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Investigation on the soil corrosivity towards the buried water supply pipelines in Kamerotar town planning area of Bhaktapur, Nepal

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Soil parameters such as moisture content, pH, resistivity, oxidation-reduction potential, chloride and sulfate ions can give an indication of the soil corrosivity towards the buried-galvanized steels and cast-iron pipelines used to supply the drinking water in Nepal. Present research work was focused to examine such soil parameters collected from Kamerotar town planning area of Bhaktapur district of Nepal. Concentrations of these soil parameters measured in this study are found as: moisture content (18-77%), pH (3.0-9.3), resistivity (11600-71400 ohm.cm), oxidation-reduction potential (87-426 mV vs SHE), chloride (28-135 ppm) and sulfate (20-226 ppm). These soil parameters gave an indication of “moderately corrosive” to “mildly corrosive” behavior of soils on the buried-galvanized steels and cast-iron pipelines used in the study area. It was found a good correlation between the soil resistivity and moisture content as well as the chloride content in soils. The soil resistivity was generally decreased with increasing both the moisture and chloride contents in soils.

Keywords: Chloride & sulfate, Moisture content, Resistivity, Soil corrosion, Oxidation-reduction potential.

1. Introduction

The buried materials like water supply galvanized steel and cast-iron pipelines are corroded due to the corrosive nature of soils. The soil corrosivity towards these buried materials can explain on the basis of two types of soils; one is disturbed soil and the other is undisturbed soil. The disturbed soil is one in which digging, back filling are taking place and oxygen is introduced in such soil. The soil corrosivity towards the buried materials in undisturbed soil is generally negligible as compared with the corrosive nature of the disturbed soil [1]. The difference in the corrosivity of the disturbed and undisturbed soils is mainly attributed to the difference in oxygen content in soils [1,2]. Corrosion rate of the buried materials in the disturbed soil is influenced by number soil parameters (i.e., moisture content, pH, resistivity, oxidation-reduction potential, chloride and sulfate so on) [1-4]. Estimation of these parameters can give an indication of soil corrosivity towards the buried materials.

The buried-pipelines used to supply the drinking water; natural gas and crude oil have been affected by corrosive nature of soils all around the world [5-24]. When a failure of water supply buried–pipelines occurs, there is a high degree of environmental and economic consequences. It has been studied the corrosion behavior of galvanized steels, bare steels and zinc metal in different soils of USA [5,6]. Clayey soils are characterized by fine texture, high water–holding capacity, poor aeration and drainage, and hence the clayey soils are also prone to be potentially more corrosive towards the buried materials than soils of coarse nature such as sand or gravel. On the other hand, well–drained soils are recognized to be less corrosive than poorly drained ones [1,2,3-6]. It has been reported that the corrosion of mild steel increased when the soil moisture exceeds 50% [5,6,8]. Research data strongly suggested that the maximum corrosion rates occur at saturations of 60-85% [5,6,8,17]. Soil structure, permeability and porosity determine the moisture content of a soil. When the moisture content of a soil is in the range of 20 to 40 %, the rate of uniform corrosion of the buried materials is increased [25]. Below this value, a pitting type of corrosion attack is more likely occurs.

Soils have a wide range of acidity/alkalinity, reaching from 2.5 to 10 pH values. The pH 5 or below can lead to extreme general corrosion or premature pitting corrosion of the buried materials [1,2] and hence a neutral pH around 7 of soils is most desirable to minimize the soil corrosion of the buried materials. The soil pH range of 5–8 is not usually considered to be a problem for soil corrosion towards the buried materials such as galvanized steels, cast- iron, zinc coatings and so on [3,4]. The soil pH can also dramatically affect the nature of microbiological activity in soil that can have a large impact on corrosion rates, especially in microbiologically induced corrosion [1].

On the other hand, it has been reported that the soil resistivity decreased with increasing the moisture content [15]. Hence, the corrosive nature of the soils towards the buried materials is increased with increasing the moisture content or decreasing the soil resistivity [6,15]. Therefore, sand and gravel are considered to be less corrosive towards the galvanized steels, because they showed a high resistivity of 6000 ohm.cm or more. On the other hand, clayey and silty soils with the resistivity value less than 1000 ohm.cm are generally considered to be highly corrosive for the buried-galvanized steels [1,23,25,26].

