The k is 35 m/day for coarse sand and 2.26×10^{-2} m/day for silty clay as observed by the laboratory method. In both cases k of the clayey soil is not suitable for using as the lining at the landfill site. Clay having hydraulic conductivity 2.5×10^{-9} m/day is considered suitable for clay lining (CKV and JICA, 2002). But the clay from the Kalimati Formation (where $K = 1.25 \times 10^{-6}$ m/day) which is located nearby the landfill site is considerable for lining matrial because this was the only clay that can be found near the landfill site. The clay of Kalimati Formation from Koteshwore and Minbhawan area along the course of the Bagmati and the Manahara Rivers is suitable for the application.

Status of contamination

At present, the upper surface of the landfill site has been sloped towards NW at about 8^o. Small water drainage has been developed to divert surface water preventing percolation. But the drainage is not sufficient and can not channelise all the surface water. In addition, at the middle part of the landfill site, a depresed area is present. Sometimes it becomes swampy land. Shallow groundwater is highly contaminated with leachate. The contamination level at the west portion of the site is higher compared to the other sides. Leachate contamined groundwater flows as seepage at different locations around the landfill site (Fig. 4).

Sisdole landfill site

Sisdole landfill site lies at about 20 km southwest from Kathmandu, and has been planned to be operated in two phases. The first phase operation is going on. The landfill site consists of two basins, of which the first basin has 11200 square metre area, and having capacity of 166085 cubic metre. The second basin has 9501 square metre area and capacity of 108910 cubic metre (CKV 2000). The landfill site has capacity only for two years.

Facilities in the Sisdole landfill

The landfill site is semi-aerobic type that was designed according to the design developed by Fukuoka City Environmental Bureau (FCEB), Japan

