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Variation of Soil Physicochemical Conditions and Teir Influence on Enteric Pathogen Load from Landfills in Zaria, Kaduna State

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ABSTRACT: Landfills represent complex ecosystems where varying physicochemical conditions significantly shape microbial dynamics, including the survival and proliferation of enteric pathogens. This study investigated the variation of soil physicochemical conditions and their influence on enteric pathogen load in landfill soils within Zaria, Kaduna State. Fifty-two (52) soil samples were collected in duplicate from each of these four locations, Tudun-Wada, Zaria city, Sabon-Gari and Samaru landfills in Zaria. Standard analytical procedures were employed to determine temperature and pH. The results showed that soil temperature ranged between 29.51°C and 34.13°C, while pH values varied from 7.16 to 8.27, indicating slightly alkaline conditions. Microbial analysis was conducted using serial dilution and selective culture techniques for the enumeration of enteric pathogens. The mean bacterial counts ranged from 2.1×10^8 to 3.3×10^8 cfu/g across sampling locations. Statistical analysis using Pearson Correlation revealed a strong positive correlation (r = 0.653) between temperature, pH, and bacterial counts, suggesting that variations in these parameters significantly influenced microbial proliferation. Principal Component Analysis (PCA) further showed that temperature accounted for 65.4% of the variation in microbial activity, whereas pH contributed 18.7%, emphasizing the dominant role of temperature in shaping microbial dynamics in landfill soils. Pathogenic bacteria identified included *Salmonella enterica* (6.92%), *Vibrio cholerae* non-O1 (1.35%), and *Escherichia coli* O157:H7 among other species. The findings highlight those physicochemical conditions, particularly in temperature and pH, strongly influence the survival and distribution of enteric pathogens in landfill environments, posing potential risks to public and environmental health.

KEYWORDS: Soil physicochemical variation, Enteric pathogens, Landfill, Temperature, pH, Zaria.

1. INTRODUCTION

Landfills or waste dumpsites refer to areas or lands where material waste from several sources and processes are deposited (Odeyemi, 2012). Solid waste disposal is crucial for the maintenance of both human and environmental health. Notwithstanding, the waste dumps are indiscriminately placed in developing countries (Arigbede & Yusuf, 2010). Waste management has emerged as one of the greatest challenges facing environmental protection agencies in Nigeria. The volume of solid waste generated continues to increase at a faster rate than the ability of the agencies to improve on the financial and technical resources needed to parallel its' management in Nigerian cities as characterized by inefficient collection methods, insufficient coverage of the collection points and system and improper disposal of waste irrespective of the types (Sa'idu, 2011; Stanley et al., 2012; Zaria at a glance, 2013). Because these wastes are not properly disposed of, they constitute serious health problems, such as dissemination of infectious disease

pathogens to man and animal living within the vicinity (Wachukwu et al., 2010; Awisan et al., 2011; Kalwasinska and Burkowska, 2013).

Zaria Metropolis situated in Kaduna State in northern Nigeria, is an urban city densely populated with a lot of economic and social activities such as markets, institutions and industries. This has created a steady growth in population and human activities which result in the indiscriminate littering and dumping of refuse which sometimes contribute to flooding or outbreak of disease epidemic such as gastroenteritis which is a common feature in this city during rainy seasons making pollution a serious problem and a negative impact on the public health (Interim Management Committee, 2016). Over 5.2 million people, who include 4 million children, die each year from waste related diseases and about 57 to 85 % of the wastes generated worldwide are disposed in dumpsites devoid of effective treatment (Ziraba et al., 2016; Vinti et al., 2021; WHO, 2021)

Solid municipal waste deposited in uncontrolled landfill commonly contains mixed organic refuse, animal and human excreta, and recyclable materials that favour colonization and survival of enteric bacteria such as *Escherichia coli*, *Salmonella* spp., *Shigella* spp. and other Gram-negative organisms Nyandjou et al., 2018; Frączek et al., 2022). Recent systematic reviews highlight that solid waste disposal sites commonly harbor a wide spectrum of enteric agents and that these sites pose measurable public-health risks through direct contact, runoff to water supplies, and vector-mediated spread (Ncube et al., 2017; Vinti et al., 2021; Ginn et al., 2022; Addy *et al*., 2023)