The oxidation-reduction potential (ORP) is a measure of how reduced or oxidized the soil environment is. The measurement of soil ORP is significant to explain the soil corrosivity towards the buried materials, because it determines partially the stability of the materials. In general, an anaerobic soils having ORP value less than about 100 mV vs SHE are not helpful for the formation of oxide layers on the surface of the materials, because the anaerobic soils do not contain any free oxygen which is necessary for the passivation of the buried–iron/steels [25-27]. Furthermore, the presence of excess amounts of free oxygen in soils is generally indicated from the ORP value greater than 100 mV vs SHE [25-27]. Hence, the ORP value of a soil is helpful to indicate whether the soil is corrosive or not towards the buried materials. On the other hand, the soil ORP indicates whether or not a soil is capable of sustaining sulfate-reducing bacteria, which contribute greatly to the corrosion of soil. A low ORP indicates that oxygen content in the soil is low and consequently, the condition is ideal for the proliferation of the sulfate-reducing bacteria, the greater the sulfide content in soils by reducing sulfate to sulfite. This is possible only the ORP is less than zero or negative values. It is meaningful to mention here that the presence of sulfide in soils is not beneficial to the buried-galvanized steels and cast-iron pipelines.

Maslehuddin *et al.* [17] studied the effect of chloride concentration in soil on the corrosion behavior of reinforcing steels in concrete by measuring the corrosion potential and corrosion current density. The result indicated that the corrosion current density increased with increasing chloride concentration in soil. Compared to the corrosive effect of chloride, sulfate is generally considered to be more benign in their corrosive action towards the buried-metallic substances [1,2]. However, the presence of sulfate amounts more than 200 ppm in soils can pose a major risk for the buried-structural materials [23-25], because it can readily be converted to highly corrosive sulfides by anaerobic sulfate-reducing bacteria. It is also meaningful to mention here that a high concentration of sodium sulfate in poorly drained soils makes the soil very corrosive to the buried-structural materials. Soils are generally considered to be "mildly corrosive" if the sulfate and chloride are below 200 ppm and 100 ppm, respectively, for soils with pH of 5–8 and the resistivity greater than 3,000 ohm.cm [1,2,23-25].

The supply of water from water reservoirs to distribution terminal is mostly through the buried-galvanized steels and cast-iron pipelines in Nepal. The buried-galvanized steel and cast-iron pipes, although susceptible to corrosion are widely used in Nepal, because of their low cost and high strength. The study of the corrosion behavior of these buried materials in soil is a major importance for the underground corrosion, because thousands of miles of buried-galvanized steels and cast-iron pipelines are used to supply the drinking water in Nepal. In this context, it is very urgent to investigate the effects of different soil parameters those affect the corrosion behavior on the buried materials.

The main objective of this research work is to investigate the effects of soil parameters to the corrosion of the buried materials like galvanized steel and cast-iron pipelines used to supply the drinking water in Kamerotar town planning area of Bhaktapur, Nepal.

2. Materials and Experimental Methods

Thirty soil samples were collected from Kamerotar town planning area of Bhaktapur, Nepal which is located within the latitude of 27^o 40' 25"-27^o 40' 50" north and within the longitude of 85^o 23' 30"-85^o 24' 20" east as shown in Fig. 1. All soil samples were taken from the depth of about 1 meter from the ground level for the real location of the buried-pipelines for the purpose of the supplying the drinking water. All the soil samples were collected in the months of January to April of 2013. The distance between two samples was taken about 300 to 500 meters. The soil sample was taken in an air tight polyvinyl bag so that the moisture remained same for a period of moisture content analysis in the laboratory.

