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Study on the Soil Corrosivity towards the Buried-Structures in Soil Environment of Tanglaphant-Tribhuvan University Campus-Balkhu Areas of Kirtipur

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Abstract
Soil parameters such as moisture, pH, resistivity, oxidation-reduction potential, chloride and sulfate ions were investigated, because these parameters affect the corrosive nature of soils toward the buried-galvanized steels and cast-iron pipelines used to supply drinking water in Tanglaphant-Tribhuvan University Campus-Balkhu areas of Kirtipur. The soil parameters examined in the study areas are found as: moisture (7-48%), pH (7.0-7.9), resistivity (6,300-37,000 ohm.cm), oxidation-reduction potential (307-490 mV vs SHE), chloride (13-92 ppm) and sulfate (62-309 ppm) contents. The results gave an indication of mildly corrosive to non-corrosive nature of soils on the buried-galvanized steels and cast-iron pipes used to supply drinking water in the study areas of Kirtipur.

Key words: soil corrosion, moisture content, resistivity, chloride and sulfate contents, oxidation-reduction potential.

Introduction
Corrosive environment is one of the key factors for the corrosion of engineering materials. The buried-materials like galvanized steels and cast-iron are important engineering materials which are widely used to supply drinking water, city gas and petroleum products. The study of the corrosion of these buried-structural materials in soil is of major importance for underground soil corrosion, because millions of miles of the buried-materials are used to supply the drinking water, gas, oil and so on in the world. Corrosion of these buried-structural materials necessitates a huge amount of money for regular maintenance and replacement.

In general, the corrosivity of the buried-structural materials can be explained on the basis of two broad categories of soil environments, they are disturbed and undisturbed soils. The soil corrosivity towards the buried-structural materials in the undisturbed soil is generally negligible as compared with the corrosive nature of the disturbed soil (Uhlig & Revie 1991, Bhattarai 2010 a, 2010 b). The corrosion rate of the buried-structural materials in the disturbed soil is influenced by numbers of soil parameters like moisture content, pH, resistivity, oxidation-reduction potential, chloride, sulfate, sulfide and oxygen contents and so on (Uhlig & Revie 1991, Bhattarai 2010 a, 2010 b). Numerous studies on soil corrosion of the buried-structures have been carried out (Starkey & Wight 1983, Benmoussa *et al.* 2006, Alamilla *et al.* 2009, Ismail & El-Shamy 2009, Yahaya *et al.* 2011, Norhazilan 2012). Estimation of such soil parameters can give an indication of the soil corrosivity towards the buried-structural materials like galvanized steel and cast-iron pipes. It has been reported that the corrosion of galvanized steels, bare steels and zinc after exposure to different soil conditions for a maximum of 13 years in early of 1950s (Denison & Romanoff 1952). Similarly, the most comprehensive data available in the field of underground corrosion are the results of extensive field testing on the buried-metal pipes and steel sheets (Romanoff 1957). It has been reported that the corrosion of mild steel increased when soil moisture content exceeded 40% and suggested that the maximum corrosion rates occur at saturations of 60–85% (Denison & Romanoff 1952). It has been reported that soil resistivity has the largest effect on the observed maximum average pitting corrosion rate on the surface of the buried-pipelines (Schashle & Marsh 1963). Many buried-structural materials, such as galvanized water supply pipelines, natural gas and crude oil pipelines have been corroded by soils all around the world (Levlin 1992, Doyle 2000, Doyle *et al.* 2003, Rim-rukehand & Awalefe 2006, Alhazzaa 2007, Shamsuri 2010). It has been reported that the aggressiveness of soil towards the drinking water supply pipeline used in Toronto city of Canada was affected by soil properties such as resistivity, pH and the presence of sulphate-reducing bacteria (Doyle *et al.* 2003). Study on Nigeria pipeline used to supply crude oil showed that the soil resistivity was found to be decreased with increasing the moisture content and temperature (Rim-rukehand & Awalefe 2006).

Soils having high resistivity (i.e., low conductivity) are generally least corrosive for the buried-structural materials. It has been reported that the sandy and rocky soils have a high resistivity (more than 6000 ohm.cm) and therefore, considered to be mildly corrosive or excellent corrosion resistance for the galvanized steels and cast-iron pipes, while a clayey soil with a resistivity less than 1000 ohm.cm is generally considered to be highly corrosive for the buried-galvanized steels (Uhlig & Revie 1991, Bhattarai 2010 a, 2010 b). The effect of chloride concentration in soil on the corrosion behavior of reinforcing steels was studied (Maslehuddin *et al.* 2007). Compared to the corrosive effect of chloride (Cl^-) ion, sulfate is generally considered to be more benign in their corrosive action towards the buried-metallic substances. However, the presence of sulfate amounts more than 200 ppm in soils can pose a major risk for the structural materials (Robinson 1993, Escalante 1989, Bayliss & Deacon 2002), because it can readily be converted to highly corrosive sulfides by anaerobic sulfate-reducing bacteria. It has been reported that soil is generally considered mildly corrosive if the sulfate and chloride ions are below 200 ppm and 100 ppm, respectively, for soils with pH of 5–9 and the resistivity greater than 5,000 ohm.cm (Uhlig & Revie 1991, Bhattarai 2010 a, 2010 b, Robinson 1993, Escalante 1989).