The persistence and infectivity of enteric microorganisms in landfill soils are not uniform: they are strongly mediated by the soil's physicochemical environment. Soil pH and organic carbon content exert major, predictable effects on bacterial community composition and on survival of faecal indicators; acidic soils and low organic content tend to reduce survival for some taxa, while neutral to alkaline pH and high organic matter can protect and prolong pathogen persistence by providing nutrients and micro-habitats. Several studies report that neutral to slightly alkaline soils tend to sustain longer survival times for certain enteric strains including some *E. coli* O157:H7 isolates, whereas acidic conditions suppress persistence through direct effects on cell physiology and by shaping competing microbial assemblages. Because waste decomposition, ash residues, and leachates can all change local soil pH at dumpsites, pH variability is a mechanistic link between waste composition and pathogen dynamics (Oshoma et al., 2017; Fraczek et al*.,* 2014; Aziz et al., 2010; Osunwoke & kuforiji, 2012; Zainol, 2012; Adekanle et al., 2014).

Temperature and moisture interact to control metabolic rates and desiccation stress warmer, moist conditions typically support longer survival of many enteric bacteria, whereas cyclic drying and UV exposure accelerate die-off. These patterns have been documented across landscape and experimental studies linking soil physicochemical gradients to shifts in microbial diversity and pathogen fate (Yeşiller et al., 2005*;* Tognetti et al., 2007; Chua et al 2022). Laboratory and field investigations show that temperature is one of the most important environmental determinants of enteric bacterial survival in terrestrial matrices. Higher soil temperatures generally accelerate die-off of many enteric bacteria by increasing metabolic stress and desiccation, though the magnitude of the effect depends on strain, inoculum size, and soil microhabitat. Conversely, cool, moist conditions often prolong the environmental persistence of some species, enabling longer windows of infectivity and transport (Rmadass & Palaniyandi, 2007; Yeşiller, 2005; WHO, 2011).

Despite the clear mechanistic links between temperature, pH and enteric bacterial survival documented elsewhere, locally relevant data from Nigerian landfills and specifically from Zaria Metropolis remain sparse. A limited number of studies have documented the presence of clinically important enteric bacteria in Zaria dumpsite soils, but few have explicitly examined how temperature and pH influence pathogen occurrence (Nyandjou *et al.,* 2019; Anand *et al* 2021).

This study aimed to investigate how temperature and pH influence enteric pathogen load in landfill, with implications for environmental and public health safety in Zaria, Kaduna State.

2. MATERIA AND METHODS

2.1. Study Area

This study was conducted in Zaria Metropolis. The locations were Zaria City, Tudun Wada, Sabon Gari, Samaru and a Control/uncontaminated site located in Kabama. Zaria Metropolis is located on the high plains of Northern Nigeria, 652.6 meters above the sea level, and 950 km away from the coast. It lies approximately on latitudes 11˚07'N to11˚51'N and longitudes 7˚43'E to 7˚45'E and is presently one of the most important cities in Northern Nigeria (Uba et al*.,* 2013). It is a very large, heterogeneous city whose 975,228 population comes from different parts of the world. Zaria is second in size only to the state capital, Kaduna. It has attracted such a large population partly because of the presence of many educational institutions which attract people all over Nigeria for academic and employment purposes and also because it is a populated city with a lot of economic and social activities.

2.2. Collection of samples

Soil samples were collected in duplicate from four study locations in Zaria Metropolis landfill soils. Fifty-two (52) soil samples were collected in duplicate from each of these four locations, Tudun-Wada, Zaria city, Sabon-Gari and Samaru. Soil samples were collected from around the refuse dump sites as suggested by Isirimah et al. (2005). At each sampling site, surface debris was removed and soil was dug to a depth of 15cm using a hand trowel. Soil was then scooped into a sterile low density

polythene bag and transported in cool boxes to the Bacteriology Laboratory in the Department of Microbiology, Ahmadu Bello University, Zaria for analysis. Samples were stored at 4 oC if not analysed immediately.

