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HEAVY METAL TOLERANCE OF BACTERIAL ISOLATES FROM SOLID WASTE DUMPING SITES IN ABUJA, NIGERIA

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Abstract

Bacteria have special bio-mechanism to resist toxic heavy metals. This study investigated heavy metal tolerance potentials of bacterial isolates from solid waste dumping sites (Abaji, Bwari, Gosa, Gwagwalada, Kuje, and Kwali) in Abuja, Nigeria. Soil samples were randomly collected from each location using soil augers at depths of 0 – 15, 15 – 35 and 35 – 45 cm. They were analyzed bacteriologically using cultural/biochemical techniques and chemically by exposing the isolates to graded concentrations (50 - 400 µg/mL) of chromium (Cr), nickel (Ni) and lead (Pb) on nutrient agar for heavy metal tolerance test. Statistical analysis revealed a significant decrease ($p<0.05$) in the heterotrophic bacterial count with soil depth; with the highest counts (6.89×10^9 CFU/g) noted at 0 – 15 cm (Gosa) and lowest (1.32×10^3 CFU/g) found at 30 – 45 cm (Kuje). The isolated bacteria (n=54) were *Proteus* (33.3 %), *Providencia* (29.6 %), *Pseudomonas* (16.6 %), *Bacillus* (9.3 %), *Micrococcus* (5.5 %), *Escherichia coli* (2.1 %), *Enterobacter* (2.1 %), and *Serratia* (2.1 %). All these isolates except *Micrococcus* spp., *Enterobacter* spp., *Escherichia coli* and *Serratia* spp. displayed 100 % resistance to Cr, Ni and Pb at ≥ 200 µg/mL with MICs (µg/mL) being 850 – 1700 (*Pseudomonas* – *Proteus* spp.), 950 – 2250 (*Pseudomonas* – *Bacillus* spp.) and 900 – 1750 (*Pseudomonas* – *Bacillus* spp.), respectively. Majority of these bacteria (24.1 - 38.9 %) were from Gosa and Gwagwalada dumping sites. Our findings suggested these bacteria could be promising for remediation of the heavy metals in the sites.

Keywords: Bacteria; Heavy metals; Metal resistance; Solid waste dumping sites.

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Introduction

Waste materials occur in different forms such as solids and liquid. Those which are in solid forms are referred to as solid wastes. They are constantly generated from municipal, commercial and industrial sources. These wastes are then transported from the generation sites to a landfill or dumping sites for further processing (Agamuthu and Fauziah, 2010; Ojiego *et al.*, 2019). Industrialization and rise in human population in recent years has increased the number of tons of municipal solid waste generated (Okoronkwo and Okpokwasili, 2018; Ojiego *et al.*, 2019; Ojiego *et al.*, 2022a). Decomposition of wastes and leachates from these landfills could affect health of humans and destabilize balance of the environment (Afolagboye *et al.*, 2020). One of the major pollutants from dumpsite leachates are heavy metals, which are non-degradable and can bio-accumulate and bio-magnify in cells and tissues of plants and animals (Agamuthu and Fauziah, 2010). Leachates and soils from dumpsites have been reported as major reservoirs of different types and concentrations of heavy metals (Odukoya, 2015; Imron *et al.*, 2021).

The ubiquity of heavy metals in the environment has been attributed to their widespread applications in industrial products such as batteries, insecticides, pesticides, plastics, and petrochemicals (Nath *et al.*, 2019). Apart from these, wastewater from industries, automobiles exhaust, burning of fossils and other anthropogenic activities are other major sources of heavy metals in the environment (Zhang *et al.*, 2010; Nath *et al.*, 2019). Naturally, some of the heavy metals, such as cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), magnesium (Mg), selenium (Se) are useful in normal physiological and biochemical activities of the organisms. However, other heavy metals such as cadmium (Cd), lead (Pb), sliver (Ag), mercury (Hg), nickel (Ni), arsenic (As) can significantly disrupt normal cellular functions of organisms even at relatively low concentration (Tchounwou *et al.*, 2012). Due to their hazardous nature and negative effects on the environments, heavy metals have continued to gain worldwide attention (Tchounwou *et al.*, 2012; Chessed *et al.*, 2018; Nath *et al.*, 2019; Imron *et al.*, 2021).

