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Impact of Muncipal Solid Waste on Geotechnical Properties of Soil

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Abstract; **Municipal solid waste (MSW) disposal in open dumpsites poses significant environmental challenges, particularly in rapidly urbanizing regions. This study investigates the impact of MSW on the geotechnical and elemental properties of soil at the Haldwani dumpsite in Uttarakhand, India. The dumpsite has been an active repository for over two decades, receiving a variety of waste materials, including organic matter, plastics, metals, and construction debris. Soil samples were collected from three depths (0.5m, 1m, and 1.5m) across the dumpsite and analysed for key geotechnical properties such as moisture content, bulk density, permeability, and Atterberg limits. Additionally, the elemental composition was determined using Energy Dispersive Spectroscopy (EDS) to identify the concentration of heavy metals and essential nutrients. The results indicate significant contamination of the topsoil with elevated levels of heavy metals, including lead (Pb), cadmium (Cd), and arsenic (As), which exceeded background levels. Geotechnically, the soil exhibited lower bulk density and permeability in the topsoil, reflecting the influence of organic waste decomposition. The study highlights the potential environmental risks associated with prolonged MSW disposal and underscores the need for sustainable waste management practices to mitigate soil contamination and maintain soil health.**

INTRODUCTION

Municipal solid waste (MSW) management has become a critical environmental issue in many parts of the world, particularly in developing countries like India. The rapid urbanization and population growth observed in these regions have led to a substantial increase in the generation of MSW, placing immense pressure on waste management systems. Open dumpsites have become a common solution for waste disposal due to their low cost and ease of implementation. However, this method poses significant risks to the environment and public health. The uncontrolled disposal of waste in these open dumpsites often leads to the release of pollutants into the surrounding environment, affecting soil, water, and air quality.One of the most concerning byproducts of waste degradation in open dumpsites is leachate. Leachate is a liquid that forms as water percolates through the waste material, dissolving and carrying with it various contaminants, including heavy metals, organic compounds, and pathogens. When leachate infiltrates the soil, it can alter its physical, chemical, and biological properties, leading to contamination. Such contamination not only diminishes soil fertility and disrupts plant growth but also poses serious risks to human health through the potential contamination of groundwater and the food chain.

The Haldwani dumpsite, located in the Nainital district of Uttarakhand, India, exemplifies the environmental challenges associated with long-term MSW disposal in open dumpsites. Operational for more than two decades, the Haldwani dumpsite has served as the primary waste disposal site for the surrounding urban area, receiving a diverse range of waste materials, including household refuse, industrial waste, construction debris, and hazardous substances. The dumpsite's location in a subtropical region with substantial annual rainfall exacerbates the issue, as it increases the generation of leachate and its infiltration into the soil. Over the years, the continuous deposition of waste at the site, coupled with the lack of proper management practices, has likely led to significant changes in the soil's properties, raising concerns about soil contamination and its broader environmental impact.

Understanding the impact of MSW on the soil at the Haldwani dumpsite requires a detailed examination of both its geotechnical and elemental properties. Geotechnical properties, such as moisture content, bulk density, permeability, and Atterberg limits, are crucial indicators of the soil's physical condition and its ability to support various land uses, including agriculture and construction. These properties also influence the soil's stability, compressibility, and water retention capacity, which are essential factors in determining the overall health and usability of the land.

In addition to these geotechnical aspects, the elemental composition of the soil is a key factor in assessing its quality and fertility. Elements like phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) are

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essential nutrients for plant growth and overall soil health. However, the presence of heavy metals such as lead (Pb), cadmium (Cd), and arsenic (As) is particularly concerning due to their toxicity and persistence in the environment. Heavy metals can accumulate in the soil over time, often as a result of industrial activities, waste disposal, and other human interventions. In the context of dumpsites, the decomposition of waste and leachate infiltration are major contributors to the contamination of the soil with these harmful elements.

Despite the widespread use of open dumpsites for MSW disposal across India, there is a limited understanding of how long-term waste deposition affects the geotechnical and elemental properties of soil. The Haldwani dumpsite, with its extensive history of waste accumulation, provides a unique opportunity to study the specific impacts of MSW on soil quality. This research aims to fill the gap in knowledge by systematically investigating the changes in soil properties at the Haldwani dumpsite and assessing the potential environmental risks associated with these changes. The primary objectives of this study are to assess the geotechnical properties of soil samples collected from different depths at the Haldwani dumpsite, including moisture content, bulk density, permeability, and Atterberg limits, and to determine the elemental composition of the soil with a focus on the concentration of heavy metals and essential nutrients. By analysing the spatial variation of soil contamination across the dumpsite, this research seeks to evaluate the potential environmental and health risks posed by the site. The findings of this study are expected to be significant for several reasons. First, they will provide crucial data on the impact of MSW on soil quality, which is essential for developing effective waste management strategies in the region. Second, the results can inform land-use planning and environmental policy decisions, particularly in areas where open dumpsites are prevalent. Lastly, this study will contribute to the broader understanding of soil contamination processes, offering insights that can be applied to similar dumpsites in other regions. By addressing these issues, the research will provide valuable information to environmental scientists, policymakers, and waste management professionals working to mitigate the negative impacts of MSW disposal and promote sustainable waste management practices in India and other developing countries.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted at the Haldwani dumpsite located in the Nainital district of Uttarakhand, India. The site, which spans an area of approximately 25 acres, has been a repository for municipal solid waste (MSW) for over 20 years. The waste composition includes a mix of organic matter, plastics, metals, and construction debris. The dumpsite is situated at an elevation of 424 meters above sea level, with a subtropical climate characterized by an average annual rainfall of 1,800 mm, which influences leachate formation and soil contamination.