2.3. Determination of Temperature and pH

Soil physicochemical analysis was carried out to determine Temperature (°C) and pH *in situ* using thermometer and pH meter respectively.

2.3.1. Soil Temperature

Using mercury in- glass thermometer, waste dump soil temperature was determined by directly dipping thermometer bulb into the scooped soil. Temperature (°C) readings were collected in duplicate at each sampling spot.

2.3.2. Soil pH

Ten grams of the soil sample was suspended in 10ml distilled water and mannualy stired using a flame sterilysed glass rod. The resultant mixture was then allowed to stand for 30mins at room conditions. Using standardized pH meter (Orion 3 Star model No 115220 VAC) calibrated with buffer 4 and 7, the electrode was inserted into the mixture and reading taken.

2.4. Enumeration of Aerobic Bacterial Counts

For each sample 25g of soil was suspended in 225ml sterile distilled water, and mixed using a flame sterilized glass rod. The resultant stock solution was then serially diluted 10-fold by taking 1ml into 9mls sterile peptone water. This step was then repeated serially up to 10^8. Then 0.1ml of the mixture was spread plated on previously sterilised and cooled Nutrient agar plate amended with Nistatine (1mg/ml) and Brain Hearth Infusion (BHI) agar using a sterile glass rod followed by incubation at 37°C for 24hrs. Distinct colonies formed were then counted and expressed in colony forming units per gram of soil (CFU/g).

2.5. Cultural Isolation of Enteric Pathogenic Bacteria

Twenty-five grams (25 g) of soil was suspended in 225 ml sterile distilled water and mixed using a flame sterilized glass rod. 1ml of the resultant solution was inoculated into 9ml of sterile alkaline peptone water (pH 8.6), tryptone soy broth and selenite-F-broth in duplicate in sterile McCarney bottles and incubated at 37°C for 24 h. Aseptically, inoculations were made from the overnight samples on prepared sterile plates of Thiosulphate-Citrate-BileSalt-Sucrose (TCBS), Eosin Methylene Blue (EMB) Salmonella Shigella (SSA) agar. All inoculated plates were incubated aerobically at 37°C for 24 h and observations were taken thereafter. Any distinct colonies formed were Gram-stained. Pure isolates were maintained on Nutrient Agar (NA) slants at 4°C for further laboratory investigation. Biochemical tests were performed using the procedures of Cheesbrough (2006). All media were prepared using instruction manuals of their manufacturers. Discreet colonies showing greenish metallic sheen with dark centered, small red and/or colourless colonies with black centered, yellow (sucrose-fermenting) and blue-green (non-sucrose fermenting) colonies were picked as presumptive *E. coli* O157:H7, *Salmonella* spp. and *Vibrio* spp. respectively. The presumptive isolates were subjected to routine IMViC tests (Indole, Methyl red, Voges Proskaur and citrate utilization tests), oxidase test, string test among other tests. Isolates giving atypical responses for any of the abovenamed tests were examined further using MICROGEN GNA+B-ID test kit. The data obtained by the Microgen GNA+B-ID microwell strip was designed to generate a 4-digit octal code for Enterobacteriaceae and 9-digit octal code for Vibrionaceae which was used to interpret the result from the Microgen Identification System Software (World Health Organization/Centers for Disease Control and Prevention/ United States Agency for International Development, WHO/CDC and P/USAID, 2003). It is worth nothing that not all the presumptive discreet colonies that gave atypical responses for any of the above-named tests that were identified as target pathogens. Microgen Identification System Software identified some as other Gram-negative pathogenic bacteria species among which *Acinetobacter baumannii, Citrobacter sakazakii*, *Citrobacter freundii, Citrobacter sakazakii Enterobacter Liquefaciens, Salmonella* Typhi, *Salmonella* Arizonae, *Salmonella* Pullorium, *Hafnia alvei*, Non-O157:H7 *Escherichia coli, Proteus mirabilis, Morganella morganii, Pseudomonas spp., Klebsiella oxytoca, Klebsiella pneumonia, Klebsiella ozaenae, Vibrio parahaemolyticus, Vibrio vulmificus.*