Microorganisms are ubiquitous in existence due to the fact that they colonize diverse environment and utilize any available organic and inorganic compounds as sources of carbons and energy (Jabora *et al.,* 2013). In heavy metal polluted environments, some bacteria have developed certain biochemical mechanisms in order to overcome their negative effects (Hughes and Poole, 1989; Jabora *et al.*, 2013). The heavy metal tolerance mechanisms used by bacteria include efflux system pump, complexation/stabilization, enzymatic

transformation/detoxification and plasmid-meditation (Ianeva, 2009; Sevgi *et al*., 2010). Bacteria with efficient mechanisms for heavy metals tolerance possess selective advantages in diversity, abundance and proliferation (Duxbury, 1986; Ianeva, 2009). Biotechnologically, these bacteria can be exploited as potential bioremediation agents of heavy metals and hydrocarbon polluted environments (Jabora *et al.,* 2013). Considering the environmental importance of such bacteria, it is pertinent to constantly explore heavy metal polluted areas, such as waste dumpsites/leachates, for isolation, characterization and identification of heavy metal tolerant/resistant bacteria. Hence, this study investigated the heavy metal tolerance properties of bacterial isolates from solid waste dumpsite within, Abuja, Nigeria.

Methods

Study area

The study was carried out at selected solid waste dumpsites within Abuja, Nigeria. The coordinates of are latitude 8º22'N and 9º20'N, and longitude 6º45'E and 7º39'E (Figure 1). Abuja landmass is approximately 7,300 km^2 with an estimated population of 2,238,800 (Sawyerr *et al*., 2017). As the capital city of Nigeria, Abuja is becoming highly populated as a result of rural-urban migration. Consequently, several solid waste dumpsites abound due to expansion in constructions, institutions, agricultures, industries and other anthropogenic activities. The six major solid waste sites employed were located within Abuja municipal (Gosa), Abaji, Bwari, Gwagwalada, Kuje and Kwali local government areas.

Sample collection

Solid waste materials were gently cleared off the top soil before the soil samples (n=72) were collected from each of Abaji, Bwari, Gosa, Gwagwalada, Kuje and Kwali dumpsite using soil augers and core soil containers at depths of between 0 – 15 cm, 15 – 30 cm and 30 – 45 cm in other to estimate the distribution of bacterial populations with depth. All the samples were appropriately labeled and transported in ice-packed bag to the laboratory for further analysis.

