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THE RELATIONSHIP OF BIOFILMS AND PHYSICOCHEMICAL PROPERTIES OF SOIL SAMPLES WITH CORROSION OF WATER PIPELINES IN MINNA, NIGER STATE, NIGERIA

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ABSTRACT
This study investigated the relationship of biofilms and physicochemical properties of soil samples with corrosion of water pipelines in Barkin-Sale, Bosso, Chanchaga, Keteren-Gwari, Maikunkele and Kwangila areas of Minna metropolis. Corroded water pipes and soil samples were analysed for microbiological and physicochemical properties and their influence on corrosion correlated between the months of February and July, 2008. The corrosion products detected in the soil samples were sulphide and phosphide. The mean concentration of sulphide ranged from 1020 to 3033ppm and that of phosphide ranged from 13.50 to 22.58ppm. The mean organic carbon ranged from 0.35 to 0.89%, mean organic matter ranged from 0.62 to 1.57%, mean pH ranged from 6.73 to 7.70 and mean moisture ranged from 4.33 to 16.63%. There was a significant difference ($P<0.05$) in the level of sulphide, phosphide, organic carbon, organic matter and moisture in the locations but there was no significant difference ($P>0.05$) in their pH. The mean total aerobic bacterial counts ranged from $3.5x10^3$cfu/g to $7.2x10^4$cfu/g, mean total aerobic bacterial counts ranged from $3.0x10^3$cfu/g t0 $5.6x10^5$cfu/g. total aerobic bacterial counts (TABC) was positively correlated with phosphide and negatively correlated with organic matter, pH, moisture, total fungal counts (TFC) and total anaerobic bacterial counts (TAnBC). The total anaerobic bacterial counts (TAnBC) was positively correlated with sulphide, phosphide, organic carbon, organic matter and pH while the total fungal counts (TFC) was positively correlated with sulphide, organic carbon, organic matter, pH and moisture and negatively correlated with phosphide total aerobic bacterial counts and total anaerobic bacterial counts

KEY WORDS: Biofilms, physicochemical properties, corrosion, water pipes and soil samples

INTRODUCTION

It is well recognized that microorganisms are the major cause of corrosion of metal pipelines (Beech and Sunner, 2004). Microorganisms and/or products of their metabolic activities e.g. enzymes, exopolymers, organic and inorganic acids as well as volatile compounds such as ammonia or hydrogen sulphide, can affect cathodic and/or anodic reactions at metal surfaces, thus altering electrochemical process at the biofilm/metal interface (Beech and Gaylarde, 2008). Microbes can cause and accelerate corrosion because of their ability to affect changes in their environment. If microorganisms are to alter their environment, there must be adequate sources of carbon, energy and hydrogen for their growth and metabolism (Kobrin, 1993). In biocorrosion, metabolic activities of microorganisms associated with metallic materials (e.g. Manganese oxides/hydroxides MnO/MnOH) which are able to accept electrons from the bare metal. These sequences of biotic and abiotic reactions produce a kinetically favoured pathway of electron flow from a metal anode to the universal electron acceptor oxygen (Beech and Sunner, 2004).

Basic research to increase our understanding of the composition and variability of microbial communities causing corrosion of pipelines and their activities and interaction with other abiotic and biotic factors will be the basis for the development of new approaches for the detection, monitoring and control of microbial influenced corrosion.

Therefore, the objectives of this research are:

(i) To enumerate, the microorganism found in biofilms attached to corroded water pipes surfaces.
(ii) To analyze soil samples around the corroded pipelines for microbial metabolic products.

MATERIALS AND METHODS

Study Area

The study area for this research work was Barkin-Sale, Bosso, Chanchaga, Maikunkele, Keteren-Gwari and Kwangila areas of Minna metropolis (Latitude 09 39N, longitude 06 32E). Minna is the capital city of Niger State (longitude 8^{O} 20'N and 11^{O} 20'N and 11^{O} 30'N and longitude 3^{O} 30'E and 7^{0} 20'E).

Physical Examination of Water Pipelines

The types of water pipelines affected by corrosion was surveyed and observed. The environments where the pipes were laid were identified as whether they were waterlogged, dried or damp. The physical appearance associated with corrosion was also noted as described by Geiger *et al.*, (1993).