2.5.1. Identification of *E. coli* Serogroup O157 using the M44 MICROGENR *E. COLI* O157

A smooth suspension of the presumptive *E. coli* O157:H7 grown on Sorbitol MacConkey agar for 24 h at 37oC was prepared in two wells of an agglutination slide. The slide was rocked gently for 30 seconds and observed for agglutination. If there was no agglutination in either well, a drop of Microgen R E. coli O157:H7 Test Latex (M44 a) was added to one well and one drop of control Latex (M44 b) to the other. The slide was then rocked gently for 2 min. An obvious agglutination only in the well containing the test latex indicates a positive result. 2.3.2 Serological identification of *Vibrio cholerae* using Vibrio cholerae O1 and Vibrio cholerae O139 Antisera Three (3) colonies of the overnight bacterial growth on Nutrient agar at 37 °C were suspended in 0.5 ml physiological saline and use antigenic suspension. A drop of antiserum and physiological saline (30ul) as a control were placed onto a clean glass slide partitioned into several parts. The antigenic suspension was placed onto the serum and the physiological saline on the glass slide. The reagents were then mixed by tilting the glass slid back and forth for 1 min to see if there was agglutination. Only strong agglutination observed within 1min in the reaction with each serum was regarded as positive. Delayed or weak agglutination was regarded as negative (Cheesbrough, 2006). All the test organisms with negative polyvalent sera were retested by heating antigen suspension as follows. Three colonies of the bacterial growth were suspended in 3 ml physiological

saline and heated at 121ºC for 15 minutes. The heated solution was then centrifuged at 900 rpm for 20 mins, the supernatant was discarded and the precipitate was suspended with 0.5ml physiological saline and used as heated cell suspension. Only Polyvalent sera that showed negative results with the heated antigen suspension were identified as Vibrio cholerae non-O1.

2.6. Data Analysis

Laboratory findings were subjected to Simple Statistical Analysis at $p>0.05$, Pearson Correlation using Colour Separation to detect the significant level, Principal Component Analysis was carried out to determine the physicochemical factors (Temperature, pH) that strongly influence the abundance of enteric pathogens in soil from landfill. Results were simplified in tables and Figures.

3. RESULTS

The results of Temperature and pH of Soil from Landfill in Zaria are presented in Table 1. The temperature of the soil ranged between 29.51°C and 34.13°C. The pH varied from 7.16 to 8.27.

Table 1: Temperature and pH of Soil from Landfill in Zaria, Kaduna State

Sampling Location	No. of Samples Analyzed	Temp (ºC)	Mean Temp (ºC)	pH	Mean pH
SG_1	52	31.78	31.82	7.23	7.26
SG_2	52	31.85		7.29	
SM_1	52	29.61	29.51	7.49	7.21
SM_2	52	29.41		6.93	
TW_1	52	30.49	30.53	7.32	7.16
TW_2	52	30.57		7.00	
ZC_1	52	35.06	34.13	8.76	8.27
ZC_2	52	33.19		7.78	

KEY: pH- Degree of acidity**;** Temp- Temperature; SG- Sabon-Gari; SM- Samaru; TW- Tudun-Wada; ZC- Zaria City; CS- Control Site

Zaria City has the highest mean temperature (34.13°C) and pH (8.27) followed by SG-Sabon-Gari with mean temperature (31.82°C) and pH (7.26), Tudun-Wada with mean temperature (30.53°C) and pH (7.16). Samaru location has the least temperature (29.51°C) but it pH is a little bit higher(7.21) than that of Tudun-Wada location (7.16).

The mean Total Viable Bacterial Counts of soil from Landfills in Zaria ranged as follows: SA ($2.1x10^8$cfu/g), SG ($2.7x10^8$cfu/g), TW ($2.8x10^8$cfu/g) and ZC ($3.3x10^8$cfu/g) with Zaria city having the highest number of counts followed by Tudun-Wada and Samaru having the least number of counts.