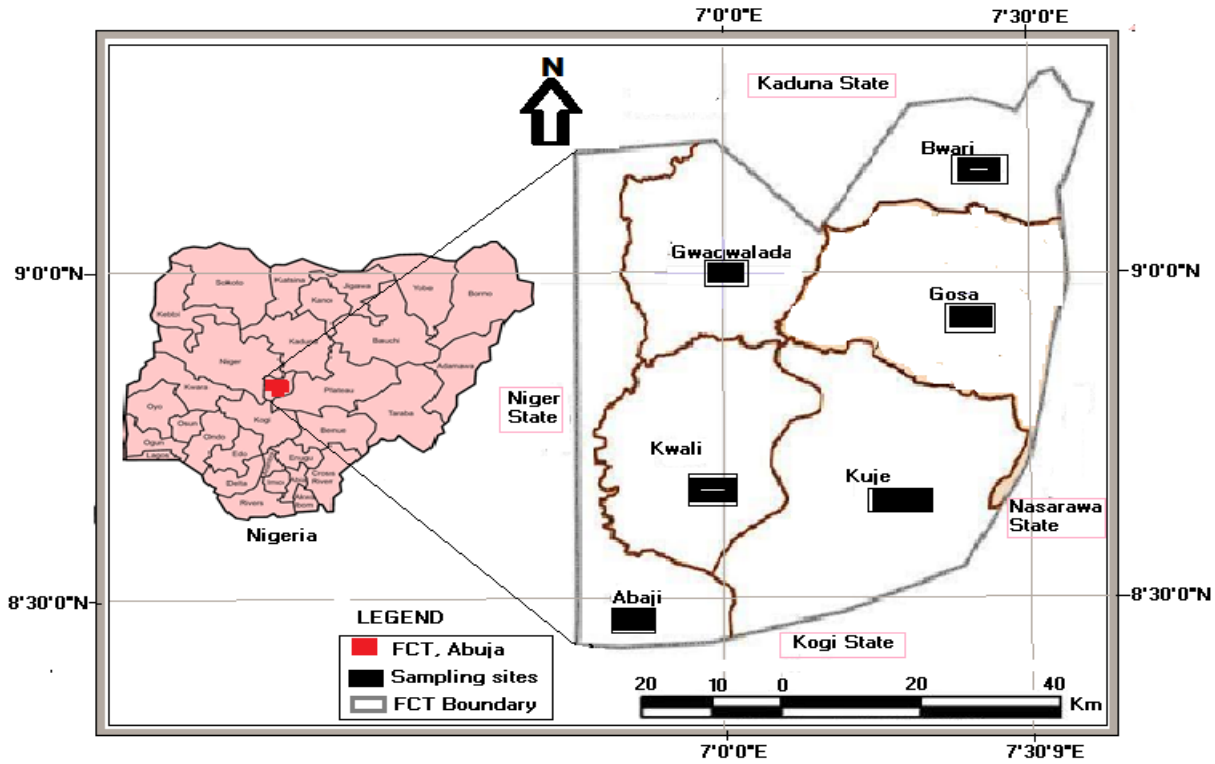

Figure 1: Location map of FCT, Abuja showing the study areas.

Enumeration and identification of bacteria load in soil samples

This was carried out according to the method described by Eze *et al.* (2014). Briefly, 10 g of soil samples was aseptically weighed into 90 mL of sterile distilled water in a 100 mL conical flask. The samples were vortexed to homogenize and allowed to stand for 10 min. From the initial dilution, 10-fold serial dilution was carried out in sterile test tubes containing 9 mL of sterile distilled water. Thereafter, 0.1 mL of the desired dilutions 10^{-3} to 10^{-5} were spread plated in triplicate onto nutrient agar supplemented with 50 µg/mL of Nystatin to inhibit the growth of fungi. Plates were incubated at 35 ^{o}C and bacterial counts recorded after 24 h of incubation. Following enumeration of total heterotrophic bacteria, representative colonies were picked at random and sub-cultured repeatedly into fresh nutrient agar for purification. Purified isolates were characterized by their colonial morphologies, Gram reactions and biochemical tests using the scheme in Bergey's Manual of Determinative Bacteriology (Holt *et al.*, 1994; Cheesbrough, 2000).

Determination of heavy metal tolerance

The Agar dilution method previously described by Lee *et al.* (2009) was adopted in evaluating the heavy metal tolerance of the bacteria isolates. Briefly, a loopful of 12 – 16 h bacterial culture in tryptic soy broth was inoculated by streaking in duplicate on Mueller-Hinton Agar (Oxoid UK) plates previously supplemented with increasing diluted concentrations (50 µg/mL, 100 µg/mL, 200 µg/mL, and 400 µg/mL) of the heavy

metals (Cr, Ni, and Pb). The metals were used as potassium chromate ($K_2Cr_2O_7$), nickel chloride ($NiCl_2$) and lead chloride ($PbCl_2$), respectively, based on the reported concentrations from the dumpsites in previous study (Ojiego *et al*., 2022b). All the plates were incubated at 37 ºC for 24 – 48 h. After incubation, the plates were examined visually and recorded as tolerant (resistant) if there was presence of growth or non-tolerant (sensitive) if there was absence of growth (Lee *et al.*, 2009).

Determination of minimum inhibitory concentration (MIC)

The minimum inhibitory concentrations (MICs) were determined using the techniques reported earlier (EFSA, 2012). An overnight culture of each resistant bacterial isolate was exposed to a starting concentration of 50 *µg*/mL in Mueller-Hinton Agar (Oxoid UK) plates and then steadily increased until the cut-off point where the isolates fail to produce colonies on the agar plates. The MIC is then recorded accordingly.

Data analysis

Data was analyzed using ANOVA for differences in means at $p<0.05$. Mean values that were significantly different were separated using Duncan Multiple Range Test.

Results and discussion

Dumpsites contain diverse municipal, commercial and industrial waste materials which are the major sources of heavy metals (Afolagboye *et al*., 2020; Imron *et al*., 2021). Heavy metals have been found to impact negatively on the microbial qualities and quantities of the soil (Hassen *et al*., 1998; Kormoker *et al.*, 2019). In this study, heavy metal tolerance potentials of bacteria isolated from waste dumping site, a major reservoir of heavy metals (Ojiego *et al.,* 2022b), were investigated with a viewing to exploiting them as potential tools for bioremediation of heavy metal pollutions. Analysis of the total heterotrophic bacterial population of the dumpsites, as presented in Table 2, shows that the bacterial counts were significantly ($p<0.05$) highest at soil depth of 0 – 15 cm and least at 30 – 45 cm. The dumpsite with the most bacterial population at 0 – 15 cm was Gosa (6.89×10^9 CFU/g), followed by Gwagwalada, Kwali, Kuje, Abaji and Bwari (5.42×10^6 CFU/g) being the least. A similar trend was noticed as the soil depth increased to 45 cm (Table 2). Statistically, there was significant difference ($p<0.05$) between each of the dumpsites and the soil depths. The top soils are well known to support high population of bacteria because they are richer in, air, moisture and plant roots, which are good source of nutrients for microorganisms. Hence, the high population of bacteria at the top soil could be attributed to these reasons. Similar findings were reported earlier (Williams and Hakam, 2016; Nireti *et al.*, 2018; Auta and Paul, 2020).

