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Research Article
Influence of Physicochemical and Mineralogical Characteristics of Soils on Groundwater Pollution Potential

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Abstract

Background and Objective: Soil is an intermediary phase of land filled waste and groundwater and its physicochemical and mineralogical aspects are indicators of possible pollution. The current study assayed these characteristics in soils of Round hill landfill vicinity and correlated them to groundwater pollution. **Materials and Methods:** Soils were collected from 9 sampling sites of the landfill vicinity and analyzed for various physicochemical and mineralogical features. Physicochemical parameters were analyzed using descriptive statistics and analysis of variance while mineralogical data was presented as spectrum. **Results:** The findings showed infiltration potential of soil contaminants based on the ionic content and conductivity of topsoils and subsoils. High bulk density values indicated compaction and ability of soils to retain contaminants. High clay content in all soils depicted high surface area, low permeability and high potential of the soils to retain leachate. It was observed that quartz and halloysite were the major mineral phases in all soils. The presence of halloysite in sampled soils confirmed that they had high potential to adsorb leachate. Albite was present in 5 topsoils (L0, L50, L100, East 1 and West 1) but only in one subsoil (West 1). **Conclusion:** A low potential to pollute groundwater was deduced in the soils from their assayed physicochemical characteristics.

Key words: Soil contaminants, albite, leachate, halloysite, landfill vicinity, physicochemical parameters, groundwater pollution

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INTRODUCTION

Soil is a natural body, which is dynamic, living and whose formation and transformation is continuous based on temporal and spatial variations[1]. During dry conditions, soil textural changes are evident due to water retention capacity variations[2]. Furthermore, factors such as mineral availability, water redistribution and mineral supply influence soil functionality[3]. Therefore, the knowledge on dynamics of soil physicochemical and mineralogical characteristics is imperative even in decisions regarding solid waste management. This is because variability in soil characteristics due to land filling influences surface-and-ground-water resources[1]. Understanding soil behaviour particularly, its physical, mineral and water phases is essential in management of all other resources that it supports including solid waste[2,3]. Soil physical-chemistry of landfills defines the influence of leachate on the matrix as it moves along its migration paths. The concept is relevant in modern day where soils are threatened by high preference to landfill disposal, increased waste generation trends and limited waste management approaches. The situation is serious in landfills where soils are intermediary phases from dumpsites and aquifers and channel contaminants to groundwater[3]. Soil physicochemical properties thus have a significant role in influencing leachate plume migration, infiltration and contamination to both sub-surface and surface environs. Most relevant properties in this context include texture, moisture content, bulk density, particle density, electrical conductivity, dissolved ions and pH. A study in Abakaliki region of Nigeria, confirmed that soil physicochemical characteristics influence leachate contamination to ground water through the introduction of hazardous wastes in aquifer zones[4]. Furthermore, soil minerals have high affinity for trace element sorption where they scavenge and retain these contaminants[5].

Soil physicochemical and mineralogical characteristics assessment in landfills should be a mundane procedure to enhance safe solid waste management. These initiatives are aimed at controlling gaseous emissions, protecting aquifers and surrounding surface waters, characterising leachate and controlling its mobility[6]. In most cases, evaluation of physicochemical characteristics of landfill vicinity soils is not done and this has negative impacts on surrounding resources[3]. This negligence has made it difficult to leverage the soil strata abilities to retard pollutant dispersion and worsened their effects[6]. To reverse this trend, mineralogical and physicochemical properties of soils in land filled areas should be assayed periodically to assess any variability. Such periodic checks of soil aspects enhance contaminant buffering through their attenuation in soil phases and reduce environmental impacts associated with its pollution[7]. Landfills influence t he physical and chemical composition of soils in their vicinities and conclusions on groundwater contamination threat can therefore be drawn by characterising soils as aimed in the current study. This study assessed the physical, chemical and mineralogical characteristics of soils from Roundhill landfill vicinity to evaluate their influence on groundwater contamination potential.

