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ESTIMATION OF LEACHATE PRODUCTION FROM A PILOT SCALE LYSIMETER IN NEPAL

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ABSTRACT

More than eight million tons of solid waste is produced per day in developing countries. While Europe and industrialized countries go for high-tech solutions (e.g. modern incineration technologies), there is still a huge demand for proper landfilling in developing countries. This paper presents the outcome of the research on the water management of landfill in Nepal using a pilot scale lysimeter. The related leachate production as an effect of climatological factors is assessed. The Hydrologic Evaluation of Landfill Performance (HELP) model has been used to compute estimates of water balances. The local weather data (evapotranspiration data and daily values of rainfall, temperature and solar radiation), vegetative growth were prepared as required and variable soil and waste data (porosity, field capacity, wilting point, initial moisture content and saturated hydraulic conductivity of layers and materials) have been determined.
With the simulation carried out, it indicates that the evapotranspiration (ET) is nearly constant, but not high. This may be due to the small area of lysimeter and higher portion has been percolated before evaporation could take place. The trend of leachate generation on HELP simulation seems to be similar in October to December season, but in June to September, the trend shows higher percolation rate compared to the model. The annual data shows that percolation is about 81-84% of rainfall amount whereas evapotranspiration is about 15-19%. The daily production rate of percolation is about 3.47 L/m^2/day. Within highest rainfall days during 2000 to 2004 (88 L/m^2/day), average percolation is about 5.78 L/m^2/day (6.5% of the rainfall).
The application of the model in the developing country like Nepal has raised issue like effect on water balance by the large variation of short-term rainfall, which might have greater input into percolation.

KEYWORDS

Evapotranspiration; HELP model; Landfill; Lysimeter; Water balance.

1 BACKGROUND

More than eight million tons of solid waste is produced per day in developing countries. Over 95% of this waste is disposed off in landfills, open dumps, on riverbanks, directly into the sea, or just combusted on site because of insufficient waste collection and final disposal systems. Meanwhile, Europe and industrialized countries go for high-tech solutions (e.g. modern incineration technologies) there is still a huge demand for proper landfilling in developing countries. Landfilling is likely to be the most appropriate and cost-effective final disposal option for solid waste in developing countries. Facing the accelerated generation of solid

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waste caused by an ever-increasing population, migration from country side, urbanization, and industrialization, the problem has become one of the primary environmental issues in low and middle income Asian countries [1]. Especially in developing countries like Nepal, landfilling is considered to be a reliable and cost effective method if adequate land is available. However, improper management and operation of landfill is creating a severe environmental impact such as surface and subsurface water pollution and nuisance odor. This is basically due to improper operation and management of landfill in the past, especially regarding leachate and landfill gas management. Uncontrolled disposal of municipal solid waste (MSW) causes considerable environmental pollution besides being directly harmful to public health. Rivers in the Kathmandu city have been seriously polluted by discharges of untreated industrial and domestic solid waste. Improvement practices have been attempted in the waste management sector over the last twenty years in Kathmandu Metropolitan City. After the closure of Gokarna Landfill, which had been used from 1986 to 2000, making availability of landfill site and improved operations of waste management are the Kathmandu's most pressing issues. Lands and rivers are contaminated from improper disposal practices in and around Kathmandu city as they continue to impact public health, environmental quality, and land values. The cost to clean up these contaminated sites will always be significantly higher than the cost incurred to dispose off the waste properly in the first place. To prevent the water resources from further polluted, the municipal solid waste measures should be set as soon as possible with a proper waste control system in place. The new site of sanitary landfill site started near Okharpauwa in Sisdole village, which is expected to provide a way forward for waste management of Kathmandu Valley also is not properly operated. The proper implementation of waste management plan and operation of this new site along with the proper leachate management is a challenge faced by Kathmandu Metropolitan City (KMC) at present.

2 THE RESEARCH

Leachate may be defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials. In most landfills, leachate is composed of liquid that has entered the landfill from external sources, such as surface drainage, rainfall, and groundwater and the liquid produced from the decomposition of waste. The organic, inorganic and biological contaminants in the waste get solved in leachate. By preparing a water balance on the landfill, the potential for formation of leachate can be assessed. The need to understand and control leachate production at landfill sites is not a new phenomenon but it has perhaps become a more significant consideration during the last few years. Leachate management is a dire need to control surface and subsurface pollutions. For proper management, leachate quantity as well as quality aspect need to be given attention and properly planned [2]. This will help the landfill management agencies such as municipalities, private companies and other organizations to develop advanced technologies and also natural methods that could be utilized. Also the technologies in the developed and developing countries could be compared and shared. This research aims to estimate water balance for landfill on quantitative and qualitative basis using a Landfill Lysimeter Model for Kathmandu city, Nepal.