Table 2: Total Viable Bacterial Counts of soil from Landfills in Zaria, Kaduna State

Sampling Location	Samples Analyzed/Location	No. of Samples Analyzed	Mean ABC±SE(cfu/g)/season	Mean TABC(cfu/g)
Sabon-Gari	SG_1	52	$2.97x10^8$	$2.7x10^8$
	SG_2	52	$2.39x10^8$	
Samaru	SM_1	52	$2.14x10^8$	$2.1x10^8$
	SM_2	52	$2.16x10^8$	
Tudun-Wada	TW_1	52	$3.10x10^8$	$2.8x10^8$
	TW_2	52	$2.46x10^8$	
Zaria City	ZC_1	52	$4.13\ x10^8$	$3.3x10^8$
	ZC_2	52	$2.50x10^8$	

$p<0.05$

KEY: N=Total number of samples analyzed**;** TABC- Total Aerobic bacterial counts

The degree of relationship among the temperature, pH and the bacterial count of soil samples from landfills was established (Table 3). Statistical analysis using Pearson correlation test revealed that temperature and pH are highly correlated to bacterial counts. However, temperature is highly correlated ($r = 0.653$) to bacterial count than pH ($r = 0.579$).

The results of the principal component analysis revealed that temperature has 65.4% influences on microbial activities while pH has only 18.7% (Figure 1).

Table 3: **Correlation of Temperature, pH and Enteric Pathogen Load.**

	Temperature	pH	Bacterial counts
Temperature	1		
Ph	0.579**	1	
Bacterial counts	0.653**	0.561**	1

Pearson Correlation. The estimation is restricted maximum likelihood. colour separation was used to detect the significant level.
**= Highly significant

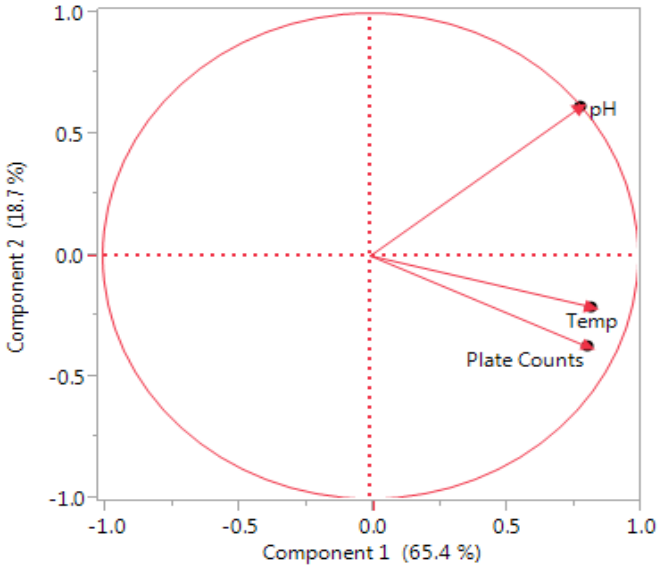

Figure 1: Principal Component Analysis of the Temperature and pH of the Soil Sample in Relation to Enteric Bacterial load from Landfills in Zaria, Kaduna State.

Key: pH- Degree of acidity**;** Temp- Temperature**;** Plate Counts- Enteric Pathogen Load
Component 1- Temperature; Component 2- pH.

The prevalence of the various bacterial species differed significantly (P<0.05) throughout the sampling period. All the organisms were isolated in all the sampling locations (Table 4). On the basis of the agglutination with the Polyvalent O1 and O139 antiserum, out of the 7 *Vibrio cholerae* identified, *Vibrio cholerae* non-O1 accounted for 7(100%). Other serotypes were not identified. A prevalence of 5% of *Vibrio* spp. was recorded.

Table 4: Occurrence of Bacterial Isolates from Landfill soils at Various Sampling locations

Bacteria Isolates	Sampling location ZC N=104(%)	Sampling location SG N=104(%)	Sampling location TW N=104(%)	Sampling location SA N=104(%)	Total Frequency N=416(%)
Acinetobacter spp.	1(0.96)	2(1.92)	1(0.96)	0(0.0)	4(0.96)
Citrobacter spp.	2(1.92)	1(0.96)	2(1.92)	1(0.96)	6(1.44)
Enterobacter spp.	2(1.92)	1(0.96)	1(0.96)	2(1.92)	6(1.44)
E. coli O157:H7	9(8.65)	5(4.81)	5(4.81)	3(2.88)	21(5.05)
Salmonella enterica	14(13.50)	7(6.73)	9(8.65)	6(5.77)	36(8.6)
Hafnia alvei	1(0.96)	0(0.0)	2(2.88)	0(0.0)	3(0.72)
Non-O157 *E. coli*	16(15.68)	9(8.65)	11(10.57)	7(6.73)	

