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Evaluating the soil corrosion of Bushehr, Iran, based on a new classification system for corrosive soils

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Abstract

Purpose – The purpose of this study is to develop a new classification system for corrosive soils by considering the most effective factors of metal corrosion in soil environments.

Design/methodology/approach – The classification is based on valuing each factor as its different range effects on soil corrosion. Finally, according to this classification, the soils with corrosion potential are divided into four major groups, including extremely, strongly, moderately and slightly corrosive. A total number of 20 soil samples were taken from Bushehr, Iran, and their corrosion potentials were evaluated.

Findings – Results showed that most samples were within the slightly corrosive group, although these have high contents of soluble salts.

Originality/value – The study's findings could be insightful in mapping of corrosive lands for pipeline works.

Keywords Corrosion classification, Corrosive soil factors, Soil corrosion

Paper type Case study

1. Introduction

The significance of soil potential as a corrosive environment has been investigated by many researchers through the past decades. The fundamental arguments of these studies were to broaden the knowledge about the corrosiveness ability of soils and its factors to reduce the destructive consequences of metal corrosion in the soil environment. Soil corrosion is mainly affected by the following factors: resistivity, moisture content, pH, redox potential, soluble salts, temperature, mineralogy and texture, soil variability and existence of sulphate-reducing bacteria (SRB) and stray current sources (Alamilla *et al.*, 2009; Bushman and Mehalick, 1989; Elias *et al.*, 2000; Bonds *et al.*, 2005; Dillon, 1994; Bhattarai, 2013). Based on some of these factors, there are a few major classifications that determine soil corrosion potential. One of the main classifications is the AWWA ten-point soil evaluation system for ductile-iron pipe systems, known as C105/A21.5; ANSI/AWWA, 1999 (Bonds *et al.*, 2005). Another similar classification submitted by Dillon (1994) divides soil corrosion into four major groups. Both of these classifications consider only five factors of soil corrosion. Although these classifications have good usage in practice, but still there is no comprehensive classification considering all effective factors of buried metals corrosion, because soil corrosion, when compared to that of the atmosphere or seawater, is often more difficult to categorise with regards to both pipe-specific parameters and surrounding soil properties (Ferreira and Ponciano, 2006).

The main purpose of this study is to introduce a new classification system which classifies corrosive soils by considering new investigations in soil corrosion. Some effective factors of soil corrosion, which have not been used in previous classifications, were added to this system. One of the main usages of this classification could be in soil corrosion mapping for different areas regarding the most important factors of buried metals corrosion.

2. Background

As indicated previously, one of the main classification systems for corrosive soils is the AWWA (1999), which has been used widely in many researches and practical works (Palmer, 1989; Ismail and El-Shamy, 2009; Doyle *et al.*, 2003). The ten-point system's evaluation procedure uses information drawn from five tests and observations, including: soil resistivity, pH, oxidation-reduction potential, sulphides and moisture. The points for all five areas are totalled, and if the sum is ten or more, the soil is considered potentially corrosive to an iron pipe and warrants taking protective measures (Bonds *et al.*, 2005). Palmer (1989) studied the characteristics of soils controlling the external corrosion of ferrous pipes with particular reference to the AWWA rating formula. He found that amongst the variables included in the AWWA formula, only resistivity appears to be generally relevant, and the other factors may be pertinent where differences in corrosion rate are experienced with otherwise similar conditions. He proposed that chloride determination and stray current

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evaluation can be useful and informative in such works. Doyle *et al.* (2003) applied the AWWA system to study the corrosion of iron water mains in Toronto, Canada. They found that a qualitative test, such as the one specified in the AWWA standard for soil sulphide content, is insufficient for the purpose of their investigation. Based on the results, they concluded that the AWWA soil corrosiveness scoring system adequately predicts "corrosive" soils, but considerably over-predicts soils as being "noncorrosive". Therefore, it does not adequately distinguish between "corrosive and noncorrosive" soils.

Although the AWWA ten-point system is a quick way to decide about pipeline protection against corrosion, it never intended to quantify the corrosiveness of a soil. There are some limitations to the practical use of this system, such as:

- qualitative scales of factors such as sulphides and moisture content;
- lack of important factors which have significant effects on soil corrosion (such as chloride and sulphate ion content, stray currents); and
- low level of precision in distinguishing between noncorrosive soils and corrosive ones.

