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Physicochemical Characteristics of Soil Moisture and Their Effects on the Corrosion Behavior of Buried Mild Steel in Calabar Metropolis, Nigeria

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Abstract

Soil moisture collected from three locations, namely University of Calabar (UNICAL), Calabar municipal solid waste dumpsite (MSWD) and a mechanic workshop (MW) all within Calabar metropolis, Nigeria, were analyzed quarterly in a one year study at different depths (0.5 m and 1 m) for some physicochemical parameters. UV-visible spectrophotometer, titration and atomic absorption spectrophotometer (AAS) were the employed analytical techniques. With the exception of chloride, all other parameters showed higher values with depth. Higher values for the analyzed parameters were generally reported for MSWD and this was largely the result of the presence of a variety of contaminants in this location. Microbial analysis of soil samples from the locations revealed the presence of SRB in MW, which could have possibly influenced the soil moisture chemistry of the location. Corrosion rate was calculated from weight loss measurements and the quarterly results were all for follow the trend: UNICAL < MW < MSWD. At the end of the 4th quarter, the corrosion rates at 0.5 m depth were 0.0057, 0.0070, and 0.0101 mm/hour for UNICAL, MW, and MSWD, respectively, while their corresponding values at 1 m depth were 0.0087, 0.0114, and 0.0128 μm/hour. The values were shown to increase with depth. R-mode factor analysis identified some important factors which could have been responsible for the variation in the chemistry of the soil moisture.

Keywords

Soil Contaminants, Heavy Metals, Mild Steel, Metal Corrosion

1. Introduction

Generally, soil properties vary from place to place within a single site depending largely on the environmental factors around the soil vicinity. Consequently, the use for which these soils can be applied is affected by the variation. Soil constitutes one of the three key environmental media, the other two being air and water, but soil differs significantly from these two media because it is predominantly solid and has the capacity to retain many types of contaminants [1]. This retention ability of soils makes them to operate as sinks for contaminants.

Soil corrosion is caused by direct contact of buried metallic structures with aggressive soil environments (moisture, chemicals, etc.). The corrosion mechanism and nature of products formed depend on the type of metal, characteristics/composition of the metal and the soil properties. Compared to atmospheric corrosion, soil corrosion is less predictable because of the fluctuating characteristics of soil parameters within a single site. Soil corrosion has been implicated as one of the main reasons for the reduced service life of underground structures and pipelines [2] [3] [4] [5]. The influence of several environmental factors, such as temperature, moisture content, oxygen content, environmental pH, microbial activity and soluble salts, has been reported as the main factors affecting the corrosion of underground structures [6]-[14]. The corrosion of underground metals is a significant problem for operators of water distribution, sewerage management and oil and gas systems.

Mild steel finds to be applied as the most widely used material in the construction of underground structures because of its advantage of being cost effective, but it however shows susceptibility to corrosion under different environments. Underground metal structures are usually designed to have a lifetime of about 50 to 100 years [15] but in some cases, metal storage tanks have been destroyed within months, while in other cases, metal tools have survived hundreds of years in desert climates. Therefore, it is necessary to ensure continuous inspection and maintenance of these structures in order to secure their life span and reliability. Failure in underground metal structures can have severe consequences on the environment, economy and human lives.

Cole and Marney [16] reported soil moisture as the most important parameter in assessing the corrosion of buried pipelines. Soil moisture contains a wide range of chemicals which have percolated through the soil surface. Some examples of these chemicals are salts (such as chlorides, nitrates, nitrites, sulfate, etc.), and heavy metals (such as cadmium, chromium, copper, iron, manganese, nickel, lead, zinc, etc.). Together with the influence of microbial activity and environmental factors (such as temperature, pH, conductivity and dissolved oxygen concentration), salts and heavy metals make the studies of soil moisture an interesting topic as it relates to the corrosion of underground metal structures.

This paper aims to investigate the potential presence of the physicochemical parameters released from a municipal solid waste dumpsite, a mechanic work-

shop and a university campus around Calabar metropolis, Nigeria, and their effects on the corrosion rate of mild steel coupons buried at different depths. The ability to predict the fate of the buried mild steel coupons is attractive to pipeline engineers and urban developers of the Metropolis as waste separation and environmental management is still a far cry from enforcement.