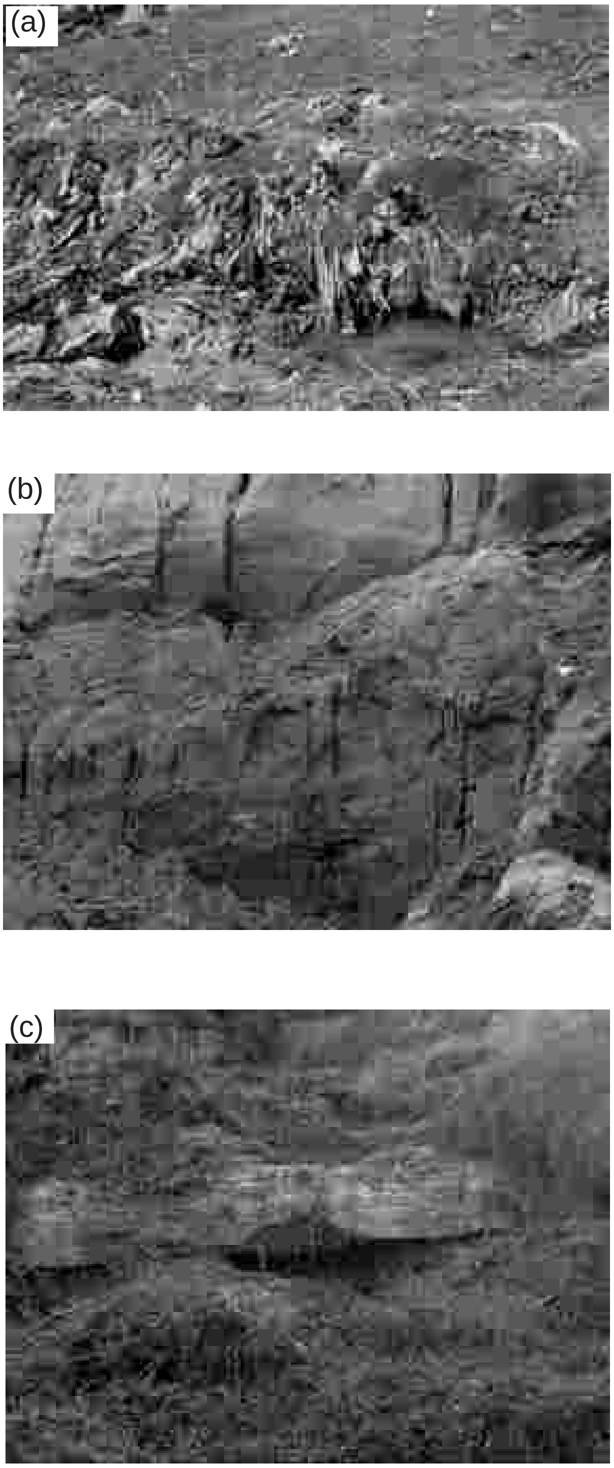

Fig. 4 Photographs showing (a) Leachate comming from disposed solid waste at the NW corner of the Gokarna landfill site, (b) Leachate coming from disposed waste at the west portion of the Gokarna landfill site, and (c) Contaminated groundwater seeping from disposed waste at the NW portion of the landfill site.

(FCEB 1999). The Fukuoka method is categorised into 4 types on the basis of facilities used in the site. The Sisdole landfill site is the type-3 landfill site.

The first basin (phase I)of the landfill site was constructed in the lower portion (Fig. 5). The length of the site is 120 m with gradient 4% laterally and 3% longitudinally (CKV and JICA 2002). At the base, two clay liners are present and are overlain by gravel. A sandwich method has been operated to fill the solid waste material. Leachate-perforated collection pipes and ventilation pipes, which were constructed on the material, drian leachate and ventilate. The lower part contains leachate collection pond. Three groundwater monitoring wells were installed. There is no evidence of groundwater contamination.

The leachate which was collected in the collecting pond was acid and that varied according to the seasons. The second basin (Phase II) is under construction. One-third perforated pipes have been used for drainage collection and have been adjusted as parallel branches of trees (Fig. 6).

Geology and geotechnical conditions of Sisdole landfill site

The Sisdole landfill site comprises a thick river deposit of black clay silt underlain by gravelly sand. The river deposit is underlain by limestone which is fractured and has three sets of discontinuities. The volumetric joint number of the limestone varies from $9/m^3$ to $15/m^3$. The black clay silt has hydraulic conductivity of 3.2×10^{-2} m/day.

Drainage materal and clay lining

The drainage material used in the landfill site consists of 50 to 150 mm sized gravel. The modal size however is 70 mm. Gravel is subangular to subrounded.

Red residual clay produced on limestone from surrounding of the landfill site has been used for clay lining and is alkaline (pH = 8.5 to 8.9). The hydraulic conductivity of the red clay (in compact condition) is 2.06×10^{-8} m/sec. The clay has been lined in two compacted layers, i.e., the first 0.25 m and the second 0.25 m. A thin sand layer has been placed in between them.

Fig.5 Drainage material, leachate collection pipe and gas pipe of Sisdol landfill site

Fig. 6 Perforated pipe used for leachate collection

Status of contamination

Leachate produced from the solid waste is acidic and the lining clay is basic. In this instance, reaction between them may result in increase in hydraulic conductivity of the liner, which ultimately causes leakage of leachate and contamination of the underlying soil and groundwater.

Pokhara municipal sanitary landfill site

The Pokhara municipal sanitary landfill site lies at the left valley wall of the Seti River in Pokhara, and is an anaerobic type landfill site. This is the first landfill site in Nepal where geo-membrane has been used. The landfill site was developed by cutting the vertical valley wall (Fig. 7). The clay lining has not been used. Instead of clay lining, silty sand has been used.

Structure of the landfill site

The landfill site has very good leachate control system. here both civil engineering and vegetative methods have been used to control leachate. The geo-

Fig. 7 View of Pokhara municipal sanitary landfill site in Pokhara

membrane has also been used to channelise leachate at a point. A lined vegetation has been used to allow leachate to pass through it. Mostly, Narkat (*Phragmetis karka*) has been adopted and has been planted in the plots. Before allowing leachate to the plots of Narkat, at first leachate is allowed for aeration, settlement in a settlement tank, and then only is allowed to pass through drying beds and vertical reed beds (Fig. 8).

Drainage material and clay lining

The landfill site area comprises thick gravel deposit in which gravel is cemented by calcareous cementing material. The deposit is very porous as a result of channelised solution of cement. Porosity of the basal gravel is very high and the water table of the landfill site areas is quite down from the surface. The drainages in the calcite cemented gravel deposit are deep making gorges which indicate remarkable vertical erosion.

