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Sanitary Landfill Design for Sustainable Solid Waste Management in Jeetpur Simara Sub-Metropolitan City, Nepal

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Abstract

Sanitary Landfill (SLF) is designed on the principle of waste control and is characterized by the presence of a liner and a leachate collection system to prevent groundwater contamination and a capping system to prevent air contamination. This paper aims to design a SLF for an enduring and sustainable Solid Waste Management (SWM) system in Jeetpur Simara Sub-Metropolitan City (JSSMC), assisting researchers and designers working in the field of waste management with an easy methodology of SLF design and encouraging municipalities for SLF practice. An area type SLF of dimension 80 m x 80 m with a mineral linear system and a capping system can accommodate Municipal Solid Waste (MSW) of this city for 15 years in an environmentally sound modus producing an achievable amount of 3,434 x 10^6 m^3 of Landfill Gas (LFG) over the lifetime of the SLF. The total heat content value of this achievable LFG over the lifetime of the landfill is about 6.40 x 10^{13} KJ.

Keywords: Jeetpur Simara; Solid waste management; Sanitary landfill; Landfill gas; Leachate collection; Liner system; Nepal

Introduction

Landfilling of wastes means the final and permanent disposal at a site without the intention to remove the waste in future (Ramke, 2001). SLF refers to an engineered facility designed and operated for the disposal of MSW to minimize the public and environmental health hazards and impacts. Landfilling includes monitoring of the incoming waste, compaction, and placement of the waste and installation of landfill environmental monitoring and control facilities. In the past, non-engineered facilities and poor management were the major problems associated with landfills (Carey and Carty, 2000). Therefore, every landfill needs appropriate design and operation to reduce negative impacts on the environment (Ramke, 2001). There are many potential environmental problems associated with the landfilling of waste, which are often long-term and includes possible contamination of the groundwater and surface water bodies, the uncontrolled migration of the LFG and the generation of odor, noise and visual nuisances (Carey and Carty, 2000). In landfills, leachate poses the greatest threat to groundwater (Hughes et al., 2007). Leachate is a liquid which percolates through the waste, picking up suspended and soluble materials that originate from or are products of the degradation of the waste (Carey and Carty, 2000). Landfill liners are designed and constructed to create a barrier between the waste and the environment and to drain the leachate to the collection and treatment facilities. Therefore, the type of liner system required for each type of landfill is determined by the potential threat posed by the waste (Hughes et al., 2007). A leachate collection system principally consists of a drainage layer of inert material with high permeability, the drainage pipes to collect the leachate to discharge it out of the dumping area, collection and inspection shafts, and collection pipes (Ramke, 1989). The uncontrolled migration of the LFG, generation of odor, noise and visual nuisances are another threat encountered at the landfill site. Capping system is designed and constructed to minimize exposure in the landfill site, to prevent vertical infiltration of water into wastes which might cause contamination of leachate, to control emission of gas from wastes and to serve as a land surface for vegetation or other uses etc. Active control of LFG is achieved through an extraction system designed in the final capping system. Extraction system requires a gas collection network which comprises gas wells, wellheads and collection pipes. The rate of LFG generation varies throughout the life of a landfill and is dependent on factors such as waste types, depths, moisture content, the degree of compaction, landfill pH, temperature and the length of time since the waste was deposited (Carey and Carty, 2000).

In Nepal, only 6 municipalities' use SLF for final disposal and 45 practice open dumping which includes Riverside and roadside dumping. In total, only 37% of MSW in Nepal is disposed in landfills but not necessarily in a sanitary manner. Majority of the municipalities have established separate section or unit responsible for SWM. 17 municipalities do not have established separate section or unit and these municipalities either do not provide any SWM services or have only a few sweepers who work under the ward offices or another unit (ADB, 2013).