2. Material and Methods

2.1. The Study Areas

The selected study areas and their locations are Calabar Municipal solid waste dumpsite, denoted by MSWD, (5°2'3"N, 8°21'46"E), a mechanic workshop in Calabar, denoted by MW, (4°57'30"N, 8°20'41"E), and University of Calabar, denoted by UNICAL, (4°57'1"N, 8°21'3"E) all within Calabar Metropolis, Cross River state, Nigeria. The city is characterized by two main climatic conditions—dry season (October to March) and wet season (April to September, with a peak in June and July) with mean temperature recorded to be in the range of 24.0°C to 28.5°C. Additionally, the city has a high annual rainfall of 350 - 400 mm and run-off predicted to reach 90% [17].

2.2. Soil Moisture Sampling Procedure

PVC pipes were bought from the local market and cut into different lengths, 0.5 m and 1.0 m. Pipe covers were used to permanently seal the bottom of the pipes with the aid of an adhesive while the tops were firmly fitted with pipe covers only. Tiny holes were drilled evenly round the pipes at considerable distances from the top and base ends to permit water percolation and collection. Soil was dug out to 0.5 m and 1.0 m depths and the pipes were placed into the ground in a standing position in each study location and the dugout soil was returned and made to completely fill up the area around the pipe with small allowance at the top for access to the top ends during soil moisture sampling.

Soil moisture sampling was carried out using a pipette, a 1 L plastic container and a suction bulb. All sampling apparatus were washed with double distilled water and allowed to dry before sampling. The pipette was attached to the suction bulb and inserted into the PVC pipe from the top until contact was made with the percolated moisture at the bottom of the pipe. Pressure was applied by the suction bulb to collect the soil moisture. This process was continued until the liquid sample was adequately drained from the pipe into the 1 L plastic container which was immediately labeled. Temperature, pH, conductivity and dissolved oxygen (DO) were measured in situ before the sample container was transferred into an icebox. The samples were transported to the laboratory and preserved in a refrigerator for analysis. Parameters such as nitrate, nitrite and sulfate were analyzed by UV-visible spectrophotometer at 220 nm, 210 nm and 420 nm, respectively, while chloride was obtained by titrimetry. Heavy metal such as Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were analyzed using Atomic Absorption Spectrophotometer (AAS). All the measured parameters were determined by stan-

dard analytical methods as described by APHA [18]. Sampling and analyses of soil water was carried out quarterly for one year duration from September 2014 to September 2015. This was to represent both the dry and wet seasons and to evaluate the influence of seasonal variation on the chemistry of the soil moisture.

2.3. Soil Microbial Analysis

Soil from the different sample locations at 15 - 30 cm depth was collected with the aid of a hand-driven auger, placed in a sterile petri dish, labeled, covered with a foil paper, placed into an icebox and transferred to the laboratory for microbial analysis. 1 g of the collected soil was dissolved in 9 ml double distilled water. From the solution, a ten-fold serial dilution in the range of 10^{-1} to 10^{-9} was prepared from the solution. 1 ml aliquot of the sample dilution (from 10^{-4} to 10^{-6}) was seeded into sterile petri dishes and the determination of total heterotrophic bacterial count was done by pour plate technique using tryptone soya agar, a known support for the growth of aerobes and anaerobes. The aerobic cultures were incubated at 26°C ± 1°C for 48 hours while anaerobic cultures were incubated in a Baird and Tatlock anaerobic jar at 30°C for 48 to 72 hours. Obvious/visible colonies between 30 and 300 were multiplied by the reciprocal of the dilution factors and reported as colony forming units per gram (cfu/g) of soil sample. The classification of bacterial species was done according to the standards from literature [19].