The city supply water from reservoirs to distribution terminal is mostly through the buried-galvanized steels and cast-iron pipelines in Nepal. The galvanized steels and cast-iron pipes, although susceptible to corrosion are widely used in Nepal, because of their low cost and high strength. In this context, it is very urgent to investigate the effects of different soil parameters that affect the corrosive nature of soils on the buried-galvanized steel pipelines used to supply city water in Kathmandu Valley. The main objectives of this study are to know the effect of soil parameters on the corrosivity of the buried-structural materials like galvanized steels and cast-iron pipelines and to specify the corrosive nature of soil of Tanglaphant-Tribhuvan university campus-Balkhu areas of Kirtipur.

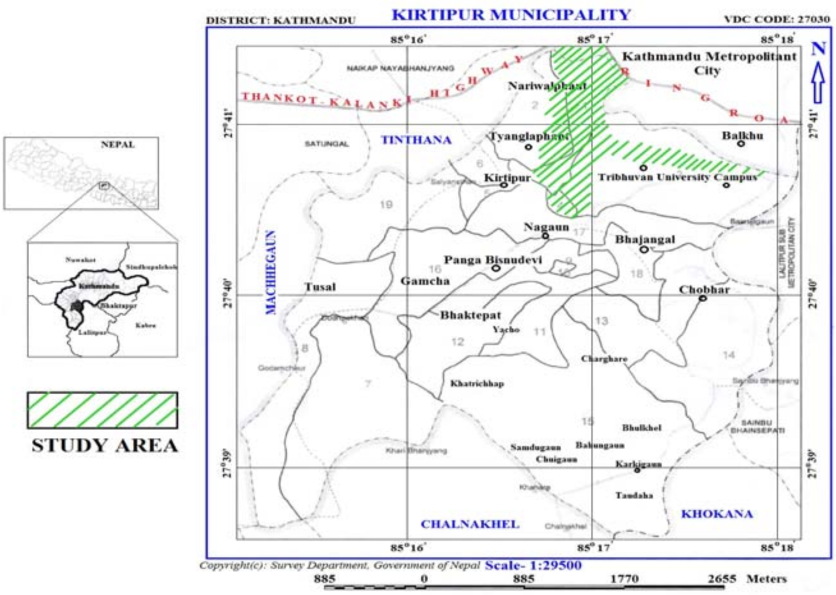

Fig.1. Location map of the sampling site of Tanglaphant-Tribhuvan University Campus-Balkhu areas of Kirtipur

Methodology

Thirty soil samples were collected from the Tanglaphant-Tribhuvan university campus-Balkhu area of Kirtipur which is located within the latitude of 27^{o} 40’ 56"–27^{o} 41’ 30" N and within the longitude of 85^{o} 16’ 45"–85^{o} 18’ 05" E. The sampling area is in the north-eastern part of Kirtipur municipality as shown in Fig. 1. All the soil samples were taken from the depth of about 1 m from the ground level for the real location of the buried-pipelines for the purpose of the supply of drinking water in the months of July 2011 to March 2012. Among thirty soil samples, eleven samples (i.e., TUCB1-TUCB11) were collected from the side of the Nayabazar-Tangla-Sita petrol pump road (Tanglaphanta), ten samples (i.e., TUCB12-TUCB21) were collected from TU main gate to M Phil building (Tribhuvan university campus), while remaining nine samples were collected from Sita petrol pump to Kalanki crossing (Balkhu). The distance between two samples was generally 300 to 500 m the apart. The soil samples were taken in air tight polyvinyl bags so that 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 (ASTM D4959-07 2007). A digital pH meter was used to determine the pH of 1:2 soil-water suspension of each soil sample in accordance with the ASTM G51-95 (2012) standards (ASTM G51-95 2012). The conductivity bridge was used to determine the electrical conductivity of the 1:2 soil-water suspension in accordance with the ASTM G187-05 standards (ASTM G187-05 2005). 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 (ASTM G200-09 2009). 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 suspension 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 all methods are discussed elsewhere (Gautam 2012, Bhattarai 2013a, 2013b, 2013c, Bhandari *et al.* 2013 c).

Results and Discussion

Soil corrosivity is not a directly measurable parameter and the corrosion of the buried-structural materials is largely a random phenomena. This research work is replete with methods and systems that attempt to predict soil corrosivity and resulting the underground structural materials corrosion from different soil parameters of Tanglaphant-Tribhuvan University Campus-Balkhu areas of Kiritpur.

Moisture content in soil

The moisture content in the collected soil samples ranged from 7-48%. Among thirty soil samples, two soil samples contained less then 10%, while twelve samples contained 10-20%, fourteen samples contained 21-40% and only two samples contained more than 40% moisture content as shown in Table 1.