Moisture content in soil was determined using weight loss method in accordance with the ASTM D4959-07 standards [28]. A digital pH meter was used to determine the pH of 1:2 soil-water suspensions of each soil samples in accordance with the ASTM G51-95 (2012) standards [29]. The conductivity bridge was used to determine the electrical conductivity of the 1:2 soil-water suspensions in accordance with the ASTM G187-05 standards [30]. The soil resistivity (bulk/saturated paste) was calculated from the conductivity. The oxidation-reduction potential (ORP) of the soil samples was measured with the help of a digital potentiometer in accordance with the ASTM G200-09 standards [31]. The platinum wire and saturated calomel electrodes (SHE) were used as working and reference electrode, respectively. The recorded ORP values vs SCE was converted to reference value of the saturated hydrogen electrode (SHE). Argentometric titration was used to determine the amount of chloride content in soil. Chloride content in the 1:2 soil-water suspensions was determined by titrating the soil suspension against standard silver nitrate solution using potassium chromate as an indicator. Gravimetric method was used to estimate the amounts of sulfate content in soil samples. The details of these methods are discussed elsewhere [32-37].

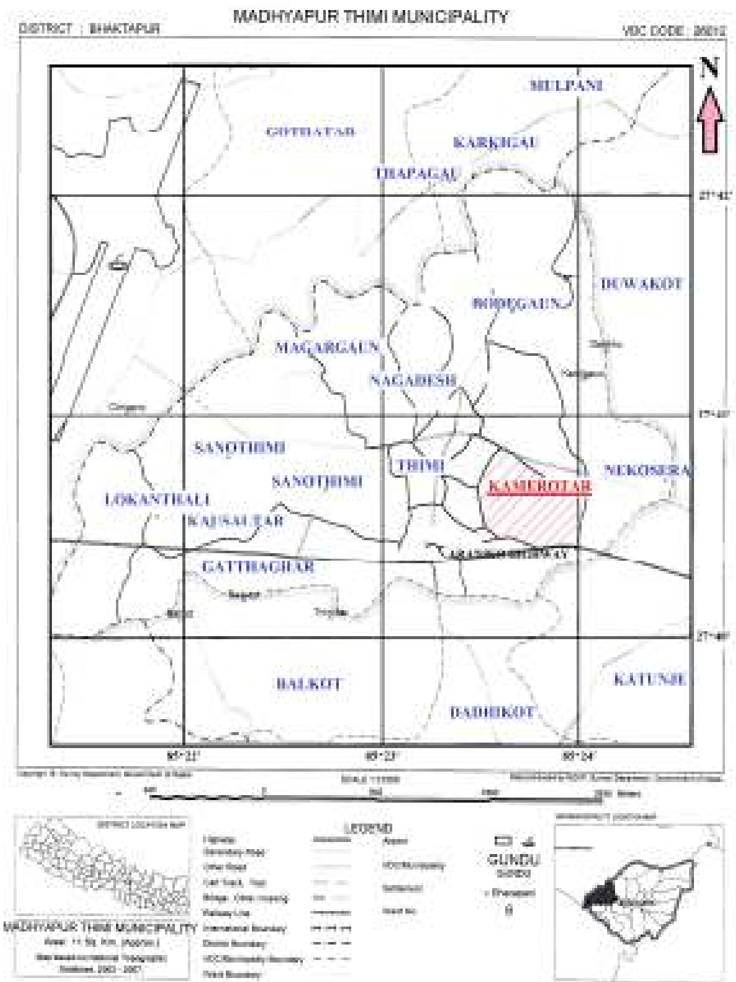

Fig. 1: Location map of the sampling sites of Kamerotar town planning area of Bhaktapur.

3. Results and Discussion

Moisture content in soil

It is found that the moisture content in the collected soil samples ranges from 18-77% which is summarized in Table 1. Among thirty soil samples from Kamerotar area, two soil samples contained 10-20%, twenty samples contained 21-40%, five samples contained 41-60% and only three samples contained more than 60% moisture content as shown in Fig. 2(a). These results revealed that most of the soil samples (22 out of 30 soil samples) are assumed to be "mildly corrosive", while eight samples containing more than 40% moisture content are classified to "moderately corrosive" to "highly corrosive" for the galvanized steels and cast-iron pipes.