JSSMC is a recently established sub-metropolitan city in Bara district of Narayani zone of central Nepal. This city practices open dumping of MSW at the bank of the river which has been the measure cause of water pollution, bad odor and nuisance, loss in aesthetic value and serious environmental and health hazards. The per capita waste generation rate of this city is 120 g/day and the quantity of waste generation is 15 tons/day which includes 13.8 tons/day wastes from household, 0.9 tons/day wastes from commercial and 0.3 tons/day wastes from the institutional sector (Dahal & Adhikari, 2018). The composition of MSW is 56% organic waste, 21% paper and paper products, 19% plastics, and 4% inert (Dahal and Adhikari, 2018). Recently, this city has proposed two locations for landfill site development. Location 1 = Bakuliya (ward no. 5), 6 km away from Jeetpur. Location 2 = Pathlaiya (ward no. 1), 12 km away from Jeetpur. Thus, to avoid all environmental and human health hazards, SLF practice can be a better solution for an enduring and sustainable SWM in this city.

2. Aims and Objectives

The objectives of this paper are to design a SLF for an enduring and sustainable MSW management in JSSMC, to provide an easy methodology for SLF design to the researchers and designers terminating the difficulty of following lengthy and confusing manuals and to encourage municipalities in Nepal for SLF practice.

3. Study Area

The study area is JSSMC in Bara district of Narayani Zone, Nepal.

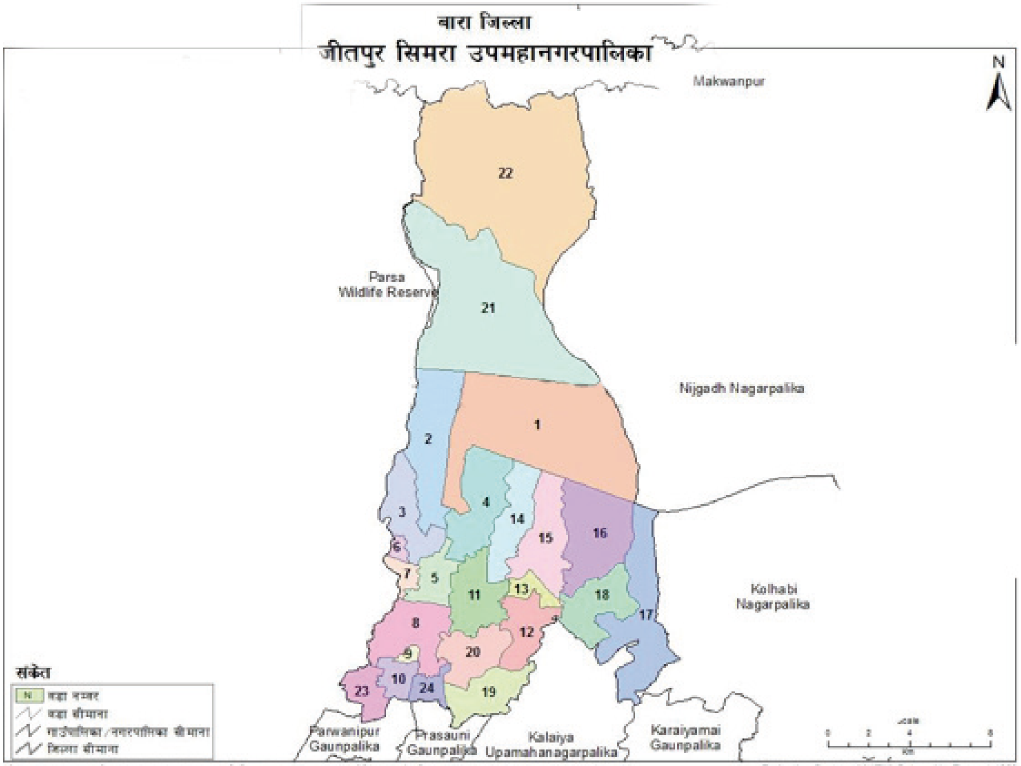

Figure 1. Location Map of Jeetpur Simara Sub-Metropolitan City (Source: MOFALD, Nepal)

4. Method and Methodology

This paper does not use any new formula and criteria for SLF design. It summarises the ideas, formulas, and methodology available in the lengthy and time-consuming manuals and research papers to a 20 step methodology which were used to design SLF for JSSMC. The steps are self-explanatory, easy to understand and give a quick image of the design of the SLF. The suggested best standards for different landfill structures/parameters were adopted to make the design of SLF economical, feasible and efficient for JSSMC. Design of SLF can be done using the following steps and formulas as below:

4.1 Fix the design period of the SLF and calculate population projection till the design period,

$P = P_o (1 + R)^N$ (Using linear model)

Where,

P = projected population till the design period

P_o = present population

R = population growth rate

N = design period

Population projection should be done till the design period of the SLF.