Table 1: Total bacterial counts of soil samples from dumpsites in Abuja

Soil depths (cm)	Total heterotrophic bacterial count (± SD × 10^6 CFU/g)					
	Abaji	**Bwari**	**Gosa**	**Gwagwalada**	**Kuje**	**Kwali**
0 – 15	9.98 ± 2.67*	5.42 ± 6.03*	6890.00 ± 9.93*	467.00 ± 8.08*	23.10 ± 4.66*	78.40 ± 0.21*
15 – 30	0.22 ± 0.24	0.04 ± 0.54	0.53 ± 3.77	0.81 ± 0.67	0.01 ± 0.08	0.05 ± 0.02
30 – 45	0.16 ± 0.01	0.01 ± 0.01	0.40 ± 3.02	0.16 ± 0.01	0.01 ± 0.54	0.06 ± 2.11

Key*: *Data presented as Mean ± Standard deviation of triplicate values; *significantly different ($p<0.05$) across the column

Phenotypic characterization of the isolates revealed a total of 54 bacteria (Table 1), which included the genera of *Proteus, Providencia, Pseudomonas*, *Escherichia coli, Bacillus, Micrococcus, Enterobacter* and *Serratia*. The frequency of the isolates were *Proteus* spp. (33.3 %), *Providencia* spp. (29.6 %), *Pseudomonas* spp. (16.6 %), *Bacillus* spp. (9.3 %), *Micrococcus* spp. (5.5 %), *Escherichia coli* (2.1 %), *Enterobacter* spp. (2.1 %) and *Serratia* spp. The most abundant and widespread isolates were *Proteus, Providencia,* and *Pseudomonas* spp. while the *Escherichia coli*, *Enterobacter* and *Serratia* spp. were the least. The high populations of *Proteus, Providencia,* and *Pseudomonas* spp. might be linked to their efficient metabolic enzymatic abilities needed to utilize diverse organic compounds (Drzeweicka, 2016; Ba and Mosimileol, 2020; Okoye *et al*., 2020; Gebrie *et al*., 2022). This finding agrees with the previous studies and thus justifying their versatilities and diversities. Moreover, *Bacillus*, *Micrococcus,* and *Serratia* spp., which were isolated, though in moderate levels, were also reported as potential hydrocarbon utilizing bacteria which are relatively prevalent in polluted soil environment (Borah *et al*., 2019; Okoye *et al*., 2020; Gebrie *et al*., 2022). *E. coli* and *Enterobacter* spp. are majorly normal flora of humans and their presence in the environments are important indicators of environmental pollution by sewage and other human wastes. An earlier study on the levels of heavy metals in some dumpsites within Abuja, showed Pb, Cu and Cr were found to be significantly ($p<0.00$) higher than control soils (200 km away from the dumpsites) (Ojiego *et al.*. 2022b). The heavy metal pollutants at the dumpsite soils might have probably affected or destabilized their populations. Previous studies reported that pollutants, such as heavy metals, affect the populations of bacteria in the receiving soil (Hassen *et al*., 1998; Kormoker *et al*., 2019; Auta *et al*., 2020). The bacterial isolates encountered have been reported from different solid waste dumpsites within Nigeria (Oviasogie *et al*., 2010; Williams and Hakam, 2016; Oshoma *et al*., 2017; Auta and Paul, 2020) and thus in agreement with this study.

Table 2: Characterization and identification of bacterial isolates from dumpsites in Abuja