Soil pH

pH is another important soil parameter that determine the soil corrosivity towards the buried-galvanized steel and cast-irons pipelines. The pH value of the soil samples collected from Kamerotar town panning area is in the range of 4.0-9.3 as shown in Fig. 2(b). Among thirty soil samples, three samples (i.e., K3, K6 and K16) are highly acidic in nature showing the pH value 4.5 or less than and two samples (i.e., K18 and K28) showed the pH value more than 8.5 as shown in Table 1. Therefore, these five soil samples are assumed to be "highly corrosive "towards the buried- galvanized steel and cast-iron pipelines. On the other hand, ten samples having the pH value in the range of 6.5-7.4 and the remaining ten samples having the pH value in the range of 7.5-8.4 are considered to be "mildly corrosive" and "moderately corrosive", respectively, towards the buried galvanized steel and cast-iron pipes. These results revealed that most of the soils of the Kamerotar town planning area of Bhaktapur are "mildly corrosive" to "highly corrosive" in nature towards the various buried materials.

Table 1: Corrosive parameters of soils collected from Kamerotar town planning area of Bhaktapur, Nepal.

Sample No.	Moisture Content (%)	pH	Resistivity (ohm.cm)	Chloride Content (ppm)	Sulfate Content (ppm)	ORP (mV vs SHE)
K1	22	5.2	71400	39	63	242
K2	73	4.9	17900	121	46	179
K3	65	3.0	14500	135	112	87
K4	49	7.0	32300	46	22	204
K5	29	6.7	27800	80	24	245
K6	38	3.4	33300	53	164	104
K7	28	6.3	58800	39	35	263
K8	25	7.9	45500	46	200	282
K9	28	7.5	47600	46	44	318
K10	44	7.5	38500	55	192	344
K11	22	7.7	50000	43	29	337
K12	54	6.7	34500	43	189	340
K13	30	6.2	45500	57	149	254
K14	34	7.7	43500	57	33	361
K15	34	7.7	29400	65	37	365
K16	22	4.0	71400	28	226	108
K17	43	8.2	43500	54	79	248
K18	24	9.3	41700	50	31	422
K19	24	8.4	37000	43	20	346
K20	21	7.3	50000	47	23	327
K21	24	7.3	37000	71	41	350
K22	28	7.6	25000	75	60	340
K23	77	7.3	11600	130	70	324
K24	18	7.1	45500	46	34	353
K25	18	7.3	71400	50	72	297
K26	30	4.5	62500	40	93	175
K27	39	7.9	40000	68	178	369
K28	55	8.7	33300	53	137	426
K29	23	7.3	52200	45	205	329
K30	30	7.4	28500	66	153	329

Soil resistivity

Figure 2(c) shows the results of the soil resistivity of all thirty soil samples. Among these thirty soil samples, three samples have the soil resistivity between 10,000-20,000 ohm.cm, four samples have

20,000-30,000 ohm.cm, eight samples have 30,000-40,000 ohm.cm, while remaining fifteen samples have more than 40,000 ohm.cm resistivity.