4.2 Calculate the total per capita waste generation in 15 years. (Per capita waste generation per year + waste coming from commercial and institutional houses).

4.3 Calculate the total per capita waste going to the SLF,

C = 80% of 2 (Assuming only 80% of the solid waste reaches to the SLF).

This is used to calculate the volume of the waste going to the SLF and to calculate the required volume of the SLF.

4.4 Fix the number of cells, the height of one lift, and the thickness of the daily and intermediate cover.

The term cell describes the volume of material placed in a landfill during one operating period, usually 1 day (Tchobanoglous & Kreith, 1999). Cover means clean soil or approved alternate material used to cover compacted MSW. If the daily cover is soil, it shall be at least 150 mm thick and if the intermediate cover is soil, it shall be at least 300 mm thick (BC Ministry of Environment, 2016).

4.5 Calculate cover to waste ratio,

$$E = \frac{(Vsw + Vsc)}{Vsw} = \frac{(Hsw + Hsc)}{Hsw}$$

Where,

E = cover to waste ratio

V_{SW} = volume of the solid waste

V_{sc} = volume of the cover material

Hsw = depth of the solid waste

Hsc = depth of the cover materials

4.6 Calculate the required volume of the SLF,

$$V_L = \frac{(P \times E \times C)}{\rho}$$

Where,

V_L = volume of the SLF

P = projected population till the design period

E = cover to waste ratio

C = total per capita waste going to the SLF

ρ = density of MSW

The density of MSW in JSSMC is 500 kg/m^3 (Calculated value from baseline data collection).

4.7 Fix the total height of the SLF and calculate the required area of the SLF,

$$A = V_L \frac{1}{H}$$

Where,

A = area of the SLF

V_L = volume of the SLF

H = height of the SLF

4.8 Calculate the length and the breadth of the SLF.

4.9 Adapt a liner system and calculate the required volume of the liner materials.

Depending on the types of waste to be placed in a landfill, liners may be described as single, composite and double liners. A low-cost mineral liner system with the required thickness of different liner materials is shown in Figure 2 (Oeltzschner and Mutz, 1996).

4.10 Adapt a capping system and calculate the required volume of the capping materials.

The purpose of a final cover system is to isolate the wastes from the surface environment, to minimize the migration of liquids through the closed landfill and to control the escaping of gas generated in the landfill. Design of a low-cost capping system with the required thickness of different capping materials is shown in Figure 3 (Oeltzschner and Mutz, 1994).

4.11 Estimate the peak leachate generation by thumb rule (total precipitation x 80% x area of active phase (Jain et al., 2016).

Estimation of the peak leachate collection is done to calculate the sump size.

4.12 Adapt a leachate collection system and fix the cross slope & the longitudinal slope.

Leachate collection system, cross slope, and longitudinal slope should be chosen in such a way in order to facilitate a gravitational flow of leachate to the sumps. For the above reasons, 'Saw-tooth' leachate collection system is preferred in a modern landfill. Minimum fall of 2% is preferred towards leachate collection sump because this gradient promotes self-cleansing and reduces clogging and the gradient of leachate collection pipes should at minimum be 1% (Carey and Carty, 2000).

4.13 Adapt a drainage pipe size.

The drainage system should be designed to collect the expected volume of leachate generated. This will vary during the life of the site (Ramke, 2001). The use of concrete-pipes is not recommended. Experiences have shown that they will be quickly corroded by the leachate and will break down. Drainage pipes in Europe and the USA normally are made of PEHD and have a minimum diameter of 250 mm depending on the height of the landfill. In developing countries, these pipes may not be easily available or are very expensive. In any case, if plastic pipes are used, they have to be well covered by drainage material (thickness of cover 2 times the size of the pipe) to reduce the pressure from the waste which will be placed on the top of it. These pipes should have a minimum diameter of 200 mm (Oeltzschner and Mutz, 1994).