The main objective of this research is to have estimation of water balance on quantitative and qualitative basis for designing and operating landfills in developing countries with different climatic conditions. The use of a computer model like Hydrological Evaluation of Landfill Performance (HELP) is expected to be tested in Nepalese context. The outcome of the research work will be beneficial in addressing waste management issues especially landfill design and operational aspects in Nepalese context. Water management is governed by water input and output from landfill. These conditions are best characterized by a season of high intensity rainfall (up to 220 mm/day and above in Kathmandu). However, it has been observed that 215–269 days per year showed up with no rain at all and there is a distinct arid period. An average temperature of 16°C over 5 years and an average solar radiation computed to be 78.56 MJ/m²/day in Kathmandu. The research under discussion focuses particularly on the leachate production in a landfill. Consideration and general conclusions shall be drawn from a research work using lysimeter in Nepal, which serves as a case study for better understanding [3].

3 LEACHATE FORMATION AND WATER BALANCE

The quantity of leachate that could be generated in a landfill can be predicted by performing a water balance. A water balance involves an accounting of liquid flows into and out of the landfill system, and of liquid stored within the system. In most landfills, the significant inflows are precipitation and water contained in the delivered waste. The significant outflow is leachate. Following is an approach that can be used to obtain an approximation of the quantity of percolation that can be expected in a landfill by a conventional hydrological water balance.

$$L = P - R - ET - \Delta S \tag{1}$$

$P =$	Quantity of net rainfall per unit area (mm)
$R =$	Quantity of runoff per unit area (mm)
$ET =$	Quantity of moisture lost through evapotranspiration per unit area (mm)
$\Delta S =$	Change in the amount of moisture stored in a unit volume of landfill (mm)
$L =$	Quantity of percolation through the cover per unit area of soil cover (mm)

The total amount of moisture that can be stored in a unit volume of soil is a function of two variables; the field capacity (FC) and the permanent wilting percentage (PWP).

4 MODEL APPLICATION AND PROCEDURE

For this research, HELP (Hydrologic Evaluation of Landfill Performance), a water balance model, has been applied. HELP has been used for testing the effectiveness of landfill designs, and specific factors influencing the water balance at site. The following data were provided as input:

- Weather parameters such as precipitation, solar radiation, temperature, evapotranspiration. Data of nearby meteorological stations of Dhulikhel have been utilized. However, the required set of data over the period from 2000 until 2004 has been analyzed. However these years sufficiently characterize the broad range of annual precipitation (1417 – 2228 mm).
- Soil properties (porosity, field capacity, wilting point, and saturated hydraulic conductivity) are determined in the laboratory. Waste values from the HELP model have been used.

- Landfill design data such as liners, leachate collection systems, surface slope, slope length and area of landfill are based on the lysimeter data.

A daily basis infiltration into the landfill is determined indirectly from a surface water balance from the *Equation 1*. It is assumed that no liquid water is held in surface storage from one day to the next. The free available water is used to compute the runoff using Soil Conservation System (SCS) rainfall-runoff relationship. Surface evaporation is then computed. Potential evaporation from the surface is first applied to the interception. The rainfall runoff is assumed to infiltrate into the landfill or evaporate. The first subsurface process considered is soil evaporation from the evaporative zone of the upper sub profile. The other subsurface processes are modeled a single sub profile at a time, from top to bottom, a lump model procedure. A storage-routing procedure is used to redistribute the soil water among the modeling segments. This procedure accounts for infiltration or percolation into the sub profile and evapotranspiration from the evaporative zone [4].The four layers of the landfill under study are soil, waste, gravel and barrier soil liner, placed at the site that have been modeled considering the site specific design data as well as assuming the standard parametric values of the model.