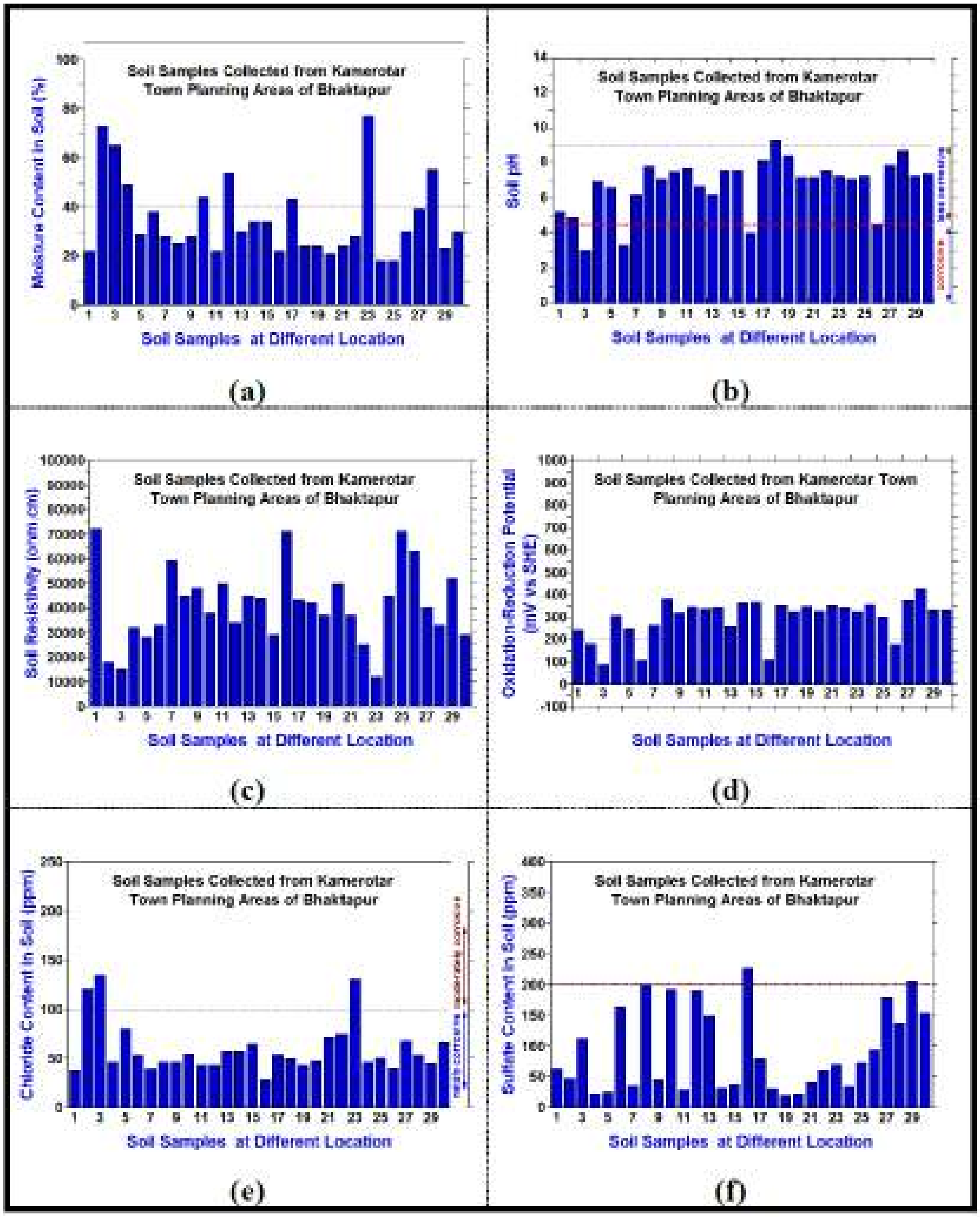

Fig. 2: (a) Moisture content (b) soil pH (c) soil resistivity (d) oxidation-reduction potential (e) chloride content and (f) sulfate content in each soil samples collected from Kamerotar town planning area of Bhaktapur, Nepal.

These results revealed that all soils collected from the Kamerotar town planning area of Bhaktapur are assumed to be "mildly corrosive" to "non-corrosive" nature towards the buried- galvanized steel and cast-iron pipelines used to supply the drinking water from water reservoir to consumer's house. This conclusion is based on the classification of the ASTM and NACE standards (23,25,26). There was a clear correlation between the moisture content and the resistivity of soils. It was found that the soil resistivity was generally decreased with increasing the soil moisture content less than about 40% which is not shown here. These results revealed that 40% or less moisture containing soils are not aggressive for the soil corrosion towards the buried materials.

Oxidation-reduction potential of soil

The oxidation-reduction potential (ORP) value of all thirty soil samples of Kamerotar town planning area is in the range of 87 to 426 mV vs SHE which is given in Table 1. Among these thirty samples, one sample has the ORP value less than 100 mV vs SHE, four samples have in the range of 100-200 mV vs SHE, five samples have in the range of 200-300 mV vs SHE, nineteen samples have in the range of 301-400 mV vs SHE and remaining one sample has the ORP value more than 400 mV vs SHE as shown in Fig. 2(d). These results revealed that most of the soil samples (except K3) are belonged to "moderately corrosive" to "non-corrosive" for the buried-structural materials based on the Johe's classification (Table 3) [24, 27]. The K3 sample has the ORP of 87 mV vs SHE and hence it is assumed to be "severely corrosive".