MATERIALS AND METHODS

Soil sampling: The study area is located within Roundhill landfill vicinity located at latitude 32°53'13.66" S and longitude 27°37'26.20" E in South Africa's Berlin town. The area is sloppy, has hot climate and previously was used as a natural grassland. Soils were collected from 8 sites and a reference site 2 km away from the landfill. Of the eight sampling sites, 5 were collected at 0 (L0), 50 (L50), 100 (L100), 250 (L250) and 500 (L500) meters away from the landfill site, one on the east (East 1), another on the west (West 1) and one on the south west side (West 2) of the facility. At each sampling site, soil was taken from 30 and 100 cm depths to represent the topsoil and subsoil, respectively using a soil auger. Soils were emptied in plastic bags for further analysis at Eureka laboratories of the University of South Africa, Florida campus. The research was conducted between October, 2018-February, 2019.

Physical analysis: Physical characteristics including analysis of soil particle sizes, bulk density, Water Holding Capacity (WHC), particle density and moisture content were determined. The clod method was used in bulk density determination[8], while Piper[9] method was used to measure the WHC of soils. Particle density was determined using the submersion method[10] while particle sizes were determined by sedimentation method[11]. Gravimetric method was used in determining soil moisture content[12].

Chemical analysis: Soil pH was determined by potentiometry while Electric Conductivity (EC) and Total Dissolved Solids (TDS) were determined using their respective meters[13]. Total Organic Carbon (TOC) was determined using the Loss On Ignition (LOI) technique where a known amount of soil was subjected to 700°C heat for 4 h to destroy its organic matter[14]. The soil was cooled, reweighed and differences of initial and final soil weight were used to calculate percentage TOC.

Mineralogical analysis: To identify the mineral phases in the soil samples, X-ray Diffraction (XRD) analysis was conducted using a prescribed method[15]. The soil samples were oven-dried at 105°C, crushed, milled and homogenised to powders of below 50 μm particle size. About 2g of each sample was placed on XRD's acrylic holder in readiness for analysis. Using XRD equipment (Siemens D500) at CuKα radiation, 30 mA, 40 kV and 2θ reflections, soil samples were analyzed at 0-80 degrees every 2 sec count time and 0.02° step size. Mineral identification was done by matching observed spectra with the International Centre for Diffraction Database (ICDD) of 2004 and results were presented as spectrum.

Statistical analysis: Descriptive statistics including graphs, arithmetic mean, maximum, standard deviation and minimum values were used to describe the physicochemical parameters of sampled soils. One-way analysis of variance (ANOVA) was used to assess significant differences in the means of various parameters at $\alpha = 0.05$ significance level. Obtained data was processed using XLSTAT statistical tool at 95% significance level.

RESULTS

Physical characteristics: Physical characteristics of sampled soils are shown in Fig. 1 and Table 1. Soils of the study area were mainly fines with a higher percentage of clay compared to silt and sand particles (Fig. 1). The distribution of soil particles was uniform in top and subsoils of all sampling sites.

Results of moisture content, WHC, bulk and particle density in soils were as shown in Table 1. Moisture content ranged from 12.7-18.7% for top-soils and 15.2-30.6% for subsoils. Bulk density values of top-soils ranged between 1.15 and 1.27 g cm^{-3} while subsoils were between 1.4 and 1.89 g cm^{-3}. Subsoils at East 1 and L500 sampling sites had higher bulk density values of 1.79 and 1.89 g cm^{-3}, respectively. Particle density values ranged from 2.55- 2.78 and 2.58-2.8 g cm^{-3} for top and subsoils, respectively. WHC levels were between 41-49 and 42-50% for top and subsoils, respectively. Standard deviation, Coefficient of Variation (CV) and skewness values of each parameter were low and depicted their minimal variability in relation to the mean. ANOVA reported a p-value of 1 and confirmed no significant differences between the means of various sampling sites at $\alpha = 0.05$ significance level as was shown in Table 2.