Media and Sterilization

The media used were nutrient agar (Biotech) and sabauroud dextrose agar (Biotech). The selective media used were Postage medium (K_2HP0_4 (0.2g), MgS04. $7H_20$ (0.2g), $(NH_4)_2S0_4$ (1.0g), Na_2S0_3(0.1g) $Fe(S0_4)_3(NH_4)_2S0_4.24H_20$ (0.1g), Ascorbic acid (0.1g), Peptone (1g), Yeast extract (1.0g), Carbon lactate (3.5ml), Agar (20g), Water(1000ml) pH:7.0) (Postage, 1966), iron oxidizing medium (NH_4Cl (0.1g), KH_2P0_4 (3.0g), $MgCl_2.2H_20$ (0.14g), S (10g), Agar (20g), Water (1000ml), pH: 4.2) (Starkey, 1935) and Starkey broth (KH_2PO_4 (3.0g), $MgS0_4.7H_20$ (0.2g), $CaCl_2$. $2H_20$ (0.2g), $(NH_4)_2S0_4$ (0.5g), $FeS0_4$ (0.001g), Water (1000ml), pH:8.0) (Starkey, 1935). The media were sterilized using autoclave at 121^{O}C for 15 minutes.

Experimental Design and Sample Collection

The one-short case study was used as described by Cook and Campbell (1979). Sterile lancets were used to obtain surface scrapings from a $1cm^2$ area of each identified corroded water pipe in Barkin-Sale, Bosso, Chanchaga, Keteren-Gwari, Maikunkele and Kwangila areas of Minna between the months of February and July. Ten samples were collected from each of these locations. The samples were collected in sterile McCartney bottles, labeled and taken to the microbiology laboratory of Federal University of Technology, Minna for microbial analysis.

Fifty (50) grams of soil samples were obtained beneath each of these sites and were collected in clean polythene bags, labelled and taken to the laboratory of soil science department, Federal University of Technology, Minna for soil analysis.

A total of sixty surface scrapings were obtained for microbial analysis (aerobic and anaerobic) and sixty soil samples were obtained for soil analysis.

Enumeration of Bacteria

One gram of surface scrapings of each corroded water pipelines obtained from Barkin-Sale, Bosso, Chanchaga, Keteren-Gwari, Maikunkele and Kwangila, was serially diluted ten folds with 9ml of sterile, distilled water and aseptically plated on nutrient agar and selective media. 1ml of diluents was inoculated into sterile petridish containing a solidified medium. Sterile bent rod (Hockey stick) was then aseptically used to spread the diluents on the surface of the media.

The inoculated nutrient agar, Starkey broth and iron oxidizing bacteria medium were incubated at 37^{O}C for 24 – 48 hours while the inoculated Postgate medium was incubated in an anaerobic jar containing alkaline pyrogalol at 37^{O}C for 24 – 48hours. A duplicate of the inoculated nutrient agar plate was also incubated anaerobically at 37^{O}C for 24 – 48hours.

After incubation, the bacterial colonies which developed from the nutrient agar plates were counted using a colony counter (Model 6399 by Stuart Scientific Co. Ltd., Great Britain) and expressed as colony forming units per gram (cfu/g) of samples. Bacterial colonies differing in size, shape and colour were selected from the different plates and further subcultured on nutrient agar by the streak plate technique and incubated at 37^{O}C for 24 hours after which, were maintained in agar slants for further characterization and identification.

Enumeration of Fungi

One gram of the surface scrapings of each corroded water pipelines obtained from Barkin-Sale, Bosso, Chanchaga, Keteren-Gwari, Maikunkele and Kwangila areas of Minna, was serially diluted ten folds with sterile, distilled water and was also cultured on sabauroud dextrose agar for the enumeration and identification

of fungi. 1ml of diluents was inoculated into sterile petridish containing sabauroud dextrose agar. Bent rod (Hockey stick) was then aseptically used to spread the diluents on the surface of the media. Colonies that arise from the plate after 72 hours of incubation were counted and expressed as colony forming unit per gram (cfu/g).

Analysis of Soil Samples

The soil samples were analysed for their sulphide, phosphide, organic carbon, organic matter, pH and moisture contents using the methods described by (International Institute for Tropical Agriculture, IITA, 1976).

Statistical Analysis of Data

The data obtained from this study was subjected to statistical analysis using one way analysis of variance (ANOVA) and Pearson correlation with MINITAB 14 package.

