Estimated leachate rate affected by climate change in landfill for radioactive contaminated hazardous waste from petroleum industries

C A W Dwipayana1, 2, S S Moersidik1, M A Pratama1
1 Department of Civil Engineering-University of Indonesia, Kampus UI, Depok 16424, Indonesia
2 Nuclear Energy Regulatory Agency, Jl.Gadjah mada No. 8, Jakarta 10120, Indonesia

Abstract. Naturally occurring radionuclides are present in the beneath the earth at different levels and can be concentrated and increased by operations related with the oil and gas industries. NORM disposal must provide adequate protection to both human health and the environment. Leachate is the major danger posed by contemporary landfills, which is affected by weather. In this paper a leach rate simulation has been carried out using the required design of class I landfill to see the effect of climate change scenarios. Simulations are carried out using the US EPA Hydrologic Evaluation of Landfill Performance software. The inputs are 60 years generated weather data from the LARS-WG program using 30 year historical data from Bogor Climatology Station. Climate change modeling uses GCM HadGEM3-ES with RCP scenarios 2.6, 4.5 and 8.5. The annual average rainfall for RCP 2.6, 4.5 and 8.5 climate change scenarios are, 3154.27mm, 3434.47mm, and 3316.33mm respectively, lower than the site base simulation 3854.24mm. The monthly average temperature of RCP scenario is higher than site base scenario, 3.78%, 4.60%, and 6.51% respectively for RCP 2.6, 4.5 and 8.5. But the leachate rate from the barrier soil layer has no difference for each climate change scenario.

1. Introduction
Naturally occurring radionuclides are present in the beneath the earth at different levels and can be concentrated and increased by operations related with the oil and gas industries. Examples of materials that can contain high concentrations of NORM are sludge, drilling mud and pipe scales, and radioactive materials can be transferred from site to site when machinery and materials are reused [1].

Even though the risk of radiation exposures arising from NORM contaminated waste streams can be generally accepted by both workers and the general public, the extent of this danger and the consequent necessity to regulate NORM have also been discussed. In the past few years, the petroleum industry has adopted methods for managing and disposing of NORM-contaminated wastes and equipment that are more restrictive than past practices and are likely to provide greater isolation of the radioactivity. Presently acceptable techniques of NORM management and disposal are including (1) burial in authorized NORM or low-level radioactive waste disposal facilities, (2) dilution and burial in authorized installations, (3) downhole encapsulation within plugged and discontinued well by license only, (4) underground injection into underground forming by license only, and (5) decontamination and reuse of controlled devices [2].

The Minister of Environment and Forestry Regulation Number P.63/Menlhk/Setjen/KUM.1/ 7/2016 of Requirements and Procedures for Hazardous and Toxic Waste Disposal in the Landfill Facilities, regulate that radioactive contaminated hazardous waste must be disposed of in class I or class II landfills.
The difference in the requirement of the two landfills is the number of geomembranes. Class I landfills have 2 geomembrane layers while class II landfills only have 1 geomembrane layer under the waste layer. While the required capping design for the two types of landfills is the same, they have 1 layer of geomembrane.

Landfilling is a managed technique for land disposal of solid waste with the double goal of eliminating public health and environmental risk while reducing nuisance, with no surface water or groundwater resources contaminated. Leachate is the major danger posed by contemporary landfills. Leachates are compounds of water and water-soluble waste that accumulate as the water passes through the site. This water could be produced by precipitation or by the waste [3]. Climate (precipitation), landscape (run-on/runoff), waste cap, plants and waste type are important factors that influence leachate generation [4].