4.14 Calculate the drainage pipe distance, L (Using Mould equation (US EPA, 1989)),

$$H_{max} = \frac{L}{4c}\left[\tan^2\alpha + 2 - 2\left(\frac{\tan\alpha}{c}\right)\sqrt{\tan^2\alpha + c}\,\right]$$

Where,

H_{max} = maximum allowable head on the liner

c = amount of leachate

α = slope

L = distance between the pipes.

The two unknowns in the equation are:

L = distance between the pipes and

c = amount of leachate

4.15 Calculate the sump size and the size of the leachate collection tank.

Sumps are constructed to collect leachate so that they can be transferred to the leachate collection tank. Nowadays, a high-density polyethene pipe with the minimum diameter of 300 mm to facilitate pump insertion is used (Carey and Carty, 2000). Typically, leachate holding tanks are designed to hold from 1 to 3 days of leachate during the peak leachate production (Tchobanoglous and Kreith, 1999).

4.16 Estimate the achievable LFG production over the lifetime of the SLF.

The achievable LFG production over the lifetime of the landfill from the whole of the waste is estimated as 102 m3/t of the waste (Carey & Carty, 2000).

4.17 Estimate the total heat content value of the achievable LFG over the lifetime of the SLF.

LFG has the heat content of about 18,629.5 KJ/m^3, which is about half of that of commercially available natural gas (Yedla, 2005).

4.18 Adapt a gas collection system.

LFG control systems prevent the unwanted movement of the LFG into the atmosphere (Tchobanoglous and Kreith, 1999). Large landfills and landfills with high landfill gas generation require an active gas collection system. Such a system is facilitated with gas wells/gas drains, gas ventilators and flares for gas collection and treatment (Ramke, 2001). Generally, vertical perforated gas well/gas collection system is preferred.

4.19 Calculate the depth of gas well/vent (75% of the total depth of the waste (Carey and Carty, 2000)).

4.20 Calculate the required number of gas well/vents and the size of the gas vent.

For passive gas vents, the rule of thumb is 1 vent for 7,500 m^3 of waste. Vertical gas wells are normally spaced at between 20 m and 60 m centres. Gas wells constructed as filling progresses usually have a minimum diameter of 500 mm; a diameter of 600 – 800 mm is preferred. Gas wells retrofitted after filling are typically drilled to 250-300 mm diameter (Carey and Carty, 2000).

5. Results

5.1 Total per capita waste going to the landfill

The present population of this city is 114,785 with a population growth rate of 2.25 per annum. For the design period of 15 years, the projected population, P is 160,264. The per capita waste generation per year in this city is 43.8 kg/year. Waste from commercial and institutional houses contribute about 8% of the per capita waste generation per year. Then, the total per capita waste generation in 15 years is calculated 709.56 kg. Thus, the total per capita waste going to the landfill in 15 years, C = 567.648 kg.

5.2 Required volume and area of the SLF

Using 5 cells in a lift (practised in 3 SLF's of Nepal), setting the height of one lift to be 5 m and the thickness of daily and intermediate cover to be 15 cm and 30 cm respectively, cover to waste ratio is calculated to be 1.219. The required volume of the landfill is calculated to be 158,854 m3 and the required area for landfill is calculated to be 6,400 m^2 (total height of the landfill = 25 m). Assuming a square-shaped landfill, the required length and breadth of the landfill is 80 m.