5 METHODOLOGY

This research has been carried out for the first time in Nepal. Lysimeter model already researched under Asian Regional Research Programme on Environmental Technology (ARRPET), a project on Sustainable Solid Waste Landfill Management in Asia supported by Swedish International Development Agency (SIDA) coordinated by Asian Institute of Technology (AIT), Bangkok Thailand [5] have been taken as reference. The research has been carried out by installation of a landfill lysimeter model made from Reinforced Cement Concrete (RCC) rings with diameter (1 m) and height (3 m). Refer to *Figure 1* for details. The drainage system (aggregates chip size between 5mm-10 mm) has been placed at the bottom layer above the barrier soil (thickness of 0.3 m) with thickness of 0.5 m. The leachate from the lysimeter is drained into 2 numbers of storage units, i.e. (two numbers of plastic buckets each with a capacity of 17 L), one draining out from drainage layer and other from barrier soil layer.

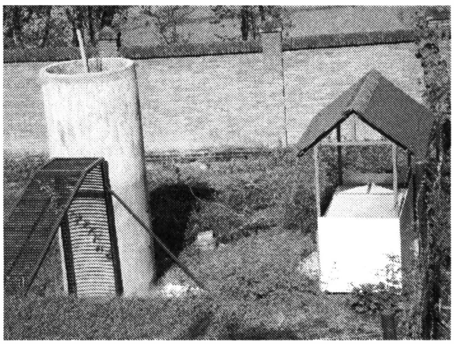

Figure 1. Pilot scale lysimeter.

Channeling of leachate was provisioned through perforated PVC pipe of 25 mm diameter installed in the drainage and barrier soil layers. Solid waste was received from a local transfer station and was placed inside the lysimeter at 200 to 250 mm thickness each time. The waste was compacted to the density of about 600 kg/m^3 until total height of 1.8 m was reached. Clay loam layer of thickness of 300 mm was placed as the cover soil layer. The lysimeter has been installed so that it represents a landfill.

The physical parameters, organic constituents, inorganic constituents and biological parameters of wastes are analyzed. Only the quantitative part has been dealt in this paper. The required test for soil parameters like Saturated Hydraulic Conductivity, Total porosity, Field capacity and Wilting Point have been carried out at laboratory scale. However, some of these parameters for waste have been taken from HELP model default value as discussed above.

6 RESULTS AND DISCUSSIONS

The simulations were run using HELP model and data analyzed. *Figures 2 and 3* show the outcome of the simulation using monthly averages.

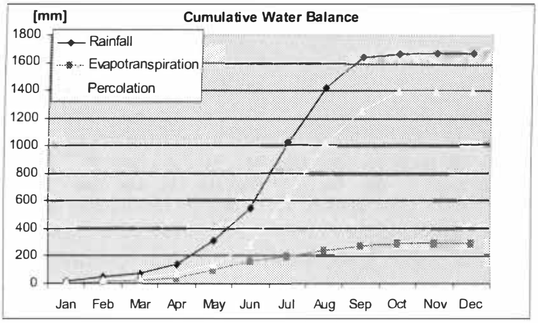

Figure 2. Cumulative water balance (2000-2004).

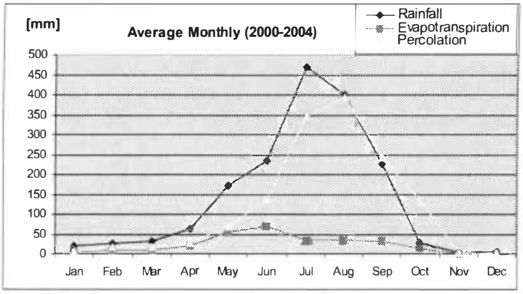

Figure 3. Monthly average of rainfall, ET and percolation.

It indicates that the evapotranspiration (ET) is nearly constant and do not follow the rainfall and percolation trend. The runoff value is zero. Solar radiation, a parameter dependent upon the temperature and sunshine duration hours, has an impact upon the evapotranspiration. The

solar radiation distribution over a year has shown that even during the wet season, the intensive solar radiation will have a strong effect on evapotranspiration. However the evapotranspiration, in this case, is not high, may be due to the small area of lysimeter and higher portion has been percolated before evaporation could take place. However, during the dry season the potential evaporation is non attainable.
The 5 yearly data as shown in *Figure 4* also indicates that evapotranspiration seems to be almost constant and percolation is following the trend of rainfall and it is a dependent parameter.