2.4. Weight Loss Measurements

The corrosion test sample were made of mild steel, MS with a size of 10 × 5 × 0.08 cm, and a chemical composition (wt%) of 0.19 C, 0.26 Si, 0.64 Mn, 0.05 S, 0.06 P, 0.09 Ni, 0.08 Cr, 0.02 Mo, 0.27 Cu and Fe balance. Before the test, the MS coupons were abraded with silicon carbide abrasive paper up to 600 grit, washed with double distilled water, cleaned with ethanol, dried and weighed [20] [21]. The exposed surface area of each MS coupon was 102.4 cm². With the aid of a thin thread, the MS coupons were inserted completely into the soil at 0.5 m and 1.0 m depths beside the soil moisture sampling pipes at each of the sampling points. MS Coupons were retrieved quarterly, washed in 20% NaOH solution, rinsed with absolute ethanol, dipped in acetone and air dried. The cleaning process should precisely remove all corrosion products from the MS coupons with a minimum removal of the uncorroded metal. The weights of retrieved MS coupons were taken and the weight loss evaluated as the difference in initial and final weights in gram. From the weight losses, the corrosion rates were calculated using Equation (1) [22]:

$$\text{Corrosion rate}\left(\mu\text{m/hour}\right) = \frac{87600\left(WL\right)}{\rho A t} \tag{1}$$

where (*WL*) is weight lossing, ρ is the density of MS in g/cm², *A* is surface area of the MS coupon in cm² and *t* is time of exposure in hours.

3. Results and Discussion

3.1. Identification and Characterization of Microbial Isolates

Table 1 gives the identified and characterized bacterial species with their respective counts for the different sample locations. Our focus was on bacteria as they have been the majorly reported species as it concerns microbiologically influenced corrosion. Eight (8) species were characterized for UNICAL while fourteen (14) and twelve (12) species were characterized for MW and MSWD, respectively. Bacteria being either aerobic or anaerobic in nature affect the oxygen activity in the soil and therefore influence corrosion mechanism of buried metals.

Of the 3 study locations, sulfate-reducing bacteria (SRB) were only characterized for MW. SRB are essential members of microbial communities implicated in metal reduction and they exist in a variety of environments, including the

Table 1. Identified and characterized bacterial species with their respective counts from soil samples from the study locations.

Bacterial species	Number (%)		
	UNICAL	MSWD	MW
Escherichia	36 (22.1)	52 (14.2)	27 (7)
Clostridium	16 (9.8)	0	23 (6)
Streptococcus	26 (16)	26 (7.1)	29 (7.6)
Desulfatomaculum	0	0	23 (6)
Cladosporium	0	0	37 (9.6)
Methanococcus	0	0	21 (5.5)
Micrococcus	43 (26.4)	40 (10.9)	39 (10.2)
Bacillus	11 (6.7)	38 (10.4)	32 (8.3)
Ferro-thiobacilllus	0	0	42 (10.9)
Acidithiobacillus	0	0	46 (12)
Thiobacillus	0	0	31 (8.1)
Staphylococccus	24 (14.7)	39 (10.6)	19 (4.9)
proteus	5 (3.1)	14 (3.8)	9 (2.3)
Pseudomonas	2 (1.2)	0	6 (1.6)
Chromobacterium violaceum	0	42 (11.4)	0
Salmonella	0	30 (8.2)	0
Shigella	0	35 (9.5)	0
Serratia	0	11 (3)	0
Enterobacter	0	25 (6.8)	0
Klebsiella	0	15 (4.1)	0
Total	163	367	384

petroleum and mining industries, industrial production sites, etc. [23]. *Desulfatomaculum*, a thermoplilic anaerobe [24], is one of such SRB and has been previously studied in its role in metal reduction [25]. *Ferro-thiobacilllus*, *Acidithiobacillus* and *Thiobacillus* act as sulfur-oxidizing bacteria where sulfur and its compounds (sulfide, thiosulfate, etc.) are readily oxidized to sulfuric acid [26]. Literature shows that they have been implicated in biogenic sulfide corrosion of underground concrete sewer installations [27]. Additionally, *Ferro-thiobacilllus*, *Acidithiobacillus* are known to cause ferrous iron oxidation [28].