Drainage material consits of gravel of 0.3 m. A gravel layer of 0.6 m thickness has been placed on the geo-membrane (PEIP 2002). The gravel represents maximum number of subangular grains. Instead of clay lining silty sand has been used, because the geo-membrane has been placed in the landfill site.

Status of leakage and contamination

There is high possibility of puncture of geo-membrane due to improper selection of material. Secondly, leachate may react with calcite cement of the underlying deposit causing intense dissolution of cementing material. This may lead to leakage of leachate and contamination of deposit and groundwater.

LEAKAGE AND CONTAMINATION PROBLEMS IN LANDFILL SITES

Among common problems, following are the major problems that lead to groundwtaer and soil contamination in landfill sites in general:

1. Compaction of drainage carpet materials at high load which may cause clogging and airing problem
2. Puncture of geo-membrane and clay lining
3. Chemical reaction between leachate and drainage material and /or clay liner

The problems traced from the three case studies also exhibit similar problems mentioned above.

The hydraulic conductivity of soil used for lining in the Gokarna landfill site showed that the soil was not recommendable for the lining. If the Kalimati Clay with K of 1.08 x 10^{-7} m/sec in compacted condition, were used, the present groundwater contamination had not had happened. If proper lining were used in marginal parts of the landfill site, groundwater contamination and leachate draining had been controlled. Similarly if there were leachate collection ponds and drainage carpet, the leachate would have been channelized and the contamination reduced.

The lessosns that should be learnt from the Sisdole landfill site is slightly different. Leachate that has been produced from the solid waste is acidic. However, the clay liners are basic and there is possibility of reaction between leachate and clay liner. The reaction may increase hydraulic conductivity of the clay liner. Thickness of the clay liner is not sufficient and the gradient of the base is also very low. Therefore, thickness and gradient of the clay liner should be increased. As geo-membrane has not been used, the gradient of the base should also be increased.

In Pokhara municipal sanitary landfiil site, geo-membranes are made up of subangular gravel which may increase probability of puncture of the membrane upon increase of overburden load of the solid waste. If rounded to subrounded gravel were used inplace of subangular gravel, possibility of puncture would have been reduced. Secondly, a clay liner below the geo-membrane has not been constructed. This is a major drawback. Absence of clay liner below the geo-membrane will not prevent leachate leaking and may contribute reaction between leachate and cementing material of the gravel deposit at the base of the landfill site. This may lead to dissolution of cementing material, generation of pores, and subsequently leads to collapse of the base. Similarly, the collapse of gravel beds is frequently found in Pokhara as a result of dissolution of cementing material between gravel.

In all the three cases, the problems are associated with the basic material which were used to prevent contamination. The problems were also due to lacking of some technical studies and/or consideration during designing and/or operation. Therefore following studies should be made in detail while designing and operating future landfill sites.

1. Engineering geological conditions

2. Geo-technical and hydraulic properties of the materials of landfill site area

3. Chemical parameters of clay liner and drainage carpet material

4. Chemical composition and viscosity of leachate

5. Shape of drainage carpet matrial

6. Swelling characteristics of clay liner

7. Size gradation of drainage material

8. Compressibility and strength of drainage material and base material, and

9. Expected weight of the solid waste and covering material

POSSIBLE SOLUTION

As sophisticated technology and material in landfill site are costly, simple and easily available techniques and material are convenient for the developing and underdeveloped countries. More economic and environmental friendly techniques are recommended in the following sections.

Clay lining

To prevent the leachate contamination to groundwater, clay lining is important. Pure clay is not found everywhere therefore, clay having little amount of silt and/or sand should be used.