5.3 Required volume of the cover materials, liner materials and capping materials

The required volume of the cover materials, liner materials and capping materials are given below:

Daily cover = 14,400 m^3
Intermediate cover = 7,680 m^3
Sand/gravel = 1,920 m^3
Mineral liner = 3,840 m^3
Subsoil = 19,200 m^3
Top layer soil = 3,200 m^3
Coarse material = 1,280 m^3
Mineral sealing = 3,840 m^3
Foundation layer = 2,560 m^3

5.4 Leachate collection system

A 'Saw-tooth' leachate collection system is adapted to facilitate a gravitational flow of leachate to the sumps. The area of 1 phase is 3,200 m^2 and the annual precipitation last year in this city was 1,860 mm/year (Department of hydrology and meteorology, Nepal). Assuming 80% precipitation in 4 months (monsoon period), the peak leachate generation is calculated to be 5 m^3/day. Taking n = 0.01 and assuming cross-section flow of the leachate, the size of the drainage pipe (HDPE, perforated) is calculated 20 cm and calculated pipe distance is

16 m. Using Hmax = 15 cm (half of the drainage layer), the suggested cross slope is 3% (for efficient working of the low-cost mineral liner recommended by Oeltzschner). The suggested longitudinal slope is 1% and the suggested size of the sump is 300 mm in diameter. The calculated size of the leachate collection tank is 4 x 4 x 10 m^3 (able to collect 3 days of leachate).

5.5 Gas well system

The achievable LFG production over the lifetime of the landfill is 33,665,097 x 102 m^3 = 3,434 x 106 m^3. Total heat content value of the achievable LFG over the lifetime of the SLF is 3,434 x 10^6 m^3 x 18,629.5 KJ/m^3 = 6.40 x 10^{13} KJ. Active gas collection system with a vertical perforated gas well system is adopted. The depth of the gas well is suggested to be 18 m and the required number of gas wells is 16 (spaced at 20 m distance). The suggested gas well size is 250 mm (Gas wells retrofitted after filling).

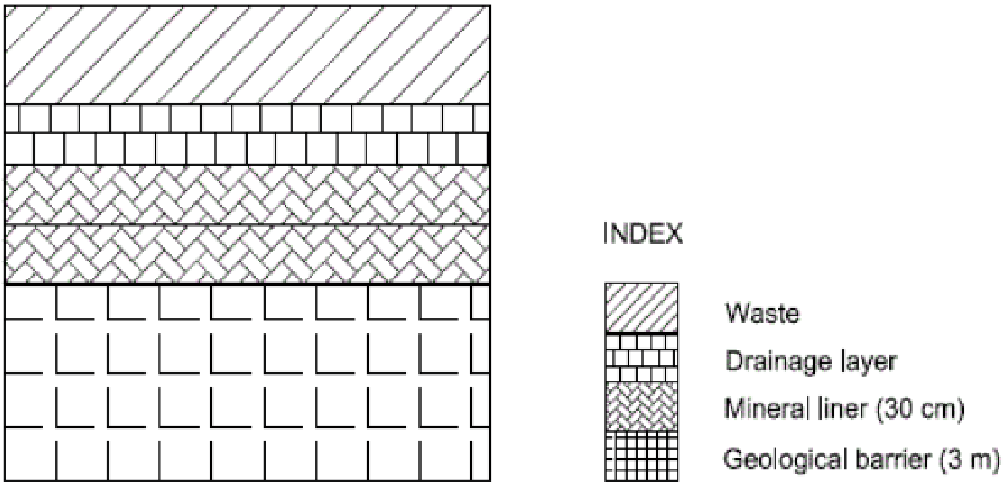

Figure 2. Liner System (Section View (Oeltzschner and Mutz, 1994))

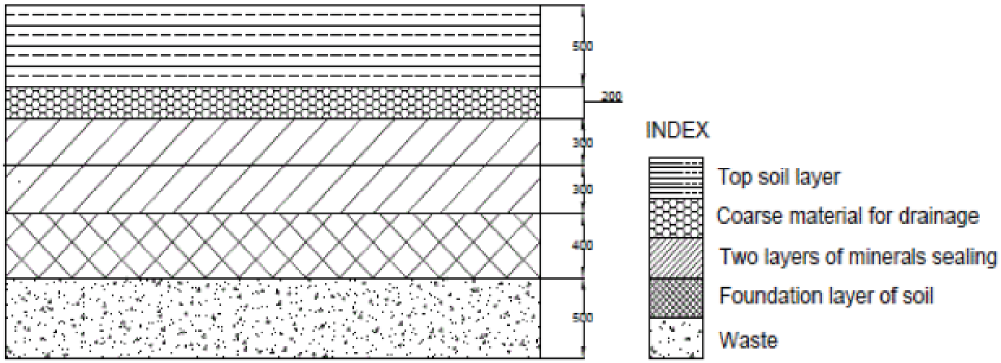

Figure 3. Capping System (Section View, All Dimensions are in cm (Oeltzschner and Mutz, 1994))