3.2. Physicochemical Analysis of Soil Moisture

The results for temperature, pH, conductivity and DO measurements are presented in Table 2. Temperature values at both depths for the second and third quarters were slightly lower than values for the first and fourth quarters for all sampling locations. These were direct reflections of the climatic season as at time of analysis. The mean temperature for all sample locations was about 27°C. The

Table 2. Temperature, pH, conductivity and DO measurements of soil moisture samples from the study locations at different depths.

Parameter	Time (Quarter)	UNICAL		MSWD		MW	
		0.5 m	1 m	0.5 m	1 m	0.5 m	1 m
Temperature (°C)	1	25.7	25.9	26	26.3	26.7	26.7
	2	30	29.5	28.7	28.8	29.4	29.7
	3	27.6	27.7	26.3	26	27.6	27.8
	4	25.3	25.1	26.1	26.3	26.2	26.4
	Mean	27.1	27.1	26.8	26.9	27.5	27.7
pH	1	6.7	6.7	7.1	6.8	6.4	6.4
	2	7.1	6.4	6.8	6.8	6.7	7
	3	6.9	6.9	6.8	6.9	6.6	6
	4	7	6.9	7	6.8	6.5	6.5
	Mean	6.9	6.7	6.9	6.8	6.6	6.5
Conductivity ($\mu S \cdot cm^{-1}$)	1	12.8	20.1	56.1	553	28.1	125.5
	2	10.9	34.1	40.6	98.8	9.5	37.8
	3	50.4	33.6	70.1	130.5	33.9	64.8
	4	20	38	71	404	35.2	140
	Mean	23.5	31.5	59.5	296.6	26.7	92
Dissolved oxygen (mg/L)	1	1.75	1.6	1.79	1.94	1.75	2.15
	2	0.83	1.33	1.15	2.02	1.19	1.4
	3	2.6	2.13	1.57	1.79	1.37	1.63
	4	1.64	1.71	1.74	1.95	1.82	2.09
	Mean	1.71	1.69	1.56	1.93	1.53	1.82

standard deviations for pH at both depths ranged between 0.07 and 0.39 indicating that there were little differences in the pH irrespective of the sampling time and analysis. The least mean pH was recorded for MW while the other sampling locations had their pH values in the same value range. This could be attributed to the increased activity of the bacteria characterized for the location, particularly the SRB. Generally, the pH values were in the range of slightly acidic to neutral.

Conductivity values were higher in MSWD than for the other sampling locations. The reason is possibly due to the diverse types, nature and composition of items found in the dumpsite. Waste management regulations are not in practice for this dumpsite and as such, all kinds of materials find their way here. The decomposition of these materials may have affected the conductivity of the soil moisture in this location and the conductivity increased with depth as the sample at 1.0 m showed higher values than that of 0.5 m. This observation was also true for UNICAL and MW. The conductivity for the different sample locations follow the trend UNICAL < MW < MSWD. Since the corrosion of metals is an electrochemical process, solutions with higher conductivities are reasonably expected to show higher corrosivity [29] [30]. This therefore means that the results from the conductivity measurement favor the association of MSWD with a higher rate of the buried MS coupons.

The DO concentrations do not show marked variation at both depths. Also, there was no established relationship between the DO concentration and depth. The results were generally lower than the WHO guideline for drinking water (4 mg/L). The low values for DO may indicate high microbial populations that might have enhanced the decomposition of organic waste [17].

Results of analysis for the chemical parameters (nutrients) for all sample locations at both depths are shown in Table 3. Apart from UNICAL, the results for chloride analysis showed higher values for the 0.5 m depth than the 1.0 m depth, suggesting the continuous deposition of chloride-bearing substances, such as sodium, calcium and magnesium chlorides, in the study locations (dumpsite and mechanic workshop) where the soluble contaminants are leached down the soil profile as explained by LaGrega *et al.* [31]. The reverse observation for UNICAL is reasonable as the location is a university campus and the deposition of chloride-bearing compounds is expected to be minimal.

For nitrate and nitrite, mean values recorded were between 0.10 to 0.40 mg/l and 0.07 to 0.11 mg/l, respectively, which are considerably lower than their WHO guideline values of 50 and 0.5 mg/L respectively, suggesting that the nitrate and nitrite levels were not greatly influenced by seasonal changes in the study locations. The low concentration levels could possibly be due to dilution by rainwater or denitrification by microorganisms.