Chemical characteristics: Results of pH, EC, TDS and OC in top and subsoils soils were as shown in Table 3. Soil pH levels were slightly alkaline and ranged between 7.14-7.9 and 7.4-7.9 for top and subsoils, respectively. Mean EC levels of top and subsoils were 250.8 and 220.3 μm cm^{-3} while TDS values were 168 mg L^{-3} and 147.6 mg L^{-3} in respective order. TOC levels ranged between 1.6-8.9 and 0.8-5.3% for top and subsoils, respectively. The standard deviation values of EC and TDS were higher compared to other parameters and depicted high variability in the sampling sites although ANOVA reported a p-value of 0.97 that showed no significant differences in the means of various sampling points (Table 2, 3).

Table 1: Physical characteristics of soils in the study area

	Moisture content (%)		Bulk density (g cm^{-3})		Particle density (g cm^{-3})		Water holding capacity (%)	
Samples	30 cm	100 cm	30 cm	100 cm	30 cm	100 cm	30 cm	100 cm
L0	16.6	30.6	1.20	1.64	2.61	2.72	45	42
L50	13.3	19.4	1.15	1.64	2.60	2.64	48	43
L100	13.2	18.1	1.15	1.62	2.65	2.70	49	50
L250	17.8	20.9	1.22	1.53	2.66	2.74	41	44
L500	15.9	16.2	1.19	1.89	2.78	2.65	47	43
East 1	12.7	15.2	1.27	1.79	2.67	2.58	44	48
West 1	17.2	17.2	1.20	1.40	2.55	2.80	49	50
West 2	18.7	20.4	1.26	1.56	2.71	2.67	42	49
Blank	15.9	15.9	1.19	1.49	2.63	2.59	44	45
Minimum	12.7	15.2	1.15	1.40	2.55	2.58	41	42
Maximum	18.7	30.6	1.27	1.89	2.78	2.80	49	50
Mean	15.7	19.9	1.20	1.60	2.70	2.70	45.4	46
Deviation (SD)	2.2	4.7	0.04	0.10	0.07	0.07	2.9	3.2
CV (%)	13.8	23.4	3.40	9.20	2.50	2.70	6.5	7.0
Skewness	-0.3	2.0	0.40	0.60	0.60	0.30	-0.2	0.2

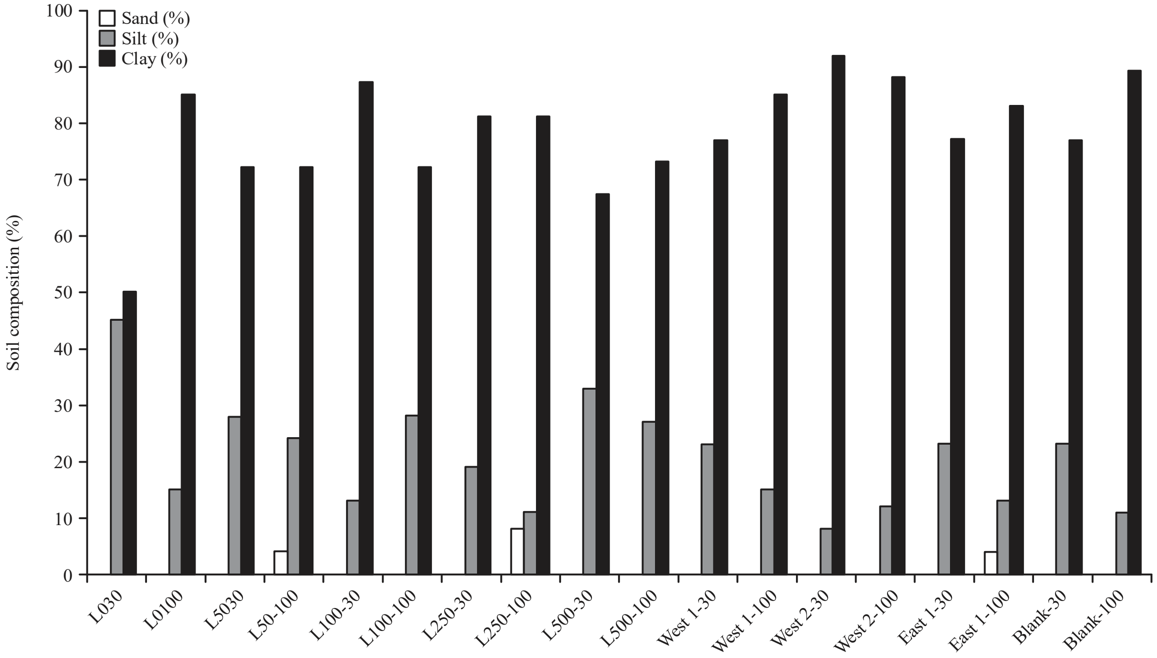

Fig. 1: Percentage sand, silt and clay in the soils

Table 2: ANOVA results of physical and chemical characteristics of soils at 95% significance level