Biochemical test	Isolates codes from Dumpsites							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Grams reaction	(-) rods	(-) rods	(-) rods	(+) rods	(+) cocci	(-) rods	(-) rods	(-) rods
Catalase	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Oxidase	(-)	(+)	(-)	(+)	(+)	(-)	(-)	(-)
Motility	(+)	(+)	(+)	(-)	(-)	(+)	(+)	(+)
Spore	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Indole	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)
Methyl red	(-)	(+)	(+)	(-)	(-)	(-)	(+)	(-)
Voges proskauer	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(+)
Urease	(-)	(-)	(+)	(-)	(-)	(-)	(-)	(+)
Citrate test	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(+)
Nitrate reduction	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Glucose	(+) Ac	(+) Ac	(+) Ga	(+)Ac	(+)Ac	(+) Ac/Ga	(+) Ac/Ga	(+)Ac
Fructose	(-)	(-)	(-)	(+)	(-)	(+)	(+)	(+)
Lactose	(-)	(-)	(-)	(+)	(-)	(+)	(+)	(-)
Sucrose	(+)	(-)	(-)	(+)	(-)	(+)	(+)	(+)
Mannitol	(+)	(-)	(-)	(+)	(-)	(+)	(+)	(+)
Probable identity	*Pseudomonas spp.*	*Providencia spp.*	*Proteus spp.*	*Bacillus spp.*	*Micrococcus spp.*	*Enterobacter spp.*	*Escherichia coli*	*Serratia spp.*
Total	9/54	16/54	18/54	5/54	3/54	1/54	1/54	1/54

Key: ***A – H****: Isolate codes;* ***Ac****: Acid production,* ***Ac/Ga****: Acid and gas production; (+): Positive; (-): Negative*

The ability of each bacterial isolate to tolerate the three heavy metals (Cr, Pb and Ni) was determined at graded concentrations of 50 – 400 µg/mL and the results are displayed in Table 3. From the result, all the isolates except *Micrococcus* spp., *Enterobacter* spp. *Escherichia coli*, and *Serratia* spp. displayed 100 % resistance to Cr, Ni and Pb at ≥ 200 µg/mL indicating that they may possess the abilities to tolerate these heavy metals in their native micro-environments. As the concentrations increased to 400 µg/mL, the rate of tolerance to each metal varied substantially. At 400 µg/mL, *Pseudomonas* spp. (isolates A) (%), *Providencia* spp. (isolates B) (%), *Proteus* spp. (isolates C) (%), *Bacillus* spp. (isolates D) (%), *Micrococcus* spp. (isolates E) (%), *Enterobacter* spp. (isolates F) (%), *E. coli* (isolates G) (%), and *Serratia* spp. (isolates H) (%) displayed 66.7, 43.8, 61.1, 75, 0, 0, 0 and 0 for Cr; 55.6, 56.3, 61.1, 100, 0, 0, 0 and 0 for Ni and 55. 6, 56.3, 50, 100, 0, 0, 0 and 0 for Pb, respectively. Similar findings were reported by Onuoha *et al.* (2016) in their study on the heavy metal tolerance of *E. coli*, *Klebsiella* spp., *Staphylococcus* spp. and *Shigella* spp. isolated from agricultural soil. The variations in resistance of the bacterial isolates observed at relatively high concencentration of the metals could probably be attributed the differences in their abilities to regulate the entry, accumulation and exit of the metals. Most bacteria have been documented to use specialized intra- and extracellular enzymes and proteins to regulate and tolerate the toxic effects of heavy metals like Pb^{2+} and Cu^{2+} (Dameron *et al.*, 1998; Nies, D., 1999; Moore *et al.*, 2005). These probably suggest that *Pseudomonas* spp., *Providencia* spp., *Proteus* spp. and *Bacillus* spp. might have acquired better cellular regulatory potentials against the effects elevated concentrations of Cr, Ni and Pb. *Proteus* strains with high heavy metal tolerance and utilization rates for Cd, Pb, Ni and Zn have been isolated from rhizosphere (Zhang *et al.* 2019) and dumpsites (Nwagwu *et al.,* 2017). Similarly, lead (Pb)-resistant *Providenicia* and *Micrococcus* spp. had been reported (Naik *et al.,*

2012; Puyen *et al*., 2012). Also, *Bacillus* and *Pseudomonas* spp., which can tolerate Cr, Pb, Fe, Hg, and Cu had been documented in previous works (Hassen *et al*., 1998; Nath *et al.,* 2019; Imron *et al*., 2021). The mechanisms used by microorganisms to resist/tolerance heavy metals have been linked to modification of their cell membrane regulation, complexation/stabilization, enzymatic transformation/detoxification and plasmid-mediation (Ianeva, 2009; Sevgi *et al*., 2010; Eghomwanre *et al.,* 2016). The use of extracellular polysaccharides, extracellular and intracellular sequestration by *Pseudomonas* spp. to resist or tolerate silver (Ag) had been reported (Banerjee *et al.,* 2020).