2.2 Soil Sampling

Soil sampling was carried out using a systematic grid approach to ensure comprehensive coverage of the dumpsite. Samples were collected from 3 depths: the topsoil (0-15 cm) and subsoil (50 and 100cm). A total of 9 soil samples were collected, 3 from each depth. The sampling locations were distributed evenly across the dumpsite to account for spatial variability.

Each soil sample was collected using a stainless steel auger to avoid contamination. The samples were immediately placed in polyethylene bags, labelled, and transported to the laboratory. Soil sampling and handling followed standard procedures as outlined in the U.S. EPA's Soil Sampling Quality Assurance User's Guide.

2.3 Geotechnical Analysis

The geotechnical properties of the soil were analysed using the following methods:

- Moisture Content: Moisture content was determined using the oven-drying method (ASTM D2216-19). Samples were weighed before and after drying at 105°C for 24 hours, and the moisture content was calculated as a percentage of the dry weight of the soil.
- Bulk Density**:** Bulk density was measured using the core cutter method (ASTM D2937-17). A cylindrical core cutter was driven into the soil to extract a known volume, which was then weighed to calculate bulk density. The formula used was Bulk Density=Mass of Soil Volume of Soil\ {Bulk Density} = \frac{Mass of Soil}}\{Volume of Soil}}Bulk Density=Volume of Soil Mass of Soil .
- Permeability: Permeability was assessed using a constant head permeameter (ASTM D2434-19). This method involves measuring the rate of water flow through a saturated soil sample under a constant hydraulic head, providing data on the soil's ability to transmit water.
- Atterberg Limits: The liquid and plastic limits, which are indicators of the soil's plasticity, were determined using standard procedures (ASTM D4318-17e1). These limits define the boundaries between different states of consistency of the soil, influencing its behaviour under varying moisture conditions.

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3. RESULTS AND DISCUSSIONS

3.1 Geotechnical Properties

The geotechnical properties of the soil samples from the Haldwani dumpsite are summarized in Table 1.

- Moisture Content: The average moisture content in the topsoil was 32.5% (±4.2%), while the subsoil showed a lower average moisture content of 28.3% (±3.6%). The higher moisture content in the topsoil is likely due to the accumulation of organic waste, which retains water.
- Bulk Density**:** The bulk density of the topsoil averaged 1.28 g/cm³ (±0.12 g/cm³), whereas the subsoil exhibited a slightly higher bulk density of 1.45 g/cm³ (±0.10 g/cm³). The lower bulk density in the topsoil suggests a looser structure, likely due to the decomposition of organic matter.
- Permeability**:** Permeability tests indicated that the topsoil had a lower permeability of 1.5 x 10^{-6} m/s, compared to the subsoil's permeability of 2.3 x 10^{-6} m/s. The reduced permeability in the topsoil could be attributed to the higher content of fine particles and decomposed organic materials.
- Atterberg Limits: The liquid limit of the topsoil was 45% (±5%), and the plastic limit was 22% (±3%), resulting in a plasticity index of 23%. In contrast, the subsoil had a liquid limit of 38% (±4%) and a plastic limit of 18% (±2%), with a plasticity index of 20%. The higher plasticity in the topsoil indicates increased susceptibility to deformation under wet conditions.

Table 1. Geotechnical Properties of Soil at the Haldwani Dumpsite

Property	**Top soil (0-15 cm)**	**Subsoil {50-100cm)**
Moisture Content (%)	32.5 ± 4.2	28.3 ± 3.6
Bulk Density (g/cm³)	1.28 ± 0.12	1.45 ± 0.10
Permeability (m/s)	1.5 x 10^{-6}	2.3 x 10^{-6}
Liquid Limit (%)	45 ± 5	38 ± 4
Plastic Limit (%)	22 ± 3	18 ± 2
Plasticity Index (%)	23	20

CONCLUSION

Understanding the physical composition of municipal solid waste (MSW) is crucial for effective waste management. The variability in waste types and sources significantly impacts the processes of gas and leachate production in landfills. This study provides a detailed analysis of the factors influencing waste composition, challenges in determining this composition, sampling procedures, and findings from the study conducted in Haldwani during the summer season.

The factors influencing waste composition include the degradable versus non-degradable components, moisture content, and the nature of biodegradable elements. Degradable components such as food waste and yard trimmings decompose, producing gases like methane and leachate with high organic content. Non-degradable components like plastics, metals, and glass do not decompose, contributing minimally to gas production but potentially affecting leachate quality. Waste with higher moisture content, such as kitchen waste, contributes more to leachate production and affects its composition. Different types of organic waste, particularly those rich in proteins or carbohydrates, decompose in distinct ways, influencing the type and amount of gas and leachate produced.

The heterogeneous nature of MSW, consisting of diverse materials with varying physical and chemical properties, makes uniform characterization challenging. Accurate statistical analysis of such diverse materials is difficult, necessitating robust sampling methods. Random sampling techniques and the quartering method are employed to obtain representative samples of MSW. The quartering method reduces the mass of waste to about 100 kg by systematically dividing and recombining portions of the waste until the desired sample size is achieved.

The study conducted in Haldwani during the summer season provided significant insights into the MSW composition. The organic waste content was found to be 57.67%, notably high due to the direct disposal of waste from fruit and vegetable markets. Landfills in the studied regions should incorporate gas collection systems to capture methane, thereby reducing greenhouse gas emissions. Effective leachate management systems are

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essential to treat high organic content and potential contaminants from the waste. Emphasizing the recycling of plastics and metals and the composting of organic waste can significantly reduce the environmental impact and burden on landfills.

Overall, the study underscores the need for improved waste management practices to prevent long-term soil contamination and protect environmental and public health. Implementing advanced landfill systems, enhancing recycling efforts, and developing effective reclamation strategies are critical steps towards sustainable waste management and soil conservation.

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