Proteus spp	4(3.85)	3(2.88)	5(4.81)	2(1.92)	14(3.37)
Morganella morganii	1(0.96)	0(0.0)	1(0.96)	0(0.0)	2(0.48)
Pseudomonas spp.	1(0.96)	2(1.92)	2(1.92)	1(0.96)	6(1.44)
Vibrio cholerae non-O1	3(2.88)	1(0.96)	3(2.88)	0(0.0)	7(1.68)
Vibrio spp	5(6.74)	6(8.66)	5(5.77)	3(3.85)	19(4.57)
Klebsiella spp.	4(3.85)	3(2.88)	4(3.85)	2(1.92)	13(3.13)

Total $p<0.05$

Key: N=Total number of samples analyzed; ZC- Zaria city; TW- Tudun-Wada; SG- Sabon-Gari, SA- Samaru

4. DISCUSION

The mean values of the Temperature and pH of the waste dump samples from various locations were compared (Table 1). The temperature of the soil samples from all the sampling sites ranged between 29.51^{o}C and 34.13^{o}C These values fall within the mesophilic range of temperatures for most pathogenic bacteria whose optimum temperature for growth is 37^{o}C with upper and lower temperature limits of 40-50^{o}C and 15-20^{o}C respectively. Hagerty et al. (1973), reported that during initial composting development, the mesophilic flora predominates and are responsible for most of the metabolic activities that occur. This increased microbial activity elevates the temperature of the compost, with the subsequent replacement of mesophilic population by thermophilic flora. The elevated temperatures in the waste dumps noted have also been reported by other authors (Bach, 1987; Yeşiller et al., 2005*;* Tognetti et al., 2007; Chua et al 2022) and are due to biological decomposition. However, the values in this work are higher when compared to the values obtained by (Obire et al., 2002) (27^{o}C – 28^{o}C) and *(*Adekanle et al*.,* 2014*)* (25.1^{o}C- 25.9^{o} C). The differences in the temperature values between this and earlier studies could be explained when factors such as the physical nature of the wastes and different moisture contents at the various sampling spots and location are considered.

The pH of the samples at different sampling locations varied from 7.16 to 8.27. This may be due to the existence of different micro-environments within each of the landfill sites. The large number of these difference niches in the landfill could have been occasioned by the very heterogeneous nature of the waste mass, the varied source of the materials, the diverse microbial population and activity as well as the stage of the waste occurring at each location as has also been reported by Pavoni et al. (1975); Atchley & Clark, (1979); Holm-Nielsen et al. (2006). The highest pH values recorded in this study (8.27) could have been due to the age of the waste. Pavoni *et al*. (1975) mentioned that in the first 2 to 3 days of composting, the pH drops to 5.0 or less and then begins to rise to about 8.5 for the remainder of the aerobic process. However, Obire et al. (2002) reported a shorter range of pH values of 5.4 to 7.9. The difference in pH for ZC, TW and SA samples could be attributed to the nature of the wastes found in these sampling locations and the age of the waste. Hagerty et al*.* (1973) reported that the initial pH of solid waste is between pH 5.0 and 7.0 for refuse which is about 3 days old.

Bacterial growth depends upon various physiochemical conditions such as media, pH, temperature, incubation period, carbon source etc. The mean bacterial counts of soils from waste dumps ranged between $2.1x10^{8}$cfu/g to $3.3x10^{8}$cfu/g. This was higher than that recorded in Benin City by Oviasogie et al. (2010) ($4.0x10^{5}$ cfu/g/ml to $10.0x10^{5}$ cfu/g/ml) and Adekanle et al. (2014) in Osun State **(**112 x 10^{5} cfu/g to 187 x 10^{5}cfu/g). However, Osunwoke & Kuforiji, (2012) reported a range of $1.0x10^{5}$ cfu/g to $7.0x10^{17}$ cfu/g in Ota, Ogun State. The higher bacterial counts recorded in this study could be attributed to the higher degree of acidity (pH) recorded for the soil (pH 7.16 to 8.24) and the type of waste generated in the refuse dumps.