RESULTS

Total Microbial Counts (cfu/g) of Water Pipeline Scrapings from Different Locations

Total aerobic bacterial counts (cfu/g)

The total aerobic bacterial counts of water pipeline scrapings obtained from Barkin-Sale ranged from ND to 1.3 x 10^5 cfu/g, Bosso ranged from ND to 1.0 x 10^4cfu/g, Chanchaga ranged from ND to 2.1 x 10^5 cfu/g, Keteren-Gwari ranged from ND to 2.0 x 10^5cfu/g, Maikunkele ranged from ND to 1.3 x 10^5 cfu/g and Kwangila ranged from ND to 7.0 x 10^4 cfu/g (Table 1).

The highest mean total aerobic bacterial count (7.16 x 10^4 ± 462.69 cfu/g) was obtained in Chanchaga followed by Maikunkele (3.88x 10^4 ± 355.49 cfu/g). The least obtained in Bosso (3.50 x 10^3 ± 39.51 cfu/g) (Table 1).

Statistical analysis of data showed that there were significant differences ($p<0.05$) between the total aerobic bacterial counts from Barkin-Sale, Bosso, Chanchaga, Maikunkele, Keteren-Gwuari and Kwangila.

Table 1: Total aerobic bacterial counts (cfu/g) of scrapings from water pipelines

	Locations					
Sample No.	BS	BO	CH	KG	MK	KW
1	ND	$1.0X10^4$	ND	ND	ND	ND
2	$1.0X10^2$	$3.3X10^2$	$5.0X10^3$	$3.1X10^4$	ND	ND
3	$1.0X10^3$	ND	ND	ND	$1.0X10^3$	$4.0X10^4$
4	$1.5X10^2$	ND	ND	$1.5X10^3$	$1.5X10^2$	ND
5	$2.0X10^3$	ND	ND	$1.7x10^2$	$3.0x10^2$	$7.0x10^4$
6	ND	ND	$1.0x10^4$	ND	$1.0x10^5$	ND
7	ND	ND	$2.3x10^3$	ND	ND	ND
8	$1.3x10^5$	ND	$2.0x10^3$	ND	ND	$3.5x10^4$
9	$1.3x10^5$	ND	$2.1x10^5$	$4.5x10^3$	$1.3x10^5$	$5.4x10^4$
10	ND	ND	$2.0x10^5$	$2.0x10^5$	$1.1x10^3$	ND
Mean count	26700^{bc} ±288.90	3500^{c} ±39.51	71600^{a} ±462.69	39600^{b} ±355.49	38800^{b} ±267.48	2000^{bc} ±117.40

KEY: BS- Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele.
KW-Kwangila, ND-not detected, ± - standard error of the mean.
Means carrying the same superscript do not differ significantly from each other ($P>0.05$) means carrying different superscripts differ significantly from each other ($P<0.05$) while means carrying two superscripts do not differ significantly from the two ($P>0.05$).

Total anaerobic bacterial counts (cfu/g)

The total anaerobic bacterial counts of water pipeline scrapings obtained from Barkin-Sale ranged from 1.1 x 10^2 to 3.5 x 10^6 cfu/g, Bosso ranged from 3.3 x 10^3 to 3.7 x10^7cfu/g, Chanchaga ranged from ND to 3.5 x 10^5 cfu/g, Keteren – Gwari ranged from ND to 7.0 x 10^6 cfu/g, Maikunkele ranged from 1.5 x 10^3 to 3.5x10^6 cfu/g and Kwangila ranged from 1.5x10^5 to 5.0x10^7 cfu/g (Table 2).

The highest mean total anaerobic bacteria count ($7.69x10^6$±49962.00 cfu/g) was obtained in Kwangila followed by Bosso ($7.14x10^6$±71413 cfu/g). The least was obtained in Chanchaga ($5.59x10^3$±454.69 cfu/g) (Table 2).

Statistical analysis of data showed that there were significant differences ($P<0.05$) between the total anaerobic bacterial counts from Barkin-Sale, Bosso, Chanchaga, Maikunkele, Keteren-Gwari and Kwangila.