We need to consider climatic variations, look at particular methods and investigate site development strategies if we want to effectively manage a shift from open dumping disposal sites to engineered landfill in the Asian community [5]. Climate change has become a major problem in the future where water availability may be questioned in the coming years [6]. An embedded assessment is therefore necessary, which can measure the effects of climate change on the waste disposal process. General Circulation Models (GCMs) are used to predict future climate change. GCMs are an Earth system-based computer model and are numerically used to simulate the current and future project climate strengthened by greenhouse gas emissions and particulate matter. Due to its coarse spatial resolution, the GCM output cannot be utilized for hydrological evaluation [7]. One of stochastic weather generator intended for climate change effect research is Long Ashton Research Station Weather Generator (LARS-WG). It has been evaluated and better than some other generators in a variety of environments. The latest research has tested LARS-WG at various locations worldwide and demonstrated their capacity to model extreme rainfall with sensible skills [8].

In this paper a leach rate simulation has been carried out using the required design of class I landfill to see the effect of climate change scenarios. Simulations are carried out using the US EPA Hydrologic Evaluation of Landfill Performance software. Weather information from LARS-WG is produced over 60 years using 30 years of Bogor Climatology Station's historical information.

2. Methodology

2.1. Estimation Future Climate Change

LARS-WG is a stochastic weather generator and is used in present and future circumstances to simulate weather information at one location. LARS-WG uses recorded daily weather information for a particular location to calculate a set of weather variables distribution probability parameters and their correlation by randomly chooses a value from the suitable distributions to create the simulated weather time series of arbitrary lengths [8].

In this paper, 30 years (1984-2013) historical data from Bogor Climatology Station will be used to generate future daily weather data for 60 year. As general circulation models (GCMs), HadCM3 with A2 scenario will be used. This model has been developed in the Hadley Centre of the UK national meteorological services and is a combined atmosphere-ocean GCMs. HadCM3 was selected as it is commonly used in numerous researches on the effect of climate change. It can also simulate for a century and demonstrates a little change in surface climatic conditions [9]. Representative Concentration Pathway (RCP) that be used in this study are RCP 2.6, 4.5 and 8.5. RCPs are based on multi-gas emission scenarios, the four RCPs cover future levels ranging from very elevated (RCP8.5) to very low (RCP2.6). The RCP numerical values (2.6, 4.5, 6.0 and 8.5) are the same as the 2100 concentrations [10].

2.2. Landfill Design

Landfill design to be used is those required in the Minister of Environment and Forestry Regulation Number P.63/Menlhk/Setjen/KUM.1/7/2016 [10]. Landfill design parameters not included in the Regulation are taken from hazardous landfill of the PPLI Cileungsi. PPLI Cileungsi has 1 landfill cell which has been closed with an area of around 6.3 ha. The waste thickness used in this simulation is
12.5m, this value is obtained from the practical approach of landfill volume data that has been closed with the final cover at PPLI Cileungsi which is 767,761 m$^3$, with a landfill area of 62,693 m$^2$. The thickness of the landfill layer used in this study is as in table 1.

| No | Lapisan                              | Thickness (m) |
|----|--------------------------------------|---------------|
| 1. | Top Soil-Fine Sandy Loam             | 0.6           |
| 2. | Drainage Layer -Sand                 | 0.3           |
| 3. | Geomembrane-HDPE-2mm                 | 0.002         |
| 4. | Capping Barrier-Barrier Soil         | 0.6           |
| 5. | Temporary Cover-Fine Sandy Loam      | 0.15          |
| 6. | Waste                                | 12.5          |
| 7. | Protective Layer-Sandy Clay Loam     | 0.3           |
| 8. | Leachate Collection Layer-Gravel     | 0.3           |
| 9. | First Geomembrane-HDPE-2mm           | 0.002         |
| 10. | Barrier Layer-Barrier Soil          | 0.3           |
| 11. | Leakage Detection Layer-Gravel       | 0.3           |
| 12. | Leakage Detection Layer -Drainage Net (0.6cm) | 0.006 |
| 13. | Second Geomembrane-HDPE-2mm         | 0.002         |
| 14. | Base Layer-Barrier Soil             | 1.0           |
| 15. | Local Soil                           | 4.0           |