Table 3: Heavy metal tolerance profile of bacteria isolates from selected dumpsites in Abuja

Heavy metal	Conc. (*µg*/mL)	A (n=9)	B (n=16)	C (n=18)	D (n=5)	E (n=3)	F (n=1)	G (n=1)	H (n=1)
Cr	50	9R (100%)	16R (100%)	18R (100%)	5R (100%)	3R (100%)	1R (100%)	1R (100%)	1R (100%)
	100	9R (100%)	16R (100%)	18R (100%)	5R (100%)	3R (100%)	1R (100%)	1R (100%)	1R (100%)
	200	9R (100%)	13R (81.3%)	15R (83.3%)	4R (80%)	1R (33.3%)	R0 (0%)	R0 (0%)	1R (100%)
	400	6R (66.7%)	7R (43.8%)	11R (61.1%)	3R (75%)	0R (0%)	R0 (0%)	R0 (0%)	R0 (0%)
Ni	50	9R (100%)	16R (100%)	18R (100%)	5R (100%)	2R (66.7%)	R0 (0%)	R0 (0%)	R0 (0%)
	100	9R (100%)	16R (100%)	18R (100%)	5R (100%)	1R (33.3%)	R0 (0%)	R0 (0%)	R0 (0%)
	200	5R (55.6%)	11R (68.8%)	15R (83.3%)	5R (100%)	R0 (0%)	R0 (0%)	R0 (0%)	R0 (0%)
	400	5R (55.6%)	9R (56.3%)	11R (61.1%)	5R (100%)	R0 (0%)	R0 (0%)	R0 (0%)	R0 (0%)
Pb	50	9R (100%)	16R (100%)	18R (100%)	5R (100%)	3R (100%)	1R (100%)	1R (100%)	1R (100%)
	100	9R (100%)	16R (100%)	18R (100%)	5R (100%)	3R (100%)	1R (100%)	1R (100%)	1R (100%)
	200	5R (55.6%)	13R (81.3%)	11R (61.1%)	5R (100%)	1R (33.3%)	R0 (0%)	R0 (0%)	R0 (0%)
	400	5R (55.6%)	9R (56.3%)	9R (50%)	5R (100%)	R0 (0%)	R0 (0%)	R0 (0%)	R0 (0%)

Key; Cr = Chromium, Ni = Nickel, Pb = Lead, R = Resistance, Isolates A = *Pseudomonas* spp., Isolates B = *Providencia* spp., Isolates C = *Proteus* spp., Isolates D = *Bacillus* spp., Isolates E= *Micrococcus* spp., F = *Enterobacter* spp., G = *Escherichia coli*, H = *Serratia* spp.

The levels of the minimum inhibitory concentrations (MIC *µg*/mL) are presented in Table 4. MIC was noted in this study as the lowest concentrations of each tested heavy metal at which the bacterial isolates were completely prevented by the heavy metal from displaying visible growth on the agar plates. Among the bacteria isolates, *Proteus, Providencia, Pseudomonas* and *Bacillus* were found to substantially resist relatively high concentrations of Cr, Pb and Ni up to MICs of between 700 – 1950 *µg*/mL. The remaining isolates had MIC values of 50 – 250 µg/mL. This finding suggest that *Proteus, Providencia, Pseudomonas* and *Bacillus* spp., are more tolerant to the metals as against *Micrococcus* spp., *Enterobacter* spp., *Escherichia coli*, and *Serratia* spp. which displayed least). The variations in the MICs could be attributed to the differences in their cell wall components and abilities to synthesize proteins with special abilities to bind metals and regulate their effects (Sevgi *et al*., 2010; Eghomwanre *et al*. 2016; Mosa *et al*., 2016). A comparison of the four remarkable isolates (*Proteus, Providencia, Pseudomonas* and *Bacillus*) revealed that *Bacillus* spp. displayed the highest