ANOVA	F-value	F critical	p-value
Physical characteristics	0.01	2.09	1.00
Chemical characteristics	0.29	2.09	0.97

Table 3: Results of assayed chemical parameters of soils

	pH		EC (μm cm^{-1})		TDS (mg L^{-1})		TOC	
Samples	30 cm	100 cm	30 cm	100 cm	30 cm	100 cm	30 cm	100 cm
L0	7.65	7.97	246	206	164.82	138.02	2.1	5.3
L50	7.70	7.46	199	186	133.33	124.62	1.6	2.6
L100	7.14	7.55	211	208	141.37	139.36	1.7	2.1
L250	7.73	7.86	287	144	192.29	96.48	2.7	0.8
L500	7.90	7.40	219	269	146.73	180.23	2.7	3.5
East 1	7.35	7.88	310	295	207.70	197.65	6.0	0.9
West 1	7.79	7.70	239	105	160.13	70.35	1.6	1.6
West 2	7.40	7.49	191	273	127.97	182.91	2.8	4.4
Blank	7.72	7.60	355	297	237.85	198.99	8.9	2.6
Minimum	7.14	7.40	191	105	127.97	70.35	1.6	0.8
Maximum	7.90	7.90	355	297	237.85	198.99	8.9	5.3
Mean	7.60	7.70	250.8	220.3	168.00	147.60	3.3	2.6
Deviation (SD)	0.20	0.20	55.6	68.2	37.20	45.70	2.5	1.5

EC: Electric conductivity, TDS: Total dissolved solids, TOC: Total organic carbon

Table 4: Minor phases of minerals in top and subsoils of various sampling sites

Sampling sites	Topsoils (30 cm)	Subsoils (100 cm)
L0	Magnesium iron sulphide, albite	Potassium silicon oxide hydroxide
L50	Albite	Goethite
L100	Rutile, albite	Goethite
L250	Calcium aluminium silicate	Faujasite, anorthitesodian
L500	Gismondine	Gismondine
East 1	Ilmenite, albite	Anorthitesodian
West 1	Calcium mica, albite	Albite
West 2	Rutile, goethite	Anorthitesodian, clinochrysotile
Blank	Anorthite	Tosudite, rutile