Table 2: Total anaerobic bacteria counts (cfu/g) of scrapings from water pipelines

	Locations					
Sample No.	BS	BO	CH	KG	MK	KW
1	$3.0x10^5$	$3.5x10^6$	$2.5x10^4$	$1.9x10^2$	$2.5x10^3$	$1.5x10^5$
2	$1.1x10^2$	$3.0x10^5$	$5.0x10^3$	ND	$2.1x10^3$	$5.0x10^5$
3	$1.5x10^3$	$3.7x10^7$	$5.0x10^4$	$1.7x10^4$	$1.5x10^3$	$5.0x10^7$
4	$2.5x10^5$	$3.3x10^3$	$3.5x10^4$	ND	$2.5x10^3$	$2.5x10^6$
5	$1.0x10^3$	$1.7x10^6$	$3.4x10^3$ ±216.06	ND	$1.0x10^5$	$6.0x10^6$
6	$3.5x10^6$	$2.0x10^5$	ND	$1.8x10^3$	$3.5x10^6$	$1.5x10^6$
7	$2.1x10^4$	$2.1x10^5$	ND	$2.8x10^5$	$1.9x10^3$	$3.5x10^6$
8	$2.5x10^5$	$2.5x10^7$	$3.5x10^5$	$7.0x10^6$	$1.7x10^3$	$3.0x10^6$
9	$4.0x10^5$	$3.0x10^6$	$3.0x10^3$	$3.2x10^6$	$4.0x10^3$	$5.0x10^6$
10	$3.5x10^4$	$2.2x10^6$	$1.3x10^2$	ND	$4.8x10^3$	$4.8x10^6$
Mean count	448900^c ±3608.33	7141300^a ±43117	55900^d ±454.69	2099400^b ±15264.50	362100^c ±3676.60	7695000^a ±49962

KEY: BS- Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele.
KW-Kwangila, ND-not detected, ± - standard error of the mean.
Means carrying the same superscript do not differ significantly from each other ($P>0.05$) means carrying differ superscripts differ significantly from each other ($P<0.05$) while means carrying two superscripts do not differ significantly from the two ($P>0.05$).

Total fungal counts (cfu/g)

The total fungal counts of water pipeline scrapings obtained from Barkin-Sale ranged from ND to $3.5x10^6$ cfu/g, Bosso ranged from ND to $1.2x10^5$ cfu/g, Chanchaga ranged from ND to $2.2x10^5$cfu/g, Keteren-Gwari ranged from ND to $3.5x10^3$ cfu/g, Maikunkele ranged from ND to $3.5x10^4$ cfu/g and Kwangila ranged from ND to $3.5x10^6$ cfu/g (Table 3).

The highest mean total fungal count ($5.63x10^5$±4555.61 cfu/g) was obtained in Kwangila followed by Barkin-Sale ($1.18x10^5$±10101.32 cfu/g). The least was obtained in Keteren-Gwari ($3.0x10^3$±6.36 cfu/g) (Table 3). Statistical analysis of data showed that there were significant differences ($P<0.05$) between the total mean fungal counts from Barkin-Sale, Bosso, Chanchaga, Maikunkele, Keteren-Gwari and Kwangila.

Table 3: Total fungi counts (cfu/g) of scrapings from water pipelines

	Locations					
Sample No.	BS	BO	CH	KG	MK	KW
1	ND	ND	$5.0x10^2$	ND	$1.5x10^3$	$1.5x10^3$
2	$1.0x10^2$	ND	ND	ND	$1.5x10^4$	1.5x104
3	ND	$2.0x10^3$	ND	$3.5x10^3$	ND	ND
4	ND	$5.0x10^2$	ND	$3.5x10^3$	ND	$7.5x10^4$
5	$3.5x10^6$	$2.0x10^4$	$1.5x10^3$	ND	$3.5x10^4$	$3.5x10^6$
6	ND	ND	$2.2x10^5$	ND	ND	$3.0x10^5$
7	ND	ND	ND	ND	$1.0x10^4$	$1.3x10^4$
8	$1.0x10^3$	$1.3x10^4$	ND	$2.0x10^3$	$1.0x10^2$ ±10.80	$2.6x10^2$
9	ND	$1.3x10^3$	ND	ND	ND	ND
10	$1.1x10^3$	$1.2x10^5$	ND	$2.1x10^3$	ND	$6.0x10^5$
Mean count	117600^b ±10101.32	83700^c ±653.12	74000^c ±893.78	3000^c ±6.36	12300^d ±70.5	563100^a ±4555.61

KEY: BS- Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele.
KW-Kwangila, ND-not detected, ± - standard error of the mean.
Means carrying the same superscript do not differ significantly from each other (P>0.05) means carrying differ superscripts differ significantly from each other (P<0.05) while means carrying two superscripts do not differ significantly from the two (P>0.05).

