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Evaluation of Municipal Solid Waste Landfill by HELP Model and Leachate Modelling by Hydrus-1d: A Review

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Abstract: The effective management of municipal solid waste (MSW) landfills is vital for minimizing their environmental and public health impacts. The Hydrologic Evaluation of Landfill Performance (HELP) model and HYDRUS-1D are widely used tools for modeling landfill hydrology and leachate dynamics, respectively. This review consolidates recent advances in their application for evaluating MSW landfills. The HELP model's capabilities in simulating landfill hydrological behavior and HYDRUS-1D's precision in modeling leachate transport through porous media are explored. The paper highlights the advantages, limitations, and future directions for integrating these models in landfill studies to promote sustainable waste management practices.

Keywords: Municipal Solid Waste (MSW), Landfill Modeling, HELP Model, HYDRUS-1D, Leachate Management, Groundwater Protection

I. INTRODUCTION

Municipal Solid Waste (MSW) landfills are engineered systems designed for long-term waste disposal. Effective management requires understanding the hydrological and solute transport processes to mitigate environmental impacts, particularly groundwater contamination. Leachate, a liquid effluent rich in contaminants, forms as water percolates through waste. Modeling tools such as the HELP and HYDRUS-1D provide predictive capabilities for assessing landfill performance.

1) *HELP Model:* Used for simulating landfill hydrology, including precipitation, infiltration, and runoff.
2) *HYDRUS-1D:* A numerical tool for modeling leachate migration and solute transport in unsaturated and saturated zones.

This section introduces the need for combined modeling approaches to holistically evaluate landfill dynamics.

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II. THE HELP MODEL

A. Overview

The Hydrologic Evaluation of Landfill Performance (HELP) model, developed by the U.S. Army Corps of Engineers, is a quasi-two-dimensional simulation tool. It divides the landfill into vertical layers and computes water balance using empirical and analytical methods. Key inputs include:

1) Climatic data (precipitation, temperature, solar radiation).
2) Soil and waste characteristics (permeability, porosity, field capacity).
3) Design features (cover systems, drainage layers).

B. Applications in Landfill Studies

The HELP model's flexibility has enabled various applications:

1) Leachate Generation Estimation: It predicts the volume of leachate generated under different climatic conditions.
2) Evaluation of Cover Systems: Assessing the efficiency of cover designs in reducing infiltration.
3) Landfill Liner Performance: Evaluating percolation rates through liners.
4) Waste Stabilization Monitoring: Estimating the time required for waste stabilization through hydrological balance.

C. Limitations

Despite its simplicity, the HELP model assumes homogeneous landfill layers, which may not reflect the complex nature of waste heterogeneity. Additionally, it does not account for solute transport, limiting its utility in contamination risk assessments.

III. HYDRUS-1D

A. Overview

HYDRUS-1D is a versatile numerical model for simulating water, solute, and heat transport in variably saturated porous media. Using a finite element approach, it solves the Richards equation for water flow and advection-dispersion equations for solute transport. Key parameters include:

1) Soil hydraulic properties (retention curve, hydraulic conductivity).
2) Initial and boundary conditions (water content, solute concentration).
3) Chemical interactions (adsorption, degradation).

B. Applications in Landfill Studies

1) Leachate Migration: Simulating the movement of leachate through liners and subsoils.
2) Contaminant Transport: Modeling the fate of solutes such as heavy metals, nitrogen compounds, and organics.
3) Liner System Analysis: Evaluating the efficiency of geosynthetic and compacted clay liners.
4) Groundwater Impact Assessment: Predicting contaminant plumes and potential groundwater pollution.

C. Limitations

HYDRUS-1D requires detailed site-specific data, which can be difficult to obtain. Its computational demands may also be a challenge for large-scale simulations.