3. Materials and methods

3.1 Soil sampling

In this article, a total number of 20 samples were collected from Bushehr, Iran, from different parts near the shoreline, from a depth of approximately 100 cm. Bushehr is a beach located along the Persian Gulf coast of south-western Iran. The chemical and physical properties of these samples were determined by appropriate in situ and laboratory methods. These properties are mentioned as the following sections. Figure 1 shows the location of the studied area on the map.

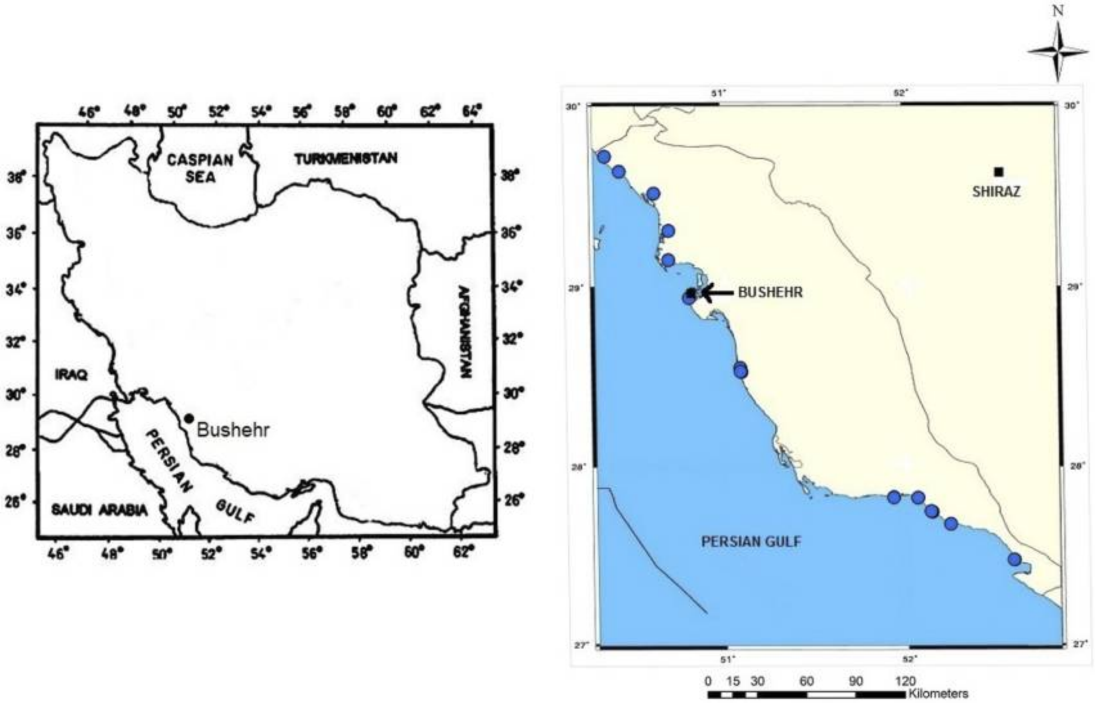
3.2 Moisture content

One of the major soil parameters contributing to buried metal corrosion is the moisture content, because under moist conditions, the soil moisture content is directly related to the corrosion rates and it increases with the increasing moisture content (Bushman and Mehalick, 1989). Although the moisture content is a qualitative factor in the AWWA system, a number of investigations attempt to quantify the critical moisture content required for buried metal corrosion. Gupta and Gupta (1979) estimated that the critical moisture content of soils in the corrosion of mild steel is when it is above 50 per cent of its holding capacity. Ismail and El-Shamy (2009) have shown that 50 to 60 per cent is the optimum moisture content for maximum corrosion. Federal highway administration (FHWA), in its report on corrosive soils (Elias *et al.*, 2000), mentions that where the moisture content of a soil is greater than 25 to 40 per cent, the rate of general corrosion is increased. It also states that the corrosion of mild steel increases when the soil moisture content exceeds 50 per cent of saturation and suggests that maximum corrosion rates occur at saturation of 60 to 85 per cent. Table I shows the relationship between different ranges of moisture content and soil corrosion. The

Table I The relationship between the moisture content and soil corrosion

Moisture content (%)	Corrosion classification	Class
0	Non-corrosive	I
1-25	Slightly corrosive	II
25-50	Moderately corrosive	III
50-60	Severely corrosive	IV
60-85	Very severely corrosive	V

Figure 1 Location of the study area and sampling points (blue points)



moisture content of soil samples was measured by ASTM D-2216 (1999). Moisture contents higher than 85 per cent could be considered as Class V.