Sulfate analysis showed higher values with depth for both MSWD and MW for all the measurements while UNICAL did not show a defined relationship for the quarterly analysis. In comparison with the WHO guideline value (250 mg/L), sulfate levels for the study locations are well within the accepted range.

Table 3. Chemical parameters (nutrients) of soil moisture samples from the study locations at different depths.

Parameter (mg/L)	Time (Quarter)	UNICAL		MSWD		MW	
		0.5 m	1 m	0.5 m	1 m	0.5 m	1 m
Chloride	1	230	301	450	390	495	340
	2	246	289	342	419	350	368
	3	395	390	427	416	465	420
	4	250	315	487	423	481	374
	Mean	280	324	427	412	448	376
Nitrate	1	0.1	0.1	0.1	0.1	0.1	0.1
	2	0.1	0.1	0.1	0.1	0.1	1.4
	3	0.2	0.2	0.2	0.2	0.1	0.1
	4	0.1	0.1	0.1	0.1	0.1	0.1
	Mean	0.1	0.1	0.1	0.1	0.1	0.4
Nitrite	1	0.05	0.05	0.09	0.07	0.07	0.05
	2	0.08	0.08	0.01	0.06	0.07	0.07
	3	0.19	0.25	0.2	0.15	0.14	0.12
	4	0.04	0.05	0.08	0.1	0.08	0.05
	Mean	0.09	0.11	0.1	0.1	0.09	0.07
Sulfate	1	2.99	2.68	1.61	1.82	1.62	1.66
	2	1.24	1.91	1.52	2.01	1.33	1.45
	3	1.84	2.28	1.89	2.04	1.72	2.55
	4	2.88	2.55	1.55	1.81	1.62	1.7
	Mean	2.24	2.36	1.64	1.92	1.57	1.84

Table 4 shows the results for the analysis of heavy metals. MSWD showed higher values for most of the heavy metals, followed by MW. A possible explanation is the unrestricted deposition of substances which contains these metals in MSWD, the nearness to major roads and the very high commercial activity around both MSWD and MW, and the possibility of accumulation from the different fuels and fuel products including aerial deposition from automobile emission [32] [33]. The high Mn concentration in MSWD is associated with its application in electroplating of automobiles parts which form a substantial composition of the refuse. The heavy metal concentrations mostly increased with depth across the study locations.

3.3. Corrosion Rate

The corrosion rates of buried MS coupons in the different study locations are presented in Figure 1. Generally, the corrosion rates were higher in the first quarter and gradually decreased with time because as the corrosion reaction progressed, the corrosion products hindered the mass transfer of corrosion

Table 4. Chemical parameters (nutrients) of soil moisture samples from the study locations at different depths.