IV. LITERATURE REVIEW

1) Krishna R. Reddy[1], Hiroshan Hettiarachchi[2] , Naveen S. Parakalla[3] , Janardhanan Gangathulasi[4],Jean E. Bogner[5](2009): This paper presents the results of a laboratory investigation to determine the geotechnical properties of fresh municipal solid waste (MSW) collected from the working phase.Laboratory testing was conducted on shredded MSW to determine the compaction, hydraulic conductivity, compressibility, and shear strength properties at in-situ gravimetric moisture content of 44% and their values are determined by laboratory test.
2) T.N Tengku Ibrahim[1] , N.Z. Mahmood[2] , F. Othman[3](2010): Landfilling is most preferred method to disposed MSW but majority of landfills do not equipped with proper leachate treatmentsystems and then environmental problems occurs. In this paper they calculate the leachategeneration from MSW. A simple mathematical calculation is used for calculation of annual leachate volume. They estimate landfill are by Google Earth and multiplied by annual rainfall.Theproduct is expressed as volume (V). Formula for calculating leachate volume is (v)= 0.15 *R*A
3) .The data indicated that the leachate production is high even it is fully closed. It is important to design the efficient landfill and proper leachate treatmentprocesses especially for the old/closed landfill. Generally, leachate production is greater whenever the waste is less compacted because compaction reduces the filtration rate. From this paper we can conclude that Although most of thenon-sanitary landfills in Selangor have been closed yet leachate production still occurs and this can badly affect particularly the water system where most landfills are located near the water system and it is source of water to the local residents.
4) V.F Nascimento1, A.C Sobral2, M. Fehr3, N. Yesiller4 , P.R. Andrade5 and J.P. Henry Balbaud Ometto[6](2008): The proper disposal of municipal solid waste (MSW) is a global challenge, mainlyin developing countries. The objective of this paper is to review recent improvements and remaining challenges of municipal solid waste disposal (MSWD) in Brazil focusing on the environmental impacts caused by inappropriate disposal of MSW. Before the implementation of the Brazilian Solid Waste Policy (BSWP), in 2008, 72.3% of all municipalities in Brazil disposedof their MSW in open dumps and uncontrolled landfills. In 2015, after the deadline given by the BSWP to close all open dumps and uncontrolled landfills had expired, 60% of all Brazilian municipalities still dispose their MSW improperly. Therefore, while progress occurred in the management practices for MSWD in Brazil, the improvements have not occurred as fast as expected by the BSWP and several shortcomings remain, which cause significant environmental impacts.

5) H.Hashemi[1], M.Safari[2], M.R.Samaei[3], A.Khodabakshi[4] (2012): Leachate may be treated anaerobically, saving environment and converting the organic material partially to biogas energy. Even toxic compounds may be degraded anaerobically depending on the process applied. At least20% of energy used in the EU coming from renewable sources and 10% of the fuels used in transport being biofuels.As a rule of thumb, wastes containing less than 60% of volatile solids ararely considered as substrates for anaerobic digestion.Few studies have been conducted on the biogas production from compost leachate. Furthermore, most of those studies use synthetic leachate. Composting leachate and young landfill leachate normally contain high amounts of volatile fatty acids. These readily biodegradable volatile acids accounts for the bulk of the chemical oxygen demand (COD) of leachate, so the ratio of biological.
6) Sachin Mishra[1], Dhanesh Tiwary[2], Anurag Ohri[3], Ashwani Kumar Agnihotri[4] (2019): This study assesses the impact of municipal solid waste (MSW) landfill leachate on its surrounding groundwater quality of village Ramna, Varanasi, India. Leachate pollution index (LPI) of landfill leachate was evaluated with their physicochemical analysis that represents the overall leachate pollution potential and hazardous nature of MSW leachate. A considerable amount of NO3, PO4 Fe, electrical conductivity (EC) and total dissolved solid (TDS) were found in the groundwater samples near to the landfill site especially during post-monsoon, indicating that groundwater quality is being significantly affected by leachate percolation.Groundwater flow modeling simulation also showing that increase in the hydraulic head during the post monsoon responsible for the downward flow of leachate pollutants from the landfill site. This Study suggests an urgentneed for the sanitary landfill to control and minimize the impact of MSW leachate on groundwaterquality around the Raman MSW landfill site.
7) Tamer M. Alslaibi[1], Yunes K. Mogheir[2] and Samir Afifi[3] (2007): Landfills are one of the groundwater pollution sources in Gaza Strip. This study focuses on two landfills operating in GazaStrip; the first is Dear Al Balah landfill which has a lining system and the second landfill is Gaza landfill which does not have a lining system. The main objective of the present study is to assess the effect of landfill components on percolated leachate to groundwater aquifer using the Hydrologic Evaluation of Landfill Performance (HELP) model. Analysis suggested that changes in lining system type, rainfall level, landfill area, and recirculation ratio have the most significantimpact on model outputs indicating that these parameters should be carefully selected when similarmodeling studies are performed.

V. INTEGRATING HELP AND HYDRUS-1D

A. Combined Approach

The integration of HELP and HYDRUS-1D combines macroscopic water balance analysis with detailed solute transport modeling. HELP provides boundary conditions such as infiltration and leachate generation rates, which serve as inputs for HYDRUS-1D.

B. Benefits of Integration

1) Improved Accuracy: Aids in realistic predictions of landfill hydrology and contaminant migration.
2) Enhanced Design Insights: Optimizes landfill cover and liner designs for better performance.
3) Comprehensive Risk Assessment: Evaluates both water balance and leachate impacts on surrounding environments.

C. Challenges

1) Integrating these models requires:
2) Consistency in input parameters (e.g., hydraulic properties).
3) Expertise in interpreting outputs from both models.

VI. STRENGTHS AND LIMITATIONS

A. HELP Model

1) *Strengths*

- Easy to use with minimal computational requirements.
- Suitable for preliminary landfill design.

2) *Limitations*

- Simplistic assumptions may not capture complex landfill dynamics.
- Limited capability to model contaminant transport.

B. HYDRUS-1D

1) Strengths

- High precision in simulating leachate transport.
- Flexibility in modeling diverse solutes and landfill materials.