3.3 Soluble salts

Significant ions include chlorides and sulphates, and chloride ions are more aggressive. The amount of corrosion that occurs will depend on the quantity of soil moisture. Very dry soils are less corrosive than wet soils, even though both might contain high concentrations of dissolved salts (Rothman and Young, 2005). The presence of increasing concentrations of chloride ions lowers the resistivity of soil, and water acts as a cathode depolariser. Thus, increasing concentrations of chlorides in the soil moisture will increase the corrosion rate (Bushman and Mehalick, 1989; Ismail and El-Shamy, 2009). Tables II and III show the threshold levels of sulphate and chloride ion concentrations for different types of corrosive soils. These factors were measured by AASHTO T-290 (1991) and AASHTO T-291 (1991). Collected samples have high concentrations of chloride and sulphate ion contents. As formerly mentioned, Bushehr is a beach; therefore, the sea water could be the source of high concentrations of soluble salts.

3.4 Resistivity

Resistivity has a reciprocal relationship with corrosion. Resistivity greatly depends on the moisture content, and it will decrease rapidly with an increase in the moisture content until the saturation point is reached, after which further additions of moisture have little or no effect on resistivity (Romanoff, 1957). Other factors influencing soil resistivity are temperature and soluble salt concentrations (Palmer, 1989; Romanoff, 1957). In this research, resistivity was measured by the Wenner four-electrode method (ASTM G-57-06, 2012). Table IV shows the soil resistivity values and corrosion effects.

3.5 pH

The pH of the soil samples was measured according to the ASTM G-51 (1995). The pH values represented by the AWWA system gives the highest score (5) to a pH range within 0 to 2. In fact, this range of pH could be rarely be encountered in natural conditions. In this article, we used the pH ranges prepared by the USDA (1998). Generally, in this classification, it has been mentioned that soils which are either highly alkaline or highly acid are likely to be corrosive to steel. Table V shows the most common pH classes of soil submitted by USDA.

If in one area the soil pH is lower than 3.5 or higher than 9.0, it could be considered as Class IV or III, respectively. Most of the samples had an alkaline pH, which could be because of the high contents of sodium in the Persian Gulf water.

Table II Relationship between soil sulphate ion concentration and its corrosiveness

Sulphate ion concentration (ppm)	Corrosion classification	Class
<150	Mildly corrosive	I
150-1,500	Moderately corrosive	II
1,500-10,000	Severely corrosive	III
>10,000	Very severely corrosive	IV

Table III Relationship between soil chloride ion concentration and its corrosiveness

Chloride ion concentration (ppm)	Corrosion classification	Class
<500	Mildly corrosive	I
500-1500	Moderately corrosive	II
1,500-5,000	Severely corrosive	III
>5,000	Very severely corrosive	IV

Table IV Soil resistivity values and corrosion effects (ASTM G-187, 2012)

Soil resistivity (Ω.cm)	Corrosion classification	Class
>10,000	Very mildly corrosive	I
5,001-10,000	Mildly corrosive	II
2,001-5,000	Moderately corrosive	III
1,001-2,000	Severely corrosive	IV
<1,000	Very severely corrosive	V

3.6 Redox potential

The redox potential is a measure of the degree of aeration in a soil. Very high corrosion rates have been observed in poorly aerated (reducing) soils where anaerobic bacteria often thrive (Escalante, 1989). Starkey and Wight (1945) observed a relationship between redox potential and soil corrosion as shown in Table VI. This factor was measured according to ASTM G-200-9 (2014) .

3.7 Soil texture and minerals

Soil texture is one of the first factors to be considered during corrosion surveys because it determines the degree of aeration and permeability of the soil (Bradford, 2000).

Table V The most common classes of soil pH

pH range	Acidity class	Class
3.5-4.4	Extremely acidic	IV
4.5-5.0	Very strongly acidic	III
5.1-5.5	Strongly acidic	II
5.6-6.0	Moderately acidic	II
6.1-6.5	Slightly acidic	I
6.6-7.3	Neutral	I
7.4-7.8	Slightly alkaline	I
7.9-8.4	Moderately alkaline	I
8.5-9.0	Strongly alkaline	III

Table VI Relationship between redox potential and soil corrosion

Range of soil redox potential (mV)	Classification of corrosiveness	Class
>400	Non-corrosive	I
200-400	Slight	II
100-200	Moderate	III
<100	Severe	IV

Generally, silt and clay are the most corrosive, while gravel and sand are the least corrosive. The Colorado Department of Transportation (Molinas and Mommandi, 2009) determined the corrosiveness of soils based on their texture (Table VII). This factor was measured by ASTM D-2488 (1993). In this article, gravel soils are considered as Class I as shown in Table VII.