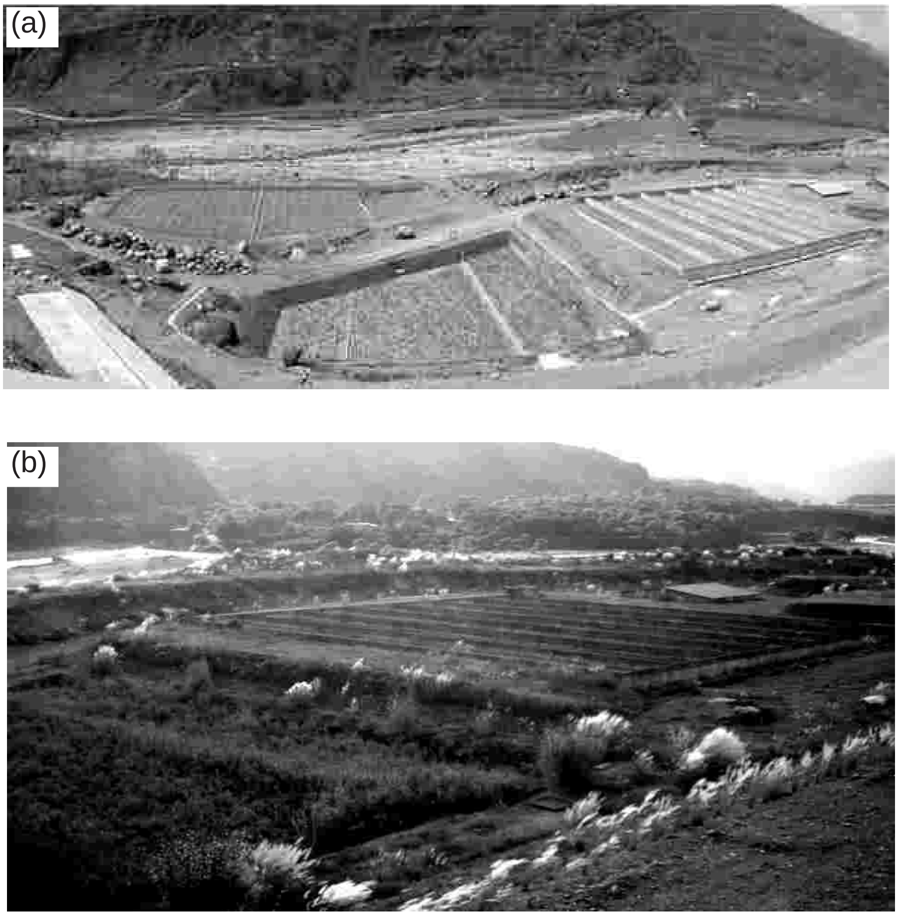

Fig.8 (a) Initial condition of vegetative leachate treatment site, and (b) Present condition of vegetative leachate treatment site

Hydraulic conductivity

Before using any clay as liner, its hydraulic conductivity must be measured. The clay having K-value less than 1.73 x 10^{-3} m/day can be used as clay liner in economic way without using geo-membrane in landfill site. However, this K-value may be changed depending on chemical composition and viscosity of the leachate developed from the waste of the area. If the leachate has toxic composition, then the K-value should be reduced. Clay having K-value above 8.6 x 10^{-3} m/day can be used following the design discussed in the following sections.

Grain size

When the percentage of sand and/or silt in clay is greater than 35 then the clay is not suitable for clay lining without geo-membrane. Moreover, the sand should be fine and below 12% in the clay to be recommended for clay lining.

Gradient of clay liner

For mixed clay, the clay liner can be placed with inclination which prevents groundwater contamination. If the clay does not contain much silt and/or sand, it can be lined in very low gradient. The gradient of clay lining should be increased according to the increasing amount of silt/sand mixture. Based on vertical and horizontal hydraulic conductivities, the final conductivity and direction of flow can be calculated for the gradient of clay liner after the equation of Todd (1995): $\text{Sin } \beta = [(K_y(K_x - K_\beta))/(K_\beta(K_x - K_y))]1/2$, where, K_x and K_y are hydraulic conductivities in horizontal and vertical directions, respectively, K_β is hydraulic conductivity in the direction making angle β with the horizontal, and β is the direction of groundwater flow.

Acidity-Alkalinity

The concetration of leachate may vary in different landfill sites but all have acidic nature. Therefore, the clay liner chosen should not be of much basic nature to avoid reaction with leachate.

Basement design

The basement of a landfill site should be designed according to the available material for use in the landfill site and geological and geotechnical conditions of basement earth material present at the site. In addition, the height that will be finally maintained should be considered in designing period. General basement sketch of the landfill site is shown in Fig. 9a and its cross-sections are shown in Fig. 9b.