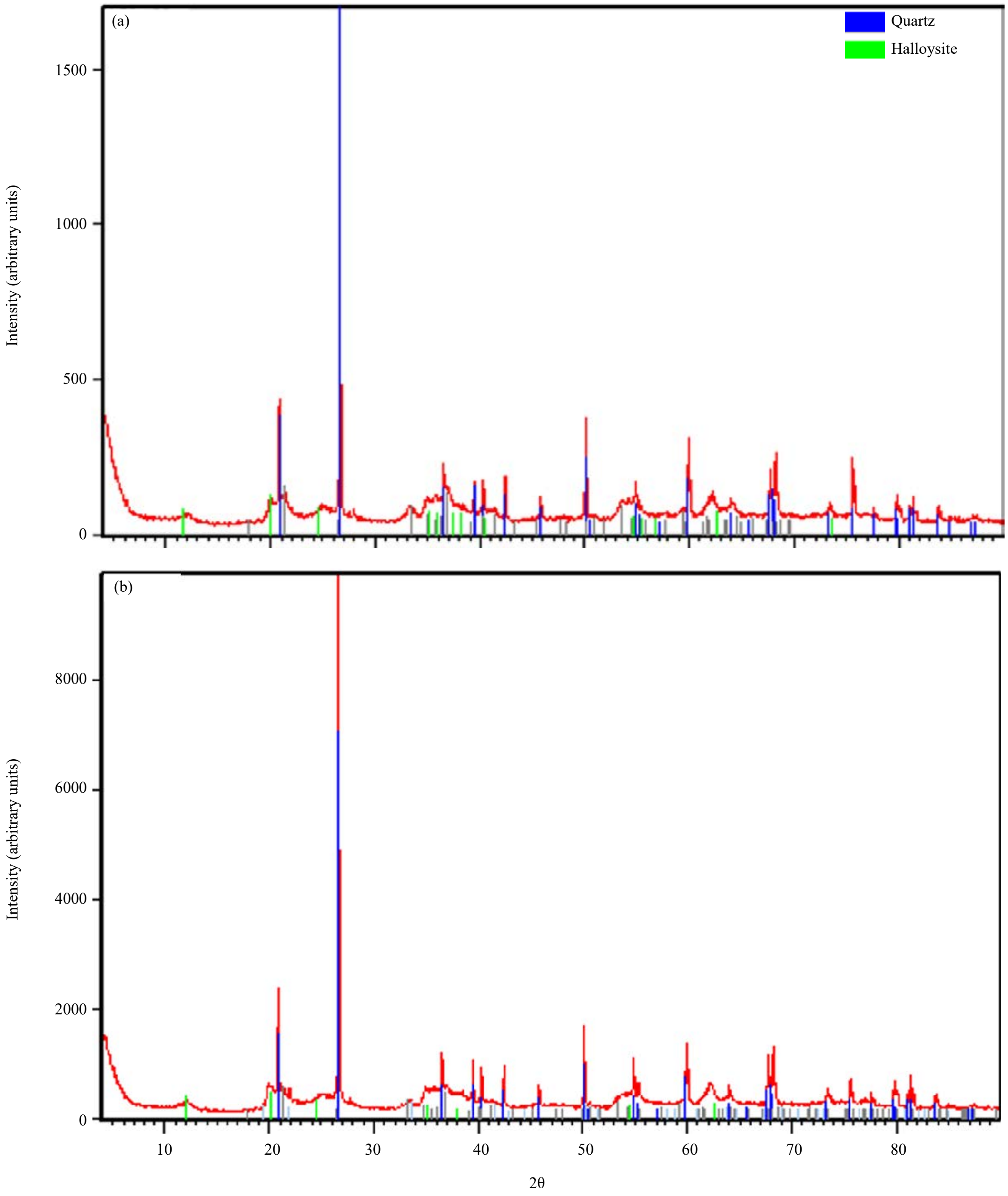

Fig. 2(a-b): Major mineral phases found at sampling site L0, (a) Topsoils and (b) Subsoils
All 9 sampling sites had quartz and halloysite minerals in both top and subsoils, although in different percentages

Mineralogical analysis: Mineralogical composition in top and subsoils of various sampling points determined by XRD were as shown in Fig. 2 and Table 4. From Fig. 2, it is observed that quartz and halloysite were the major mineral phases identified in all soils irrespective of depth.

Other minor mineral phases identified at various sampling sites are shown in Table 4. There was great variation in the composition of minerals identified and they were enriched with elements such as Na, Mg, Ca and K. Albite occurred in 5 of the 9 top soils (L0, L50, L100, East 1 and West 1) but only in 1 subsoil (West 1).