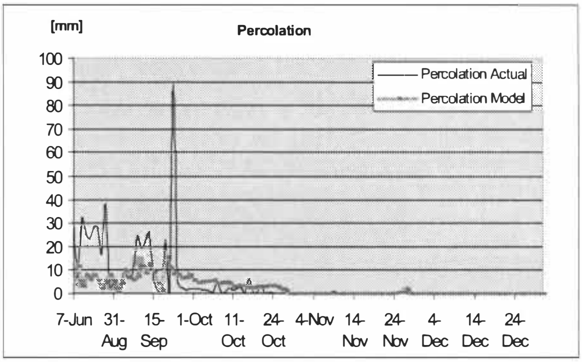

Figure 4. Annual data of rainfall, ET and percolation.

The evapotranspiration is not dependent on rainfall. There is an immediate response of percolation after rainfall. The input here is only rainfall. The moisture content of waste is negligible compared to rainfall. The annual data shows percolation is about 81-84% of rainfall amount whereas evapotranspiration is about 15-19%. On daily basis, however the percentage response may be different depending on rainfall for consecutive number of days. The response of rainfall as percolation is observed after few days, so the percentage is even more than the rainfall amount on the same day. When aggregated in weeks, months or annual, it is different than daily basis.

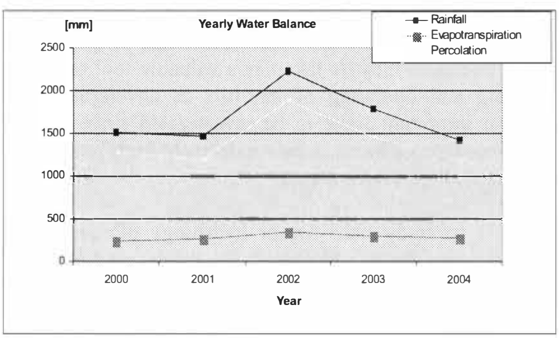

Figure 5. Percolation related to model and actual.

The daily production rate of percolation is about 3.47 L/m^2/day on an average, which is generally high. Although in the view of highest rainfall days during 2000 to 2004 the average highest rainfall is 88 L/m^2/day and percolation is about 5.78 L/m^2/day on an average (only about 6.5% of the rainfall).

The evapotranspiration component of the water balance might have been underestimated, as it is dependent on solar radiation, vegetative growth (hardly any), evaporative zone depth, wind speed, and relative humidity. These parameters need to be studied in detail and should represent the local conditions to give better results for the model. The model has been calibrated for the local situation with the limited observed data of leachate generation from the lysimeter. However the trend of leachate generation on HELP simulation and actual data seem to be similar in October to December season, but in June to September, the trend shows higher percolation rate in actual data than model (*Figure 5*). This may be due to the higher value (in the range of 10^{-5}) of hydraulic conductivity of barrier soil, which should be generally lower value (in the range of 10^{-8}). Also it may be due to the rainy season (June-September) when soil is wet at most of the time. This research has not fully discussed the variation of percolation, it may be linked with soil properties and a matter of further research. Furthermore, the parameters such as landfill design criteria (layer data: hydraulic conductivity or slope) and operation processes of landfill have to be investigated further.

7 CONCLUSIONS

The HELP model has been considered as a good tool for planning purpose. The lysimeter field investigation needs to be validated and verification of the model results by detail calibration. This can be done with the availability of long term data. Biodegradability of solid waste could not be accounted by the model. The contribution for water balance from microbiological processes have been taken as negligible in this research and as the model only simulates over a full year, variation over short time span could not be modeled, thus high rainfall over short period could not be taken into account. The application of the model in the developing country like Nepal has raised issue like effect on water balance by the large variation of short-term rainfall, which might have greater input into percolation. Nevertheless the trend for the water balance has been predicted based upon the 5-year climatic data. This research has evolved some issues regarding water management and its solutions towards proper management of sanitary landfills and other influencing parameters to be investigated in detail. The application of model may be taken as a valuable tool to determine strengths and weaknesses of designing and operating of landfills in developing countries like Nepal. Landfill hydrology is an important issue to be investigated since most Asian landfills are located in regions with monsoon climate, where extremely high precipitation for few months followed by dry season with high evaporation.

The use of lysimeters is to study behavior or hydrology of leachate generation and the characteristics of leachate production. However, the results should serve other purposes as designing leachate collection systems and landfill design. Leachate collection systems are usually designed using such models as the HELP model; a theoretical approach which may be unsuitable in some certain situations. If these theoretical models are combined with empirical results from lysimeter studies, the resulting designs could be more realistic.

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