3.8 Stray currents

The current may be either direct current (DC) or alternating current (AC) depending upon the source. Although AC can cause corrosion, it is generally considered insignificant (more than a thousand times less) when compared with corrosion from DC (Martinez, 2012). One of the best ways to detect stray currents is to place a stationary data logger to record the pipe to soil potentials for hours or days. WSSC (2008) has determined the different levels of exposure to stray currents, based on the source distance and their potential (Table VIII).

In this article, stray current corrosion potential has been examined based on the existence of stray current sources and their distance to the sampling points. There were two types of stray current sources in the area, including: cathodically protected foreign buried pipes and buried telephone lines.

3.9 Soil variability effects

A pipe passing through differing soil environments can generally be anodic within clay because of the lack of oxygen in clay soils and cathodic in loamy soils (greater aeration). This results in the formation of a "corrosion cell" (Bradford, 2000). These corrosion cells could occur where a soil facies gradually changes into another. Table IX shows the effect of the soil facies changes on the corrosion cell quality.

Table IX The effect of soil facies changes on corrosion

Soil facies changes	Corrosion cell
Loam to clay	Weak
Sand to loam	Moderate
Sand to clay	Strong

Table VII Corrosiveness of soils

Soil type and class	Description of soil	Aeration	Drainage	Colour	Water table
I – Lightly corrosive	Sands or sandy loams Light-textured silt loams Porous loams or clay loams thoroughly oxidized to great depths	Good	Good	Uniform colour	Very low
II – Moderately corrosive	Sandy loams Silt loams Clay loams	Fair	Fair	Slight mottling	Low
III – Badly corrosive	Clay loams Clays	Poor	Poor	Heavy texture Moderate mottling	2-3 feet below surface
IV – Unusually corrosive	Muck Peat Tidal marsh Clays and organic soils	Very poor	Very poor	Bluish-grey mottling	At surface: or extreme impermeability

Table VIII Different levels of exposure to stray currents

Exposure level to stray currents	Pre-construction survey and test results	Class
No exposure	No stray current detected during testing Metrorail lines are beyond 500 feet away from the pipeline Cathodically protected foreign utility buried pipes and cables are more than 500 feet away from the pipeline	I
Moderate exposure	Moderate or sporadic stray current that results in 50 mV or less potential variation (any source) Metrorail lines that are within 200 to 500 feet of the pipeline Cathodically protected foreign[aa] buried pipes or cables that are within 100 to 500 feet of the pipeline and have a ground bed within 2,000 feet or that cross the pipeline and have a ground bed over 2,000 feet away	II
Severe exposure	Continual stray current that results in more than 50 mV potential variation (any source) Metrorail lines that are within 200 feet of pipeline Future/proposed extension of Metrorail lines within 500 feet of pipeline Cathodically protected foreign buried pipes or cables that cross or come within 100 feet of the pipeline and have a ground bed[a] within 2,000 feet	III

Notes: [a] Ground bed = refers to impressed current cathodic protection anodes; [aa] Foreign = refers to another buried utility pipe or cable

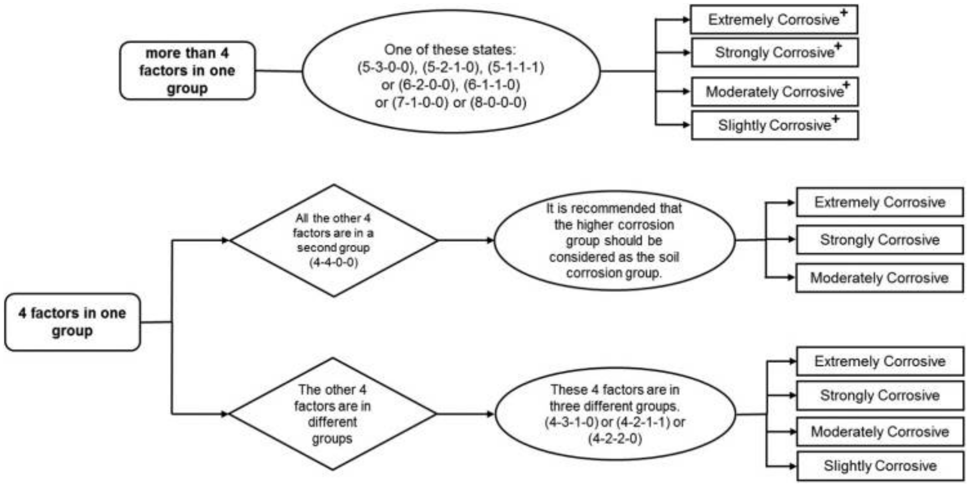
Table X Physicochemical properties of samples