Tabel 2. HELP Input Parameters

| Parameters                              | Value       |
|-----------------------------------------|-------------|
| Evapotranspiration Depth                | 20cm        |
| Maximum Leaf Area Index                 | 3.5         |
| Relative Humidity                       |             |
| • Quarter 1                             | 87.4 %      |
| • Quarter 2                             | 85.1 %      |
| • Quarter 3                             | 80.1 %      |
| • Quarter 4                             | 84.5 %      |
| Average Wind Speed                      | 1 km/hour   |
| Landfill Area                           | 6.3 Ha      |
| Percentage of area where runoff is possible | 100%        |

2.3. Hydrology Modeling

The leachate quantification of the landfill is generally modelled on the basis of principles of water balance by estimating the water percolation in the landfill and by degradation or evaporation of water [11]. Various software has been created to simulate leachate generation in landfill sites [12]. In this paper, the Hydrologic Evaluation of Landfill Performance (HELP) software will be used. The HELP system (version 3.07) for predicting landfill leachate volume and water balance analysis in landfill systems and capping systems is the most commonly used model in the United States Environmental Protection Agency [13].

Generated daily weather data of 60 years for each RCP and site base scenario are used to simulate water balance in landfill. Weather data are include daily rainfall data, daily minimum and maximum temperatures, and also solar radiation. The humidity and wind velocity parameters are taken from the average weather climatology station in 1984-2013. Other input parameters can be seen in table 2. Leachate rate from hydrological modelling will be an input for radiological modelling.
3. Result and Discussion
From LARS-WG simulation, daily future weather data of 60 years are gained. The daily data are processed into average monthly data for each parameter, as shown in figure 1 to figure 4.

![Figure 1. Comparison of precipitation for each scenario](image1.png)

![Figure 2. Comparison of minimum temperature for each scenario](image2.png)
Visual examination is done for each average monthly data to know the difference of each RCP Scenario. From figure 1 to 4 it can be seen that LARS WG is able to produce good predictions, which can be seen that the site base curve always coincides with the observation curve.

From figure 1, precipitation for future is slightly lower than historical weather. The annual average rainfall for RCP 2.6, 4.5 and 8.5 climate change scenarios are, 3154.27mm, 3434.47mm, and 3316.33mm respectively, the site base simulation 3854.24mm.

Temperature in future is predicted increase for maximum and minimum temperature. The monthly average temperature of RCP scenario is higher than site base scenario, 3.78%, 4.60%, and 6.51% respectively for RCP 2.6, 4.5 and 8.5 (figure 2 and 3). There is no difference for solar radiation data of historical and future climate (figure 4).

Predicted daily weather data of each RCP Scenario is used to simulate leaching rate of designed landfill. HELP Software produce leach rate and volume for several layers. Comparison of leach rate for each climate scenario is shown in table 3 and figure 5. Difference value of precipitation make difference value of runoff, however the water that unfiltered to the waste has same rate value. It is caused by
appearance of geomembrane in capping barrier. Geomembrane reject almost all water that try to infiltrate to waste layer. From this fact it can be concluded that the presence of geomembranes is very important in preventing contamination by reducing leachate rate.

Table 3. Comparison of HELP output for each scenario

|                          | Site Base | RCP 2.6   | RCP 4.5   | RCP 8.5   |
|--------------------------|-----------|-----------|-----------|-----------|
| precipitation            | 3854.24   | 3154.27   | 3434.47   | 3316.33   |
| runoff                   | 2092.8088 | 1443.83   | 1713.684  | 1599.634  |
| evapotranspiration       | 1220.172  | 1181.51   | 1185.787  | 1186.34   |
| percolation through capping drainage layer | 540.45687 | 528.0892  | 534.1679  | 529.5237  |
| percolation through capping barrier | 0.89467   | 0.85743   | 0.87764   | 0.86124   |
| percolation through protective layer | 0.89467   | 0.85743   | 0.87764   | 0.86124   |
| leachate collection system | 0.89456   | 0.85733   | 0.87754   | 0.86113   |
| leachate through barrier layer | 0.00011   | 0.00007   | 0.00011   | 0.00011   |
| leachate through base layer | 0.00007   | 0.00006   | 0.00007   | 0.00007   |