Spacing of leachate collection pipes

A main branch of leachate collection pipes and leachate drain pipe should be designed as shown in Fig. 9a. The leachate collection pipes at a landfill site should be set according to the slope of the clay liner and texture of clay. Here the slope of the clay liner is taken diagonally at C-C’ in Fig. 9a of the leachate generating rectangle chamber. If the lining clay has a pure clay the pipes can be placed at larger distance whereas, if the clay is mixed with silt/sand, the pipes should be set at closer distance.

Thickness and number of clay liner

Thickness and number of clay liner depends on vertical and horizontal hydraulic conductivities. A thin clay liner should be selected for the soil having very low vertical conductivity and higher lateral conductivity, whereas a thick clay liner should be selected for the opposite cases. When clay has low vertical hydraulic conductivity, the number of clay liner may be reduced. Thickness and number of the clay liner should be managed according to the gradient of the clay liner. Between clay liners, sand layer should be placed (Fig. 9b).

Strength of basement

The basement of the landfill site should be designed according to the weight of the overburden of waste and covering material. The basement material should have enough compressive strength to withstand the overburden load. Sometimes grouting or other technique may be required to strengthen the basement.

Leachate suction wells

Leachate suction well should be installed to drain out leachate-contaminated water that has infiltrated through the clay liner and drained through the sand layers. The wells should be installed at the base of the landfill site. Suction of leachate from the landfill site will reduce possibility of infiltration and contamination. The leachate thus removed should be well treated prior to disposal.