| Heavy metal (mg/L)	Time (Quarter)	UNICAL		MSWD		MW	
		0.5 m	1 m	0.5 m	1 m	0.5 m	1 m
Cd	1	0.024	0.015	0.183	0.265	0.053	0.037
	2	0.029	0.021	0.011	0.043	0.059	0.108
	3	0.07	0.125	0.105	0.099	0.063	0.081
	4	0.018	0.012	0.122	0.196	0.061	0.04
	Mean	0.035	0.043	0.105	0.151	0.059	0.067
Cr	1	0.03	0.05	0.26	0.21	0.04	0.03
	2	0.02	0.18	0.02	0.1	0.11	0.08
	3	0.13	0.1	0.22	0.21	0.07	0.07
	4	0.02	0.04	0.1	0.11	0.04	0.03
	Mean	0.05	0.09	0.15	0.16	0.06	0.05
Cu	1	0.1	0.2	0.4	0.3	0.1	0.1
	2	0.2	0	0.3	0.3	0	0
	3	0	0	0.2	0.1	0.1	0.1
	4	0.1	0.1	0.3	0.3	0.1	0.1
	Mean	0.1	0.1	0.3	0.3	0.1	0.1
Fe	1	0.4	0.6	0.9	0.7	0.7	0.6
	2	3.2	4	1.9	2.2	3.6	3
	3	0.5	0.2	0.8	0.8	0.6	0.6
	4	0.5	0.6	0.8	0.8	0.7	0.7
	Mean	1.2	1.4	1.1	1.1	1.4	1.2
Mn	1	0.09	0.09	0.13	0.11	0.1	0.09
	2	0.13	0.11	0.1	1.12	0.09	0.09
	3	0.09	0.18	0.14	0.13	0.08	0.08
	4	0.08	0.08	0.1	0.1	0.1	0.09
	Mean	0.1	0.11	0.12	0.36	0.1	0.09
Ni	1	0.01	0.02	0.02	0.02	0.02	0.01
	2	0.02	0.01	0.01	0.02	0.01	0.01
	3	0.02	0.02	0.01	0.01	0.01	0.01
	4	0.01	0.01	0.02	0.02	0.02	0.01
	Mean	0.02	0.01	0.01	0.02	0.02	0.01
Pb	1	0.03	0.02	0.15	0.13	0.08	0.06
	2	0.04	0.03	0.07	0.08	0.08	0.07
	3	0.04	0.04	0.11	0.12	0.1	0.12
	4	0.04	0.03	0.15	0.1	0.09	0.07
	Mean	0.04	0.03	0.12	0.11	0.09	0.08
Zn	1	0.3	0.4	1.2	0.9	0.7	0.6
	2	0.3	0.4	0.9	0.9	0.5	0.6
	3	0.2	1.6	0.7	1.1	0.1	0.1
	4	0.3	0.4	1	0.9	0.7	0.6
	Mean	0.3	0.7	0.9	1.0	0.5	0.5
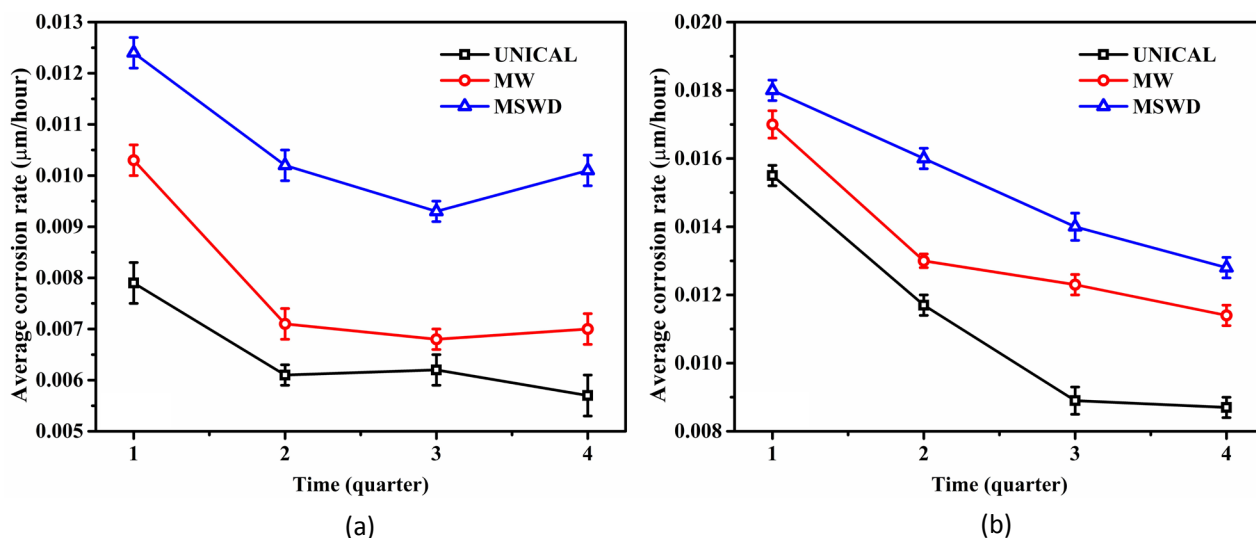
Figure 1. Corrosion rates of mild steel buried in the study locations at (a) 0.5 m depth and (b) 1.0 m depth by weight loss measurements.

causing agents on the metal surface and consequently decreased the average corrosion rates. The corrosion rates were higher in the 1.0 m depth, suggesting that the rate of metal deterioration increases with depth. The corrosion rates for both depths follow the trend UNICAL < MW < MSWD. This means that the corrosion causing agents were more abundant in MSWD and fewer in UNICAL. This is in line with the results of conductivity measurements. For all results of physicochemical parameters, UNICAL showed the least levels and this in turn, impacted its low corrosion rate values. The combined effects of dissolved salts, heavy metals activity and identified microbial species were possibly responsible for the MS corrosion in the different locations.