Physicochemical Properties of Soil from Different Locations in Minna

Sulphide (ppm)

The sulphide composition of soil obtained from Barkin-Sale ranged from 50.25 to 2362.5ppm, Bosso ranged from 63.5 to 4562.8ppm, Chanchaga ranged from 75.5 to 2825ppm, Keteren-Gwari ranged from 75.5 to 4362.5 ppm, Maikunkele ranged from 925 to 1510pmm, Kwangila ranged from 975.05 to 4506.3ppm (Table 10). The highest mean sulphide (3033pm) was obtained in Kwangila, followed by Bosso (2631). The least was obtained in Chanchaga (1919.9ppm) (Table 4). There were significant differences (P<0.05) between the sulphide composition of the soil samples obtained from the various locations.

Table 4: Sulphide composition (ppm) of soil samples obtained from different locations in Minna

	Locations					
	BS	BO	CH	KG	MK	KW
Sample no.						
1	2362.5	3187	1187	2187	1510	2362.5
2	50.25	2562.5	75.5	1162.5	2351	3131.3
3	61.25	4562.8	115.35	2093.8	925	975.05
4	3125	63.5	950.75	4362.5	1250.1	2250.1
5	3531.3	3031.3	1105.5	41.25	1431.3	3431.3
6	3718.8	2635.5	1162.5	75.5	1406.3	4506.3
7	91.25	2631.3	1531.3	1531.3	1130.3	1055.3
8	2255.3	4125	2825	3625	1406.3	4406.3
9	2312.5	2850	1150	4130	1025.5	4135.5
10	3155	1150	1041	98.54	1115.6	3500
Mean values	1761^{ab} ±510.33	2631^b ±401.67	1020^a ±275.67	2013^{ab} ±510.33	1469^a ±159.33	3033^b ±440.67

Means carrying the same superscript do not differ significantly from each other (P>0.05) means carrying different superscripts differ significantly from each other (P<0.05) while means carrying two superscripts do not differ significantly from two (P>0.05).

BS-Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele, KW-Kwangila

Phosphide (ppm)
The phosphide composition of soil obtained from Barkin-Sale ranged from 9.7 to 21 ppm, Bosso ranged from 12.5 to 35.7ppm, Chanchaga ranged from 10.35 to 21.75ppm, Keteren-Gwari ranged from 11.5 to 23.5ppm, Maikunkele ranged from 11 to 23.5ppm, Kwangila ranged from 16.5 to 29.35ppm (Table 5).

The highest mean phosphide (22.58ppm) was obtained in Bosso, followed by Kwangila (22.00ppm). The least was obtained in Barkin-Sale (13.50ppm) (Table 5). There were significant differences ($P<0.05$) between the phosphide composition of the soil samples obtained from the various locations.

Table 5: Phosphide composition (ppm) of soil samples obtained from different locations in Minna

	Locations					
	BS	BO	CH	KG	MK	KW
Sample no.						
1	10.5	17.5	11	11.5	12	22.5
2	11.5	17.5	18.35	15.35	11	29.35
3	12	23.1	15	16.01	15.75	20
4	9.7	12.5	13.5	23.5	17.5	21.1
5	12.8	35.7	10.35	15.32	12.5	18
6	15	31.5	12.5	12.65	13.55	35
7	12.5	31.5	11.5	17.53	15	19
8	12.5	21	15.75	23.5	18.9	18.5
9	21	17.1	21.75	12.7	21	20
10	17.5	18.4	17.5	18.54	23.5	16.5
Mean values	13.50^{a} ± 1.15	22.58^{b} ±2.67	14.72^{a} ±1.22	16.66^{ab} ±1.41	16.07^{ab} ±1.37	22.00^{ab} ±1.92

Means carrying the same superscript do not differ significantly from each other ($P>0.05$) means carrying different superscripts differ significantly from each other ($P<0.05$) while means carrying two superscripts do not differ significantly from two ($P>0.05$).
BS-Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele, KW-Kwangila

Percentage organic carbon
The percentage organic carbon of soil obtained from Barkin-Sale ranged from 0.18 to 0.9%, Bosso ranged from 0.35 to 1.32%, Chanchaga ranged from 0.12 to 0.65%, Keteren_Gwari ranged from 0.15 to 0.85%, Maikunkele ranged from 0.33 to 0.776%, Kwangila ranged from 0.25 to 1.45% (Table 6).