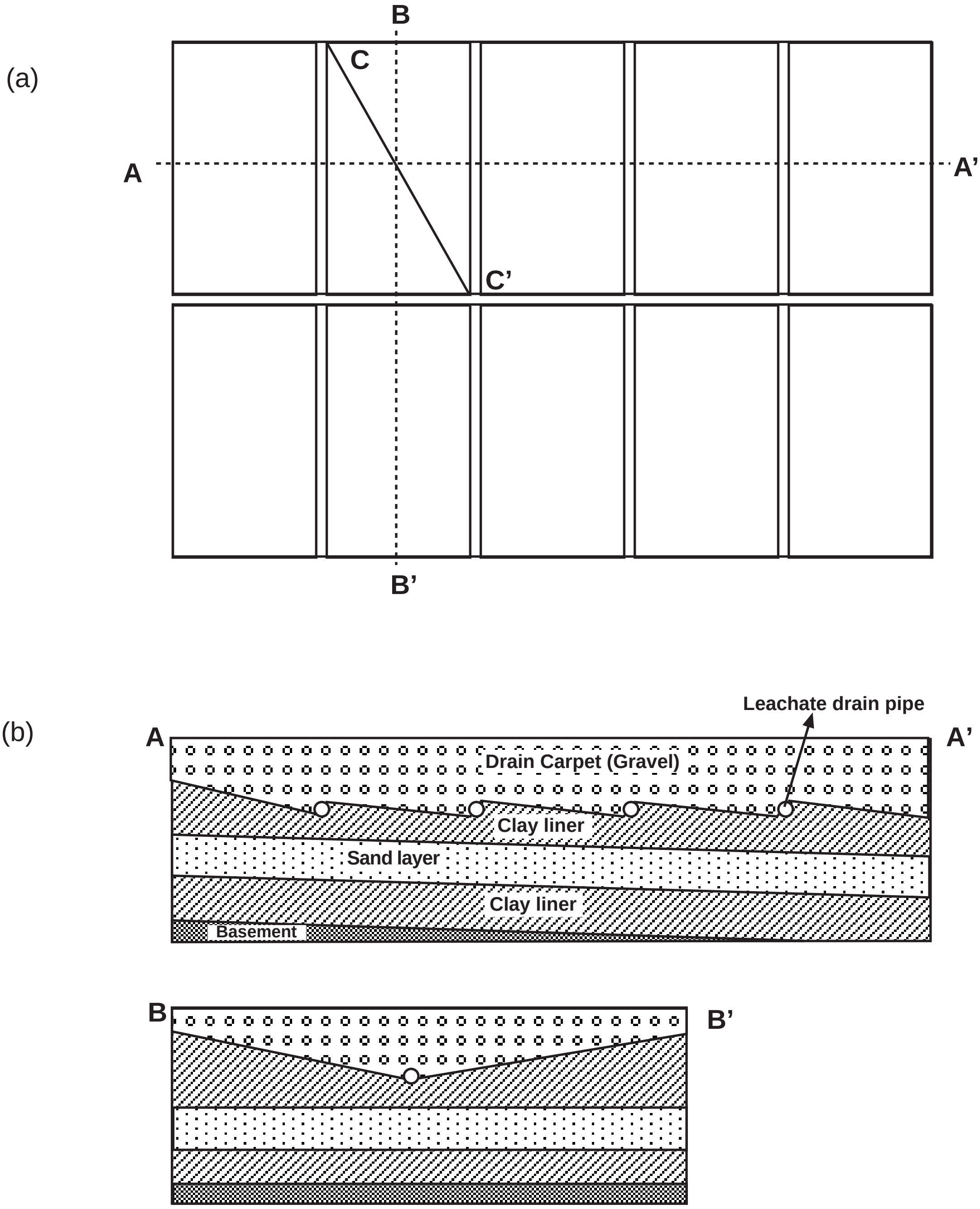

Fig. 9 Proposed model of landfill site: (a) Plan view, (b) Cross-sections through A–A' and B–B'

Water table

The water table level of the developing landfill site should be considered seriously while selecting the site. The water table of the landfill site should be lowerd if the landfill site has shallow water table. If there is obligation to design the landfill site at the area having shallow water table, the water table should be lowered by constructing wells or by using other techniques.

Drainage carpet

In all types of landfill sites, a drainage carpet is necessary to drain leachate. A drainage carpet helps aeration in case of aerobic and semi-aerobic landfill sites. Its design is also important to solve clogging and compaction problems. Generally clean and large gravel having well grading and roundness is recommended for drainage carpet. To avoid puncture and clogging problems as well as to maintain ventilation inside landfill site, drainage carpet material should be selected as below:

1. Base material should be clean gravel with well to subrounding and equant shape,

2. Base material should be covered by angular and flat or elongated gravel to enhance ventilation,

3. The angular and flat/elongated material should be covered by finer material similar to filter pack design criteria of well designing.

Vegetative technique for leachate treatment

For the leachate treatment, vegetative technique is very cost effective in developing and under developed countries. There are several species which can survive in different climates and can clean leachate. *Phragmites Karka* (terrestrial), *Eicornia crassipes* (aquatic), and *Rumex sp.* and *Lippianodi sp.* (amphibian species) are recommendaed species for leachate treatment.

CONCLUSIONS

All the three landfill sites possessed drawbacks in terms of material used, and of landfill design and operation technique. This has caused contamination of groundwater and soil by leachate in Gokarna landfill site, and possible contamination in Sisdole and Pokhara landfill sites in future. Great vulnerability of collapse of basement exists in Pokhara municipal sanitary landfill site due to the reaction of leachate and basement soil. Adequate attention should be paid on selection of landfill sites are material for carpet and liner, design of structures, treatment of leachate, and operation of landfill site.

ACKNOWLEDGEMENTS

I am thankful to Central Department of Geology for providing laboratory facility.

REFERENCES

CKV, 2002. The study of the solid waste management for Kathmandu Valley. Interim Report (2) of Clean Kathmandu Valley (CKV)

CKV and JICA, 2002. Detail design on landfill sites. Joint Report of Clean Kathmandu Valley and Japan International Cooperation Agency

FCEB, 1999. What is the semi-aerobic landfill? Fukuoka City Environmental Bureau (FCEB), Japan,

Masch, F.D. and Denny, K.J., 1966. Grain size distribution and its effect on the permeability of unconsolidated sand. Water Resource Research, v. 2, pp. 665–677.

PEIP, HMG and ADB, 2002. Design and operational management concept of the municipal sanitary landfill-Pokhara. Pokhara Environmental Improvements Project and HMG/ADB Second Tourism Infrastructure Development Project

Sakai, H., 2001. Stratigraphic division and sedimentary facies of the Kathmandu Basin Group, Central Nepal. Journal of Nepal Geological Society, v. 25 (Special Issue), pp. 19–32.

Todd, D.K., 1995. Groundwater hydrology, Second Edition, John Wiley and Sons, 300p.

Yoshida, M. and Igarashi, Y., 1984. Neogene to Quaternary lacuastrine sediments in the Kathmandu Valley, Nepal. Journal of Nepal Geological Society, v. 4 (Special Issue), pp. 73-100.