Sample no.	Moisture content (%)	SO_4^{2-} (ppm)	Cl^- (ppm)	Resistivity (Ω.cm)	pH	Redox potential (mV)	Soil type	Stray currents class
B1	7.4	4,900	2,500	31,100	8.25	342	SM	I
B2	14.22	2,300	4,300	5,400	8.26	215	ML	I
B3	14.01	4,200	7,300	5,300	7.80	203	ML	I
B4	20.34	25,000	900	1,100	7.20	76	CL	III
B5	13.22	8,400	3,500	4,700	7.30	248	ML	II
B6	18.00	6,400	1,900	2,300	7.80	−16	CL-ML	II
B7	15.64	3,600	5,400	4,600	8.20	187	ML	II
B8	7.24	2,800	3,200	41,000	8.60	364	SM	III
B9	10.20	7,200	400	32,200	6.32	302	SC	I
B10	8.12	9,300	5,800	24,000	8.30	332	SM	II
B11	9.40	5,400	3,100	29,500	8.65	307	SM	II
B12	29.14	4,800	2,600	800	5.25	−32	CL	I
B13	8.62	7,500	4,500	46,100	8.30	358	SM	I
B14	25.62	5,300	2,500	870	6.80	−25	CL	I
B15	6.32	3,700	2,100	36,000	8.30	366	SM	II
B16	8.21	3,200	7,600	30,200	8.11	387	SP	II
B17	22.47	3,600	480	1,600	9.45	103	CL	I
B18	3.84	2,100	600	27,800	5.65	457	GC	I
B19	9.31	16,400	3,600	25,500	5.25	301	SM	I
B20	36.31	14,800	8,200	620	8.80	−55	CL	II

Table XI Soil corrosion classification based on seven factors

	Soil corrosion groups			
Soil factors	Extremely corrosive	Strongly corrosive	Moderately corrosive	Slightly corrosive
1. Moisture content	V	IV	III	II or I
2. Soluble salts				
SO_4^{2-}	IV	III	II	I
Cl^-	IV	III	II	I
3. Resistivity	V	IV	III or II	I
4. pH	IV	III	II	I
5. Redox potential	IV	III	II	I
6. Soil texture and minerals	IV	III	II	I
7. Stray currents	–	III	II	I

Figure 2 Flowcharts of the soil corrosion system



4. Results

To verify the physicochemical properties of the samples, 20 soil samples were collected from different points along the Persian Gulf beach in the Bushehr Province. The results are shown in Table X.

5. Discussion

Of the most effective factors contributing to metal corrosion in the soil environment, eight have been chosen to establish a new classification system for soil corrosion. Four groups of soil corrosion have been determined by using these factors (Table XI), including extremely, strongly, moderately and slightly corrosive. The classification is simply done by valuing each factor as its different range effects on corrosion.

From eight major factors mentioned above, each soil with any conditions has at least seven of them (considering soluble salts as one factor), as shown in Table XI. In this classification, only the presence of the four factors in one group is enough to be considered as that specific kind of corrosion group. Now if this group has more factors, its corrosion group could be expressed by a plus sign ($^{+}$) above it, which means the metal corrosion in this area could be more severe than that in other areas without the additional factors. For example, the corrosion group for a clayey soil with a pH range within 4.5-5.5, moisture content of 40 per cent and chloride content

Figure 3 Flowcharts of the soil corrosion system (continue)