The highest mean percentage organic carbon (0.89%) was obtained in Kwangila, followed by Bosso (0.79%). The least was obtained in Chanchaga (0.35%) (Table 6). There were significant differences ($P<0.05$) between the % organic carbon composition of the soil samples obtained from the various locations.

Table 6: Percentage organic carbon composition of soil samples obtained from different locations in Minna

	Locations					
	BS	BO	CH	KG	MK	KW
Sample no.						
1	0.54	0.85	0.51	0.55	0.75	0.65
2	0.18	0.45	0.3	0.15	0.45	0.86
3	0.24	1.32	0.5	0.43	0.33	0.25
4	0.855	0.35	0.22	0.5	0.665	0.35
5	0.9	1.05	0.15	0.25	0.43	1.08
6	0.87	0.72	0.35	0.3	0.54	1.45
7	0.21	0.75	0.25	0.5	0.51	0.78
8	0.54	0.93	0.4	0.25	0.54	1.35
9	0.53	0.74	0.65	0.85	0.493	0.93
10	0.24	0.69	0.12	0.75	0.776	0.88
Mean values	0.51^{ab}	0.79^{b}	0.35^{a}	0.45^{a}	0.54^{ab}	0.89^{b}
	±0.10	±0.10	±0.06	±0.08	±0.05	±0.13

Means carrying the same superscript do not differ significantly from each other (P>0.05) means carrying different superscripts differ significantly from each other (P<0.05) while means carrying two superscripts do not differ significantly from two (P>0.05).
BS-Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele, KW-Kwangila

Percentage organic matter

The percentage organic matter of soil obtained from Barkin-Sale ranged from 0.31 to 1.55%, Bosso ranged from 0.60 to 2.27%, Chanchaga ranged from 0.21 to 1.12%, Keteren-Gwari ranged from 0.43 to 1.46%, Maikunkele ranged from 0.57 to 1.33%, Kwangila ranged from 0.43 to 2.50% (Table 7).

The highest mean percentage organic matter (1.57%) was obtained in Kwangila, followed by Bosso (1.35%). The least was obtained in Chanchaga (o.62%) (Table 7). There were significant differences (P<0.05) between the % organic matter composition of the soil samples obtained from the various locations.

Table 7: Percentage organic matter composition of soil samples obtained from different locations in Minna

	Locations					
	BS	BO	CH	KG	MK	KW
Sample no.						
1	0.930	1.462	0.88	0.95	1.29	1.12
2	0.310	0.774	0.52	0.26	0.77	1.48
3	0.414	2.270	0.86	0.74	0.57	0.43
4	1.473	0.602	0.65	0.86	1.14	1.60
5	1.548	1,806	0.26	0.43	0.74	1.86
6	1.499	1.238	0.60	0.52	0.93	2.50
7	0.361	1.290	0.43	0.86	0.88	1.31
8	0.930	1.591	0.69	0.43	0.93	2.32
9	0.912	1.273	1.12	1.46	0.85	1.60
10	0.414	1.187	0.21	1.30	1.33	1.51
Mean values	0.88^{ab}	1.35^{b}	0.62^{a}	0.78^{a}	0.94^{a}	1.57^{b}
	±0.17	±0.16	±0.10	±0.13	±0.08	±0.20

Means carrying the same superscript do not differ significantly from each other (P>0.05) means carrying different superscripts differ significantly from each other (P<0.05) while means carrying two superscripts do not differ significantly from two (P>0.05).
BS-Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele, KW-Kwangila

pH

The pH of soil obtained from Barkin-Sale ranged from 6.9 to 7.8, Bosso ranged from 7.3 to 8.4, Chanchaga ranged from 3.4 to 8.5, Keteren-Gwari ranged from 4.5 to 8.5, Maikunkele ranged from 6.8 to 8.4, Kwangila ranged from 6.8 to 8.4 (Table 8).