Chloride content in soil

The chloride content in soil samples collected from the study area is shown in Fig. 2(e). It is found that most of the soil samples except three samples (i.e., K2, K3 and K23) contained less than 100 ppm which is the upper limit of the chloride content in the soil for showing "mildly corrosive" nature towards the buried materials. The samples K21, K3 and K23 contained 121, 135 and 130 ppm chloride, respectively. These values are also not significantly higher than the upper limit of chloride content in soils for showing the "mildly corrosive" nature towards buried materials and hence these three soil samples are assumed to be "moderately corrosive" in nature. Among these thirty soil samples, the chloride content in fifteen samples contained less than 50 ppm chloride, twelve samples contained 50-100 ppm and remaining three samples contained more than 100 ppm chloride. These results revealed that most of the soils of the Kamerotar town planning area of Bhaktapur district are considered to be "mildly corrosive" towards the buried-galvanized steel and cast-iron pipes used to supply the drinking water in the study area. Furthermore, there was a good correlation between the chloride content in soils and soil resistivity (not shown here). It was found that the soil resistivity was increased with decreasing the chloride content in soil. This result revealed that the soil resistivity of Kamerotar town planning area is affected by the chloride content in soil.

Sulfate content in soil

Amounts of sulfate content in soils of Kamerotar town planning area are found in the range of 20 to 226 ppm as tabulated in Table 1. Figure 2(f) shows that nineteen soil samples contained less than 100 ppm sulfate, nine samples contained 100-200 ppm sulfate and remaining two samples contained more than 200 ppm sulfate which is upper limits of the sulfate content in the soil for showing "mildly corrosive" nature toward the buried materials based on the classification of the ASTM and NACE [23,25,27]. These results revealed that most of the soil samples expect two soil samples (i.e., K16 and K29) of the study area are considered to be "mildly corrosive" to "non-corrosive" for the buried-galvanized steel and cast-iron pipelines used to supply the drinking water based on the sulfate content results from the present study.

***Table 2**: Relationship between soil resistivity, chloride, sulfate and soil corrosivity towards the buried materials (23,25,26).*

Soil Parameter	Soil Corrosivity
1. Soil Resistivity (ohm.cm)	
> 20,000	Essentially Non-Corrosive
10,000-20,000	Mildly Corrosive
5,000-10,000	Moderately Corrosive
3,000-5,000	Corrosive
1,000-3,000	Highly Corrosive
< 1,000	Extremely Corrosive
2. ***Chloride Content (ppm)***	
< 100	Mildly Corrosive
3. ***Sulfate Content (ppm)***	
< 200	Mildly Corrosive

***Table 3:** Rating of soil corrosivity based on the oxidation–reduction potential of soils (24,27).*

Oxidation–reduction Potential (mV vs SHE)	Soil Corrosivity
>400	Non–Corrosive
201–400	Mildly Corrosive
100–200	Moderately Corrosive
<100	Severe Corrosive

4. Conclusions

From the above results and discussion on the corrosive nature of the thirty soil samples collected from Kamerotar town planning area of Bhaktapur, following conclusions are drawn.

1. Most of the collected soils (73.3% of 30 samples) contained less than 40% moisture content which is assumed to be "mildly corrosive" nature towards the buried-galvanized steel and cast-iron pipes. Other 26.7% of the total collected samples contained more than 40% moisture content which is assumed to be "moderately corrosive" nature based on the moisture content values.

2. The soil pH value is found to be within the limits of 3.0-9.3 pH for showing "corrosive", "mildly corrosive" and "non-corrosive" towards the buried-galvanized steel and cast-iron pipelines based on the soil pH values.

3. All thirty soil samples showed high soil resistivity (i.e., > 10,000 ohm.cm) which supports the fact that all soils are "mildly corrosive" to "essentially non-corrosive" nature towards the buried materials based on the soil resistivity values.

4. Twenty seven soil samples (i.e., 90% of the total collected samples) except three samples (K2, K3 & K23) having chloride content less than 100 ppm are considered to be "mildly corrosive" in

nature, while three samples having the chloride content more than 100 ppm are considered to be "moderately corrosive" nature based on the chloride content in soils.

5. Twenty eight soil samples (i.e., 93.3% of the total collected samples) except two samples (K16& K29) having the sulfate content is less than 200 ppm are "mildly corrosive" nature, while two soil samples having the sulfate content more than 200 ppm are "moderately corrosive" nature based on the sulfate content in soils.

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