2) Limitations

- Computationally intensive.
- Requires detailed site-specific data.

VII. FUTURE DIRECTIONS

1) *Automated Integration:* Develop seamless workflows for combining HELP and HYDRUS-1D.
2) *Real-Time Data Utilization:* Incorporate sensor-based data to improve model accuracy.
3) *Climate Change Impact Studies:* Assess landfill performance under future climate scenarios.
4) *Advanced Materials Testing:* Evaluate the performance of emerging liner and cover materials.
5) *Scenario Analysis:* Simulate various waste management practices, such as recycling and incineration, to compare environmental outcomes.

VIII. CONCLUSION

This review highlights the potential of integrating HELP and HYDRUS-1D for evaluating MSW landfills. While HELP efficiently models hydrological processes, HYDRUS-1D adds precision in leachate migration analysis. Together, these tools provide a comprehensive framework for sustainable landfill management. However, continued advancements in model integration and site-specific data collection are essential for maximizing their utility.

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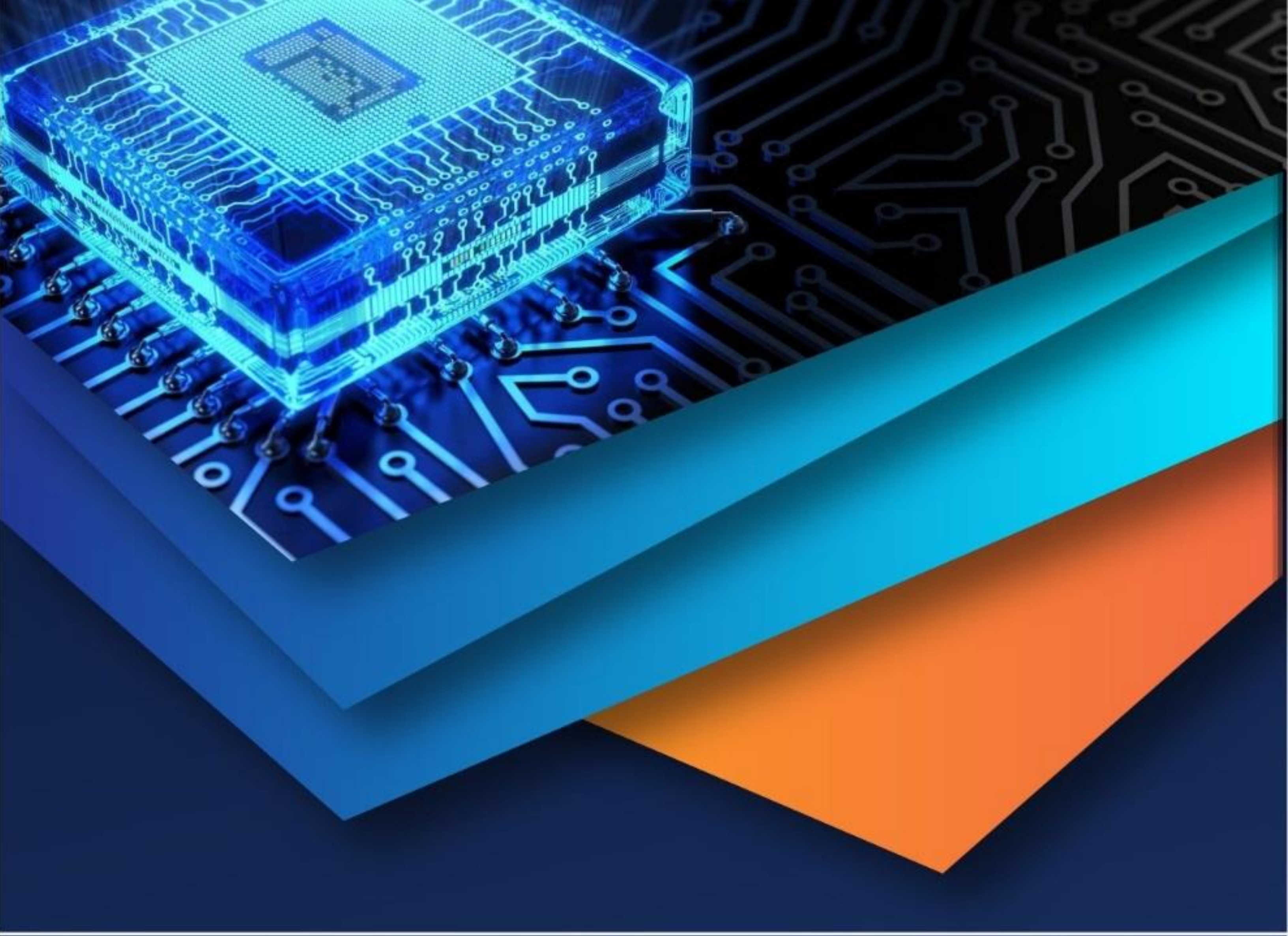

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