R-mode factor analysis of the different parameters with varimax rotation resulted in three main factors, representing three significant sources of variation in the soil moisture chemistry, thus affecting the corrosion of the MS coupons. The three factors represent 84% of the variation in the corrosion chemistry of MS. Table 5 shows the factor loadings under the three main factors. The first Eigen value is 9.00 which accounts for 49.99% of the total variance and this constitutes the first and main factor. The second and third Eigen values are 4.04 and 2.08 and these accounts for 22.44% and 11.58% respectively, of the total variance. The first factor is characterized by very high loadings of Cl^-, SO_4^{2-}, Cd, Cr, Cu, Mn, Pb, and Zn. The second factor is mainly associated with high loadings of NO_2^- and NO_3^-, as well as temperature and pH while the third factor is mainly characterized by conductivity and DO.

4. Conclusions

The physicochemical parameters of soil moisture from three locations across Calabar metropolis, namely UNICAL, MSWD, and MW have been reported and their corresponding effects on the corrosion of mild steel buried in the study

Table 5. Factor loadings of the physicochemical parameters of soil moisture for the sampling locations.

Parameter	Factor 1	Factor 2	Factor 3
Temperature	0.44	**0.85**	0.07
pH	0.33	**0.87**	0.08
Conductivity	0.59	0.06	**0.74**
DO	0.16	0.19	**0.91**
Cl^-	**0.86**	0.28	0.3
NO_2^-	0.14	**0.77**	0.04
NO_3^-	0.22	**0.74**	0.24
SO_4^{2-}	**0.77**	0.53	0.22
Cd	**0.9**	0.2	0.3
Cr	**0.83**	0.46	0.12
Cu	**0.79**	0.52	0.12
Fe	0.64	0.38	0.2
Mn	**0.73**	0.32	0.46
Ni	0.08	0.7	0.63
Pb	**0.96**	0.06	0.11
Zn	**0.81**	0.37	0.03
Eigenvalue	9.00	4.04	2.08
% Total Variance	49.99	22.44	11.58
Cumulative Eigenvalue	9.00	13.04	15.12
Cumulative %	49.99	72.43	84.01

locations have been discussed. The following conclusions were obtained:

1) Some vital SRB such as *Desulfatomaculum*, *Ferro-thiobacilllus*, *Acidithiobacillus* and *Thiobacillus* were identified and characterized for MW and they could possibly have been the major contributors to MS corrosion for this study location.

2) Conductivity values for soil moisture follow the trend UNICAL < MW < MSWD, suggesting that the decomposition of dumpsite refuse may have impacted the conductivity levels. Conductivity and DO values increased with depth for MSWD and MW giving an indication of increased corrosion rate of MS with depth for these locations.

3) Apart from chloride analysis with higher values for the 0.5 m depth than the 1.0 m depth, other analysis mostly revealed increased values with depth. This could translate to increased MS corrosion rate with depth.

4) Weight loss measurements confirmed that the corrosion rates of MS coupons were higher for 1.0 m than 0.5 m and for both depths, the corrosion rates followed the trend UNICAL < MW < MSWD.

5) R-mode factor analysis of the physicochemical parameters revealed some

significant factors which contributed to the variation in soil moisture chemistry. The first and main factor was characterized by high loadings of Cl^-, SO_4^{2-}, Cd, Cr, Cu, Mn, Pb, and Zn, and these accounted for 49.99% of the total variance. The second factor accounting for 22.44% of the total variance was characterized by the effect of NO_2^-, NO_3^-, temperature and pH while the third factor was characterized by the effects of conductivity and DO and accounted for 11.58% of the total variance.

Acknowledgements

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