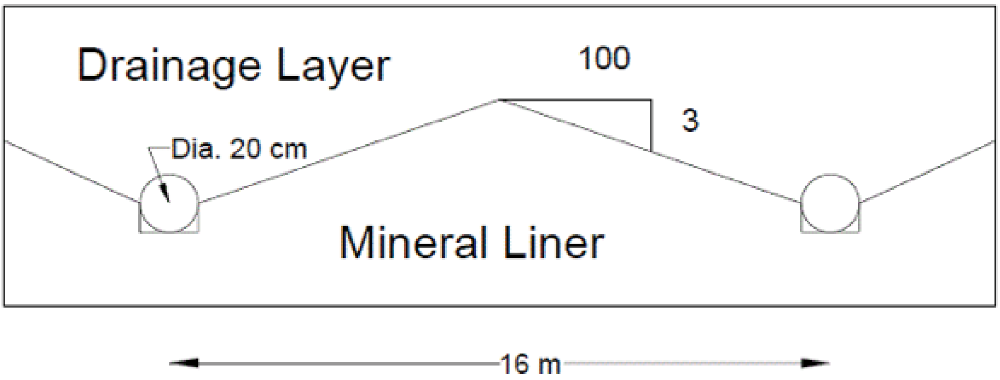

Figure 4. Leachate Collection System (Section View (Carey and Carty, 2000))

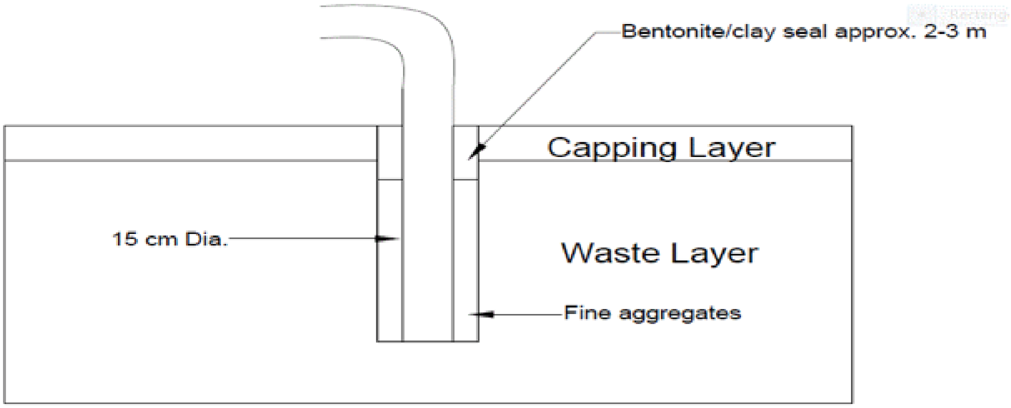

Figure 5. Gas Collection System (Section View (Carey and Carty, 2000))

Discussion and Conclusion

The designed SLF is an area-type landfill with an area of 6,400 m^2. The landfill is designed to operate in two phases (3,200 m^2 in 1 phase). The soil is chosen as a cover material because of the adequate availability of soil in the Terai region. Considering the economic limitations of JSSMC, use of standard liner system is out of the discussion. So, a low-cost mineral liner system and a capping system have been adopted. To facilitate a gravitational flow of leachate, 'Saw-tooth' leachate collection system has been adopted. The leachate collection pipes are slopped to 3% gradient for better efficiency of the mineral liner system. The estimated achievable LFG yield over the lifetime of the landfill is 3,434 x 10^6 m^3 having total heat content value of about 6.40 x 10^{13} KJ. Having regard for high achievable LFG yield, the active gas collection has been adopted. To avoid all environmental and human health hazards, SLF practice can be a better solution for an enduring and sustainable SWM in this city.

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