MIC value to Ni (1500 μg/mL) and Pb (1950 μg/mL). *Bacillus* isolates from wastes materials with high metal resistant MIC had been reported (Yusuf *et al*., 2014; Oziegbe *et al.,* 2021) and in line with this study. Similarly, comparable bacterial isolates from tannery effluents that tolerated Pb with MIC of 1900 µg/ml was reported by Marzan *et al*. (2017). Furthermore, this result agrees with previous findings by Nath *et al*. (2019) who reported high MIC values of 1650 – 2050 μg/mL for *Bcacillus megaterium* strain GCC-SOS1 and *B. cereus* strain GCC-SOS2 isolated from polluted soils *Bacillus* spp. strains are well known endospore-forming, Gram-positive bacteria, and this finding is in line with previous report that Gram-positive bacteria are more resistant to certain heavy metals than their Gram-negative counterparts (Sevgi *et al*., 2010). However, contrary reports of Gram-negative bacteria demonstrating better tolerance to Ag and Hg than Gram-positive bacteria were documented earlier (Duxbury and Bicknell, 1983; Duxbury, 1986; Hughes and Poole, 1989; Lime e Silva *et al*., 2012). This finding probably suggests that the levels of metal-tolerance by Gram-positives and Gram-negative bacteria varies with different heavy metals. The level of Pb-tolerance exhibited by *Pseudomonas* spp. in this study is concordance with 966.66 μg/mL reported previously (Nath *et al*., 2019). Similarly, *Proteus vulgaris and Pseudomonas fluorescence* with high MICs to Ni, Pb and Cr had been reported from industrial soil environment within central India (Ahirwar *et al*., 2016). Other similar studies reported Cr-resistant bacterial isolates with related MIC of 900 μg/L to 1700 μg/L from tannery (Smrithi and Usha, 2012) and petroleum effluents (Oaikhena et al., 2019). Heavy metals-resistant bacteria with high MIC values have been reported as potential candidate for biosorption and remediation of heavy polluted sites (Gillard *et al*., 2019).

Table 4: The MIC (μg/mL) of each bacterial isolates from dumpsites to Cr, Ni and Pb

Isolate (n=54)	**MIC (μg/mL)**		
	Cr	**Ni**	**Pb**
Pseudomonas spp. (n=9)	850 (700 – 950)	950 (750 – 1100)	900 (750 – 1000)
Providencia spp. (n=16)	1600 (950 – 1700)	1850 (1000 – 2000)	1750 (950 – 1900)
Proteus spp. (n=18)	1700 (1200 – 2000)	1100 (750 – 1500)	950 (900 – 1200)
Bacillus spp. (n=5)	1100 (950 – 1500)	2250 (1500 – 2500)	1750 (1600 – 1950)
Micrococcus spp. (n=3)	150 (100 – 250)	150 (50 - 100)	200 (100 – 250)
Enterobacter spp. (n=1)	150 (50 – 200)	150 (50 - 100)	100 (50 – 150)
Escherichia coli (n=1)	150 (50 – 150)	100 (50 - 100)	100 (50 – 200)
Serratia spp. (n=1)	150 (50 – 250)	50 (50 - 100)	100 (50 – 250)

The occurrence of Cr, Ni and Pb tolerant bacteria are shown in Table 5-7. It was found that distributions of Cr resistant bacteria were in the descending order of Gosa dumpsite>Gwagwalada dumpsite>Bwari dumpsite>Kwaji dumpsite>Abaji dumpsite>Kuje. A similar trend was observed Pb tolerant bacteria, except that Bwari dumpsite isolates had the least Pb tolerant bacteria. Ni tolerant bacterial isolates occurred most in soil samples from Gwagwalada dumpsite and least in both Abaji and Kwali sites. From these results, it was observed that Gosa (n=21, 38.9 %; n=20, 37.0 %) and Gwagwalada (n=18, 36.0 %) harbored majority of the metal resistant bacterial isolates.

Table 5: Distribution of chromium (Cr) resistant (R) bacterial isolates from dumpsites, Abuja

Isolates	Abaji	Bwari	Gosa	Gwagwalada	Kuje	Kwaji
Pseudomonas spp. (n=9)	-	2R	3R	2R	-	2R
Providencia spp. (n=16)	1R	2R	6R	5R	1R	1R
Proteus spp. (n=18)	1R	2R	7R	5R	1R	2R
Bacillus spp. (n=5)	-	-	2R	3R	-	-
Micrococcus spp. (n=3)	-	-	3R	-	-	-
Enterobacter spp. (n=1)	-	1R		-	-	-
Escherichia coli (n=1)	1R	-	-	-	-	-
Serratia spp. (n=1)	-	-	-	1R	-	-
Total (n=54)	3(5.6%)	7(12.9%)	21(38.9%)	16(29.6%)	2(3.7%)	5(9.3%)

Table 6: Distribution of nickel (Ni) resistant (R) bacterial isolates from dumpsites, Abuja

Isolates (n=54)	Abaji	Bwari	Gosa	Gwagwalada	Kuje	Kwaji
Pseudomonas spp. (n=9)	1R	1R	2R	4R	-	1R
Providencia spp. (n=16)	2R	2R	3R	5R	2R	2R
Proteus spp. (n=18)	-	3R	5R	7R	2R	1R
Bacillus spp. (n=5)	1R	-	2R	1R	1R	-
Micrococcus spp. (n=2)	-	-	1R	1R	-	-
Enterobacter spp. (n=0)	-	-	-	-	-	-
Escherichia coli (n=0)	-	-	-	-	-	-
Serratia spp. (n=0)	-	-	-	-	-	-
Total (n=50)	4(8.0%)	6(12.0%)	13(26.0%)	18(36.0%)	5(10.0%)	4(8.0%)