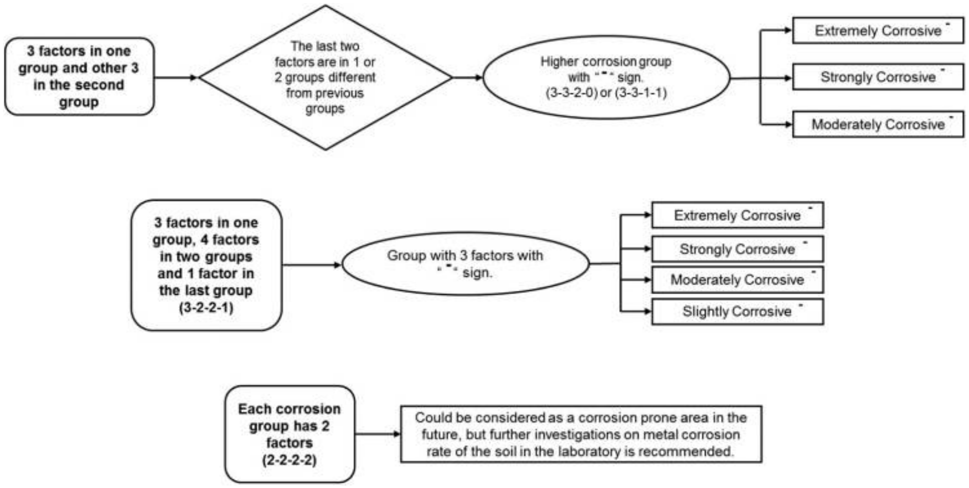


Table XII Corrosion groups of samples

	Factors in each group				
Sample no.	**Extremely corrosive**	**Strongly corrosive**	**Moderately corrosive**	**Slightly corrosive**	**Corrosion group**
B1	0	2	1	5	Slightly corrosive^{+}
B2	0	2	3	3	Moderately corrosive^{-}
B3	1	1	3	3	Moderately corrosive^{-}
B4	3	2	1	2	Extremely corrosive^{-}
B5	0	2	4	2	Moderately corrosive
B6	1	2	4	1	Moderately corrosive
B7	1	2	3	2	Moderately corrosive^{-}
B8	0	4	1	3	Strongly corrosive
B9	0	2	2	4	Slightly corrosive
B10	1	1	2	4	Slightly corrosive
B11	0	3	2	3	Strongly corrosive^{-}
B12	2	3	2	1	Strongly corrosive^{-}
B13	0	2	1	5	Slightly corrosive^{+}
B14	2	3	0	3	Strongly corrosive^{-}
B15	0	2	1	5	Slightly corrosive
B16	1	1	2	4	Slightly corrosive
B17	0	5	0	3	Strongly corrosive^{+}
B18	0	1	2	5	Slightly corrosive^{+}
B19	1	1	2	4	Slightly corrosive
B20	4	2	2	0	Extremely corrosive

of 650 ppm, will be "strongly corrosive"; now if some parts of this area have other factors like severe exposure to stray currents, the corrosion group could be expressed as "strongly corrosive$^+$". If in one area, there are less than four factors in one group, this area could be referred to as a corrosive-prone area and classified as a subgroup, which means it can be less corrosive than its major group counterpart. These subgroups could be expressed by a minus sign ($^-$). Other possible conditions are shown as flowcharts in Figures 2 and 3. In these flowcharts, for example, (4-3-2-0) means that four factors are in one group of soil corrosion (Table XI), another group has three factors, the third group has two factors and there is no factor within the ranges of the last group. The corrosion groups of the samples are shown in Table XII.

As shown in Table XII most of the samples are within the slightly corrosive group, although they have high contents of soluble salts, and other factors have been distributed in all groups. Two samples of B11 and B12 were taken from same area. B11 is a sandy soil, which gradually changes into a clay soil (B12) within a few feet. This area could form a strong corrosion cell for buried metal structures because of the different aeration properties of these soils. Only two samples have extremely corrosive potential (B4 and B20), which is mainly due to the high contents of moisture and soluble salts and the vicinity of stray current sources. Other samples are within strong and moderate groups.

6. Conclusions

In this study a new classification system for corrosive soils was formed based on seven factors of soil corrosion. This classification has four major groups of soil corrosion, including extremely, strongly, moderately and slightly corrosive. Every group that has four factors is considered as a major group of the soil corrosion. Subgroups can be expressed by a plus sign ($^+$) or a minus sign ($^-$) as explained in the text.

The results suggest that most samples are within the slightly corrosive group. Although they have high contents of soluble salts, the rest of factors have been distributed in other groups. Only two samples have extremely corrosive potential (B4 and B20), which is mainly due to the high contents of moisture and soluble salts and the vicinity of stray current sources.

The effect of soil variability may not exist everywhere, so it could be considered as an independent factor which could lead to corrosion in more severe conditions because of the corrosion cells effect. In this article, two samples of B11 and B12 could form a corrosion cell in the area.

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