The highest mean pH (7.7) was obtained in Kwangila and Keteren-Gwari, followed by Bosso (7.6). the least was obtained in Maikunkele (6.7) (Table 8). There was no significant difference (P>0.05) between the pH composition of the soil samples obtained from the various locations.

Table 8: pH composition of soil samples obtained from different locations in Minna

	Locations					
	BS	BO	CH	KG	MK	KW
Sample no.						
1	7.4	7.55	7.35	8.5	8.4	8.4
2	7.55	7.76	6.56	6.10	7.65	7.65
3	7.76	7.74	8.54	7.75	7.77	7.77
4	7.79	8.40	7.50	4.50	7.69	7.69
5	7.58	7.44	7.54	7.44	7.88	7.88
6	7.83	7.34	7.34	7.34	8.00	8.00
7	6.89	7.36	3.36	7.36	6.79	6.79
8	7.40	7.44	7.44	7.44	7.51	7.51
9	7.55	7.40	7.40	6.40	7.55	7.55
10	7.76	7.55	7.55	4.55	7.76	7.76
Mean values	7.55^{a} ±0.93	7.60^{a} ±0.11	7.10^{a} ±0.46	6.73^{a} ±0.45	7.70^{a} ±0.14	7.70^{a} ±0.14

Means carrying the same superscript do not differ significantly from each other (P>0.05) means carrying different superscripts differ significantly from each other (P<0.05) while means carrying two superscripts do not differ significantly from two (P>0.05).
BS-Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele, KW-Kwangila

Percentage moisture

The percentage moisture of soil obtained from Barkin-Sale ranged from 1.01 to 30.77%, Bosso ranged from 0.91 to 15.15%, Chanchaga ranged from 0.5 to 30.21%, Keteren-Gwari ranged from 0.91 to 9.37%, Maikunkele ranged from 2.37 to 30.26%, Kwangila ranged from 2.37 to 30.26% (Table 9).

The highest mean moisture (16.63%). The least was obtained in Keteren-Gwari (4.33%) (Table 9). There were significant differences (P<0.05) between the moisture composition of the soil samples obtained from the various locations.

Table 9: Percentage moisture composition of soil samples obtained from different locations in Minna

	Locations					
	BS	BO	CH	KG	MK	KW
Sample no.						
1	1.01	10.00	11.10	3.50	11.70	11.70
2	15.00	2.25	2.32	3.25	4.25	4.25
3	30.77	2.35	2.75	2.35	30.26	30.26
4	15.00	1.93	10.83	2.95	3.63	3.63
5	26.42	6.00	30.21	1.01	6.42	6.42
6	14.16	12.00	20.60	8.50	4.13	4.13
7	16.00	0.91	3.91	0.91	14.59	14.59
8	1.01	1.60	0.50	10.5	11.10	11.10
9	29.37	1.01	2.51	1.01	2.37	2.37
10	17.60	15.15	3.37	9.37	9.60	9.60
Mean values	16.63^{b} ±3.44	5.32^{ab} ±1.74	8.81^{a} ±3.23	4.33^{a} ±1.23	10.71^{ab} ±3.61	10.71^{ab} ±3.61

Means carrying the same superscript do not differ significantly from each other (P>0.05) means carrying different superscripts differ significantly from each other (P<0.05) while means carrying two superscripts do not differ significantly from two (P>0.05).
BS-Barkin-Sale, BO-Bosso, CH-Chanchaga, KG-Keteren-Gwari, MK-Maikunkele, KW-Kwangila

Correlation between the Soil Physicochemical Properties and Microbial Counts of Water Pipeline Scrapings
When subjected to Pearson correlation, there was a positive correlation between the phosphide and sulphide (0.405), organic carbon (0.472) and organic matter (0.486), a strong positive correlation between the organic matter and organic carbon (0.969), sulphide (0.773) as well as between sulphide and organic carbon (0.769) and the differences between them were significant (P<0.05). The total aerobic bacterial counts (TABC) was positively correlated with phosphide (0.251) and negatively correlated with organic carbon (- 0.029), organic matter (- 0.02), pH (-0.125), moisture (-0.113), total fungal counts (TFC) (-0.13) and total anaerobic bacterial counts (TAnBC) (-0.119). The total anaerobic bacterial counts (TAnBC) was positively correlated with sulphide (0.161), organic carbon (0.178), organic matter (0.173) and pH (0.030). The total fungal counts (TFC) was also positively correlated with sulphide (0.203), organic carbon (0.270), organic matter (0.258), pH (0.239) and moisture (0.119) and negatively correlated with phosphide (-0.112), total aerobic bacterial counts (TABC) (-0.131) significant differences between them (P>0.05) (Table 10).