Table 7: Distribution of lead (Pb) resistant (R) bacterial isolates from dumpsites, Abuja

Isolates (n=54)	Abaji	Bwari	Gosa	Gwagwalada	Kuje	Kwaji
Pseudomonas spp. (n=9)	1R	-	3R	2R	1R	2R
Providencia spp. (n=16)	2R	1R	6R	5R	1R	3R
Proteus spp. (n=18)	1R	2R	5R	6R	2R	2R
Bacillus spp. (n=5)	1R	-	2R	1R	1R	-
Micrococcus spp. (n=3)	-	-	3R	-	-	-
Enterobacter spp. (n=1)	-	1R	-	-	-	-
Escherichia coli (n=1)	1R	-	-	-	-	-
Serratia spp. (n=1)	-	-	-	1R	-	-
Total (n=54)	6(11.1%)	4(7.4%)	20(37.0%)	13(24.1%)	5(9.3%)	7(12.9%)

The implication of this finding is that majority of the Cr, Ni and Pb tolerant-bacteria were predominantly distributed in soil samples from Gosa and Gwagwalada dumpiste, probably due to the huge volumes of solid wastes disposed at these locations over the years. According to previous studies Gosa and Gwagwalada dumpsites are the most famous and voluminous solid waste dumping site due to their strategic locations to municipal, industrial and commercial waste generation centers (Sawyerr *et al*., 2017; Ojiego *et al*., 2019; Saidu *et al.,* 2021). The dumpsites are used by farmers for planting mostly vegetables and maize and thus, identification of the metal tolerant bacteria will be significant in proper bioremediation of the heavy metals at the sites by the bacterial agents. Previous reports have documented the concentrations of heavy metals at dumpsites in Abuja (Ojiego *et al*., 2022b). According to the study, it was observed that significantly higher concentrations of Cr (46.23 – 564.00 mg/kg), Ni (44.70 – 87.29 mg/kg) and Pb (23.50 – 31.94 mg/kg) were found at Kuje and Kwari dumpsites, Abuja. The high metal tolerance profile observed by the isolates in this study suggest that the bacteria were already used to environments with high concentrations of the tested heavy metals and thus could have accounted for the abilities of the bacterial to resist their toxicities since they are used to them in the environment (Clausen, 2000; Gillard e*t al*., 2019). The variations observed could be attributed to the age and volume dumpsites as well as the quantities of heavy metals harbored therein. The major sources of the heavy metals at dumpsite soils were linked to waste materials from metallic manufacturing, welding fabrications, and chemical/agricultural fertilizers (Kormoker *et al*., 2019; Mmaduakor *et al*, 2020). Non-biodegradability of these heavy metals makes them to persist and remain for years in soil, water, plants and even bio-accumulate along food chains, thereby posing serious health concerns to exposed humans and ecosystem (Ojiego *et al.,* 2022c). Thus, some of these promising metal-resistant bacterial isolates in this study could be considered for remediation of Ni, Pb and Cr at the dumpsites.

Conclusions

This study evaluated the heavy metals' (Cr, Ni and Pb) tolerance potential of bacterial isolates from solid waste dumping sites (Abaji, Bwari, Gosa, Gwagwalada, Kuje, and Kwali) in Abuja, Nigeria. The bacteria encountered were *Proteus*, *Providencia*, *Pseudomonas*, *Bacillus*, *Micrococcus*, *Escherichia coli*, *Enterobacter* and *Serratia* spp. Among the bacteria isolates, *Proteus, Providencia, Pseudomonas* and *Bacillus* were found to substantially resist relatively high concentrations of the metals studied. Majority of the heavy metal resistant-bacteria were recovered from Gosa and Gwagwalada dumpsites. This study therefore concludes that waste dumping sites in Abuja, particularly, Gosa and Gwagwalada harbor Nr, Cr and Pb-tolerant bacteria which could be considered for remediation of heavy metals at the polluted sites. Further studies are required to investigate the heavy metal bioremediation capacity of the isolates directly in soil environment to optimize their remediation potentialities and exploitations.

Authorship contribution statement

All the authors contributed equally to the research design, analysis and reporting of the findings. The final manuscript was read and approved by all the authors.

Conflict of interest statement

Nil.

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