Figure 5. Comparison of HELP output for each scenario

4. Conclusion
LARS WG is able to produce good predictions of future daily weather data. Precipitation for future is slightly lower than historical weather. Temperature in future is predicted increase for maximum and minimum temperature. The monthly average temperature of RCP scenario is higher than site base scenario, 3.78%, 4.60%, and 6.51% respectively for RCP 2.6, 4.5 and 8.5. There is no difference for solar radiation data of historical and future climate. Leachate rate from the barrier soil layer has no difference for each climate change scenario.

Acknowledgments
The Hibah PITTA B (Hibah Publikasi Internasional Terindeks Tugas Akhir/International Indexed Publication for Final Project) funding scheme, with contract number NKB-0785/UN2.R3.1/HKP.05.00/2019, endorsed this research by Universitas Indonesia.

References
[1] OGP 2016 Guidelines for the Management of Naturally Occurring Radioactive Material (NORM) in the Oil and Gas Industry.
[2] Smith K P Blunt D L Williams G P and Tebes C L 1995 Radiological Dose Assessment Related to Management of Naturally Occurring Radioactive Materials Generated by the Petroleum Industry in *SPE/EPA Exploration and Production Environmental Conference*.

[3] Alslaibi T M Abustan I Mogheir Y K and Affi S 2013 Quantification of leachate discharged to groundwater using the water balance method and the Hydrologic Evaluation of Landfill Performance (HELP) model *Waste Manag. Res.* 31(1) 50–59.

[4] Nasar A M Qrenawi L Jaber A and Jazar M A 2007 *Assessment of Solid Waste Dumpsites in Gaza Strip* The Japan International Cooperation Agency (JICA)

[5] Visvanthan C Trankler J Kuruparan O and Xiaoning Q 2002 Influence of Landfill Operation and Waste Composition on Leachate Control: Lysimeter Experiments Under Tropical *Second Asian Pacific Landfill Symp. Landfill Gas Leachate Manag. September 25-28, Seoul Korea Sess. 4* p. 7.

[6] Hassan Z and Harun S 2013 Impact of Climate Change on Rainfall over Kerian, Malaysia with Long Ashton Research Station Weather Generator (LARS-WG) *Malaysian J. Civ. Eng.* 25(1) 33–44.

[7] Karamouz M Fallahi M Nazif S and Rahimi M 2009 Long Lead Rainfall Prediction Using Statistical Downscaling and Artificial Neural Network Modeling *Sci. Iranica* 16 165-17

[8] Osman Y Al-Ansari N Abdellatif M Aljawad S B and Knutsson S 2014 Expected Future Precipitation in Central Iraq Using LARS-WG Stochastic Weather Generator *Engineering* 06(13) 948–959.

[9] McCarthy J Canziani O Leary N Dokken D and White K 2001 *Impacts, Adaptation and Vulnerability* Cambridge University Press, New York

[10] Al-Ghafri A Gunawardhana L and Al-Rawas G 2014 An Assessment of Temperature and Precipitation Change Projections in Muscat, Oman from Recent Global Climate Model Simulations *Int. J. Students Res. Technol. Manag.* 2(03) 109–112.

[11] Kjeldsen P and Beaven R 2011 Landfilling: Hydrology in *Solid Waste Technology and Management* 2(10.3) 709-733 Wiley Chichester West Sussex UK

[12] Beck-Broichsitter S Gerke H H and Horn R 2018 Assessment of leachate production from a municipal solid-waste landfill through water-balance modeling *Geosci.* 8(10)

[13] Yong R N Mulligan C N Fukue M 2015 *Sustainable Practices in Geoenvironmental Engineering* 2nd ed. Boca Raton, FL: CRC Press.