It was observed that ZC had the highest bacterial counts of all the sample locations (Table 2). This could be as a result of the high degree of acidity recorded in this location (8.27) and the waste composition (large amount of human and animal faeces). It was noted that most streets in this location lack public conveniences and when nature calls, any waste dump around becomes latrine. Also, the nearby clinics dispose their hospital wastes in that refuse dump site. This implies that there were enough nutrients to support large microbial populations as seen obtained from stations TW, SG and SA (Table 2).

Temperature and pH affect bacterial counts (Table 3). The study revealed a strong correlation between temperature, pH and bacterial counts. Elaigwu et al. (2007), reported that temperature and pH of soil affect all soil its properties that is chemical, physical and biological. However, there was a strong association between temperature and bacterial counts (r= 0.653). Hassen et al. (2002) reported that under aerobic conditions, temperature is the major factor that determines the rate of microbial metabolic activities. Foday et al. (2013) opined that high temperatures speed up the rate of bacterial action on biodegradable organic material.

The results of the principal component analysis revealed that temperature is the major factor with (65.4%) on microbial activities as compared to (18.7%) pH. This validates the results of the correlation analysis and confirmed the early assumption made by Hagerty et al. (1973).

Soil environment, by its nature, presents a theatre of ecological diversity and evolutionary adaptation. Many anthropogenic activities have been known to be major causes of pollution of soil. Most of the population under study dump wastes are in open spaces and drainage channels which are largely untreated and poorly managed. Most of these dump sites are situated very close to residences. Indiscriminate waste disposal and inadequate waste management account for the major source of microbial pollution and contamination of soil, air, land and water (Nwaokwe, 2004; Grisey et al., 2010).

Pathogenic bacteria isolated from soils in landfill showed prevalence of *Salmonella enterica* (6.92%), *Vibrio cholerae* non-O1 (1.35%) and *E. coli* O157:H7 (4.23%). Other bacterial species such as *Citrobcter* spp. (3.70%), *Proteus* spp. (11.64%), *Klebsiella* spp. (5.82%), *Enterobacter* spp. (3.17%), *Escherichia coli* (35.45%) etc. were also isolated, which implied that the landfill soils were heavily contaminated. The isolation of these pathogenic bacteria in these waste dumps is not surprising since the alkaline pH and mesophilic range of temperature recorded for the soil samples in the study (pH 7.16 to 8.27) and (29^{o}C to 35^{o}C) respectively could favour the proliferation of many bacteria genera. (Arora, 2004) opined that most of the medically important bacteria can grow at neutral or slightly alkaline pH, Osunwoke & Kuforiji, (2012) also reported that high pH would favours the proliferation of bacteria than that of fungi.

5. CONCLUSION

The study demonstrated that variations in soil physicochemical parameters, particularly temperature and pH, play a critical role in shaping the microbial ecology of landfill soils in Zaria, Kaduna State. The observed temperature range of 29.51°C to 34.13°C and pH range of 7.16 to 8.27 provided favorable conditions for the proliferation of bacteria, as reflected by the high mean counts of 2.1×10^{8} to 3.3×10^{8} cfu/g. The strong positive correlation ($r = 0.653$) between temperature, pH, and bacterial abundance underscores the interactive influence of these parameters on microbial growth and activity. Principal Component Analysis further confirmed temperature as the most influential factor, accounting for 65.4% of microbial variation, compared to 18.7% attributed to pH. The detection of pathogenic bacteria such as *Salmonella enterica*, *Vibrio cholerae* non-O1, and *Escherichia coli* O157:H7 indicates potential health hazards associated with landfill soils, especially where waste management practices are inadequate. Therefore, continuous monitoring of landfill soil conditions and the implementation of effective waste treatment and disposal strategies are essential to minimize environmental contamination and safeguard public health.

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