Table 10: Correlation between the soil physical properties and microbial counts of corroded water pipeline scrapings

	Sulphide	Phosphide	% organic carbon	% organic matter	pH	% moisture	TABC	TAnBC
Phosphide	0.405*							
% organic	0.000							
carbon	0.769*	0.472*						
% organic	0.000	0.000						
	0.770*	0.486*	0.969*					
Matter	0.000	0.000	0.000					
pH	-0.209	-0.164	-0.207	-0.226				
	0.108	0.212	0.113	0.082				
% moisture	-0.044	0.013	0.150	0.163	0.119			
	0.736	0.921	0.251	0.214	0.365			
TABC	-0.199	0.251	-0.029	-0.026	-0.125	-0.113		
	0.283	0.173	0.879	0.890	0.504	0.546		
TAnBC	0.231	0.161	0.178	0.199	0.030	0.030	-0.119	
	0.096	0.250	0.201	0.154	0.830	0.830	-0.572	
TFC	0.203	-0.112	0.270	0.258	0.239	0.119	-0.131	-0.024
	0.272	0.547	0.142	0.161	0.195	0.522	0.718	0.900

Pearson correlation (P-value)
TABC: Total aerobic bacterial count, TAnBC: Total anaerobic count, TFC: Total: fungi count
* significant difference (P<0.05)
- inverse relationship

DISCUSSION
The highest mean total aerobic bacterial count was recorded in Chanchaga (Table 1). The high aerobic bacterial counts in Chanchaga may be due to low levels of organic carbon and organic matter in this location (Table 6, Table 7) which favours aerobic bacterial growth. The highest mean total anaerobic bacterial counts recorded in Kwangila and Bosso (Table 2) may be due to the presence of high organic carbon and organic matter in these locations (Table 6, Table 7). Willey *et al.* (2008) reported that anaerobes proliferate more in the presence of high organic matter which produces increased hydrogen sulphide and favours anaerobic corrosion.

The highest mean total fungal count was also recorded in Kwangila and Bosso (Table 3). The presence of high organic matter in these locations may also be a contributing factor. Willey *et al.* (2008) reported that fungi are chemoorganotrophs and are therefore found abundantly wherever organic material is available. There were significant differences (P<0.05) in the mean total aerobic counts, mean total anaerobic counts and the mean total fungal counts in all the locations.

Corrosion products detected from the soil samples were sulphide and phosphide. The high sulphide (Table 4) and phosphide (Table 5) in Kwangila and Bosso, corresponded to the high anaerobic counts recorded in these locations. SRB produces sulphide which is responsible for their corrosion activities while the low sulphide obtained in Chanchaga and low phosphide in Barkin-Sale may be due to the presence of low anaerobic counts in

these locations. There were significant differences ($P<0.05$) in the sulphide and phosphide compositions in the locations.

The pH of the soil samples ranged between neutrality and mild acidic region (6.73-7.70) (Table 8). pH, near neutrality observed in most soils in all the locations may be due to the relative abundance of the SRB in all these locations as neutral pH favours their growth and proliferation (Oyeleke *et al*., 2005). The low pH observed in Maikunkele may be due to the high occurrence of acid producing bacteria and fungi. There was no significant difference ($P>0.05$) in the mean pH in all the locations but, there was a significant difference ($P<0.05$) in the % moisture with Barkin-Sale having the highest mean percentage of 16.63 (Table 8).

When the physicochemical properties of the soil and microbial counts were subjected to Pearson correlation, (Table 9), it revealed that total anaerobic bacterial counts (TAnBC) and total fungal counts (TFC) positively correlated with the correlation products and the soil physicochemical properties. This further explains why high anaerobic and fungal counts were recorded in most of the locations. There were also strong correlations between the sulphide and organic carbon as well as sulphide and organic matter. However, the total aerobic bacterial counts (TABC) gave a negative correlation with sulphide and the soil physicochemical properties examined.

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