DISCUSSION

Current findings showed that area soils had high clay content, high moisture content, slightly alkaline pH, low TOC and were dominated with silica and aluminium in their mineral phases. Soils of the study area had a silty clayey nature irrespective of depths, which corresponded to their low drainage, permeability and high pollutant retention capacity. The findings agreed with a previous research that characterised area soils as red dolerites containing more than 55% clay content[16]. Soils had uniform particulate distribution, possibly because of their natural occurrence rather than by alluviation as observed in a related study that attributed non-uniformity of particles to inter-horizon translocation of soil particles[6]. High moisture content compared to 0-10% range of semi-arid soils could be due to the landfill's ability to store water that runs-off as leachate, a trend that was reported in Gaborone landfill of Botswana[6,17]. High moisture content could be attributed to the clayey nature of area soils since such soils are de-aerated and have displaced air and oxygen that promote water retention[18]. Bulk density values of soils were within the prescribed range of 1.1-1.6 g cm^{-3} for fines[19] except two sampling sites whose values corresponded to rocky, compacted and strongly indurated soils[20]. Particle density values were within the normal ranges of 2.65-2.85 g cm^{-3} for soils where quartz is the main mineral while WHC values were in the normal range of 45-55% for clayey soils[21] and depicted the soil particles as fines with great surface area. From the physical characteristics results, area soils were protective barriers of leachate migration to groundwater just like in Abakaliki landfills where soils had low implication on groundwater due to a clayey nature, strong induration and high WHC[4].

Assayed pH values of soils agreed with findings of previous studies in dumpsites where soils were slightly alkaline[6,18,22]. The EC and TDS results corresponded to the presence of soluble salts in soils possibly from their enhancement by landfill leachate as reported in Nigerian soils near landfills[18]. Metal scraps that were part of landfilled waste were possible causes of high EC levels as reported in Enugu-Port Harcourt landfills of Nigeria[22]. Evaporation in top-soils compared to subsoils leading to salt concentration possibly explained the high EC and TDS levels of the former, as was the case in Wardha region of India[23]. TOC values depicted sampled soils as having low fertility, which is characteristic of soils from semi-arid areas due to high temperatures that enhance rapid decomposition[22,24]. Leachate concentration in topsoils compared to subsoils explain why the latter had lower TOC levels comparatively. An analysis of TOC in Gohagoda landfill vicinity soils suggested that high levels in top-soils resulted from leachate's organic content[25].

Dominance of quartz and aluminosilicate (halloysite) minerals was explained by their role in soil formation, dissolution of other elements and resistance to weathering. Similar results were reported in a mineralogical assay of landfill soils in Botswana[6]. Feldspar containing halloysite dominance was associated to the presence of mafic igneous rocks in the study area, as established in a mineral assay of Brazilian soils where such minerals were common phases[26]. Enrichment of these minerals with alkali and alkaline earth metals could have been prompted by anthropogenic enhancement from leachate. These metals occur naturally in their oxide forms unless in the presence of human enrichment[27]. Occurrence of minor phases of gismondine and clinochrysotile minerals suggested alteration of feldspar probably by landfill leachate in addition to natural occurrence. Leachate contamination transforms feldspar to kaolinite and other Ca, K, Mg, Na and Mn containing minerals[6]. Another study in Lessebo region of Sweden associated the presence of these minerals to leachate contamination[28]. Occurrence of albite, especially in topsoils showed high inorganic and organic pollutant retention in the soils as was established in a study at a sanitary landfill of western Greece[29]. Overall, the dominance of aluminosilicates in the area explained their role in attracting pollutants through sorption, which could delay groundwater contamination[30]. Ilmenite, which results from cation exchanges of kaolin minerals (identified at East 1 top soil) confirmed the effects of landfill leachate on area soils as suggested in an Australian study where structural collapses of clay minerals in the presence of leachate resulted to its formation[31]. Possibilities of soil structure alteration and contaminant infiltration reported in the current study should be validated through periodic follow-up studies in the area.

CONCLUSION

This study assessed physicochemical characteristics of soils in Roundhill landfill vicinity and their role in influencing groundwater contamination. Soils were found to be clayey, which correlated to high pollutant retention capacity. High moisture content was associated to mobilisation of landfill leachate while high levels of bulk density were due to induration that can deter groundwater pollution. The presence of clay minerals mostly aluminosilicates in area soils corresponded to their potential to adsorb leachate contaminants. Assessment of soil characteristics in this study showed susceptibility to leachate infiltration but with low groundwater pollution potential.

SIGNIFICANCE STATEMENT

This study discovered a link between physicochemical parameters of soils and groundwater pollution potential at Roundhill landfill vicinity. The results can help to devise measures towards pollution buffering and contaminant attenuation in land and water resources. The research can be replicated in other areas for comparative analysis.

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