These results revealed that the soil samples holding less than 40% moisture content are probably due to the mixture of sand and clay or sandy soils. These results revealed that most of the soil samples are assumed to be mildly corrosive to non-corrosive towards the buried-galvanized steels and cast-iron pipelines on the basis of the soil moisture content (Table 1). It is meaningful to mention here that soil moisture content greatly affects on the soil resistivity. In general, high amounts of soil moisture content enhanced to increase the electrical conductivity or decrease the soil resistivity. Dry soil shows very high resistivity than that of wet soil and hence dry soil is assumed to be less corrosive than wet soils.

Soil pH

All thirty soil samples collected from the Tanglaphant-Tribhuvan University Campus-Balkhu areas of Kiritpur are neutral or slightly alkaline in nature showing the pH values in the range of 7.0-7.9 as shown in Table 1. Among these soil samples, ten samples were neutral and remaining twenty samples wee slightly alkaline in nature. The results revealed that all thirty soil samples analyzed in this research work are assumed to be mildly corrosive to non-corrosive nature towards the galvanized steels and cast-iron pipelines based on the observed soil pH values. However, pH value is not the only parameter that affects the soil corrosivity towards the buried-galvanized steels and cast-iron pipelines.

Soil resistivity

The soil resistivity is actual bulk resistivity of soil influences by types of soil, moisture content, concentration of different dissolved salts, degree of compactness and temperature so on. Since the soil resistivity was not measured in the sampling sites, all these affecting factors except types, moisture content and dissolved salts are changed from their in-situ values. Hence, in this research work, all efforts were made to insure uniformity among the resistivity tests performed in the laboratory. All soil samples were tested at room temperature at 25^0C which was remained constant and an effort was made to compact the soils to the same degree into the square soil box.

Table 1. Corrosive parameters of soils collected from Tanglaphant-Tribhuvan University Campus-Balkhu areas of Kirtipur Municipality

S.N.	Samples Name	Moisture Content (%)	Soil pH	Soil Resistivity (ohm.cm)	ORP (mV vs SHE)	Chloride (ppm)	Sulphate (ppm)
1	TUCB1	20	7.6	20,800	383	35	110
2	TUCB2	17	7.7	17,900	385	33	110
3	TUCB3	15	7.8	18,500	441	47	82
4	TUCB4	19	7.6	23,800	307	68	67
5	TUCB5	18	7.5	26,300	395	38	82
6	TUCB6	16	7.9	20,800	418	42	102
7	TUCB7	30	7.2	10,200	342	55	192
8	TUCB8	32	7.2	10,400	361	52	165
9	TUCB9	24	7.1	13,200	344	64	137
10	TUCB10	30	7.1	10,000	331	67	137
11	TUCB11	44	7.0	6,330	353	58	110
12	TUCB12	35	7.3	7,250	388	63	165
13	TUCB13	48	7.1	8,060	362	75	137
14	TUCB14	24	7.4	7,940	385	51	219
15	TUCB15	34	7.3	7,460	366	68	165
16	TUCB16	34	7.6	6,670	372	85	192
17	TUCB17	20	7.6	10,000	375	82	247
18	TUCB18	24	7.5	7,580	381	51	137
19	TUCB19	24	7.7	6,940	425	58	282
20	TUCB20	28	7.8	8,770	440	42	302
21	TUCB21	31	7.7	8,470	337	75	274
22	TUCB22	17	7.6	20,800	437	49	82
23	TUCB23	7	7.6	37,000	445	13	70
24	TUCB24	7	7.7	35,700	420	17	62
25	TUCB25	26	7.6	9,170	446	92	225
26	TUCB26	13	7.8	23,800	442	45	147
27	TUCB27	22	7.4	20,400	407	50	165
28	TUCB28	11	7.8	22,700	418	67	77
29	TUCB29	16	7.9	22,200	490	64	89
30	TUCB30	13	7.7	25,600	489	38	165

Table 1 shows the soil resistivity of soil samples collected from Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur. The resistivity of all thirty soils ranges from 6,300 to 37,000 ohm.cm. Among these soil samples, thirteen samples had the soil resistivity between 5,000 and 10,000 ohm.cm, five samples had between 10,000 and 20,000 ohm.cm and twelve samples had higher than 20,000 ohm.cm as shown in Table 1.

These results revealed that most of the soil samples collected from the study areas is mildly corrosive to essentially non-corrosive in nature for the buried-structural materials according to the ASTM (Escalante 1989) and NACE (NACE 1993) classifications based on the bulk soil resistivity values. It is meaningful to mention here that the soil corrosivity towards the buried-structural materials was classified into six groups (that is, essentially non-corrosive, mildly corrosive, moderately corrosive, corrosive, highly corrosive and extremely corrosive) as shown in Table 2 (Robinson 1993, Escalante 1989, NACE 1993).

Oxidation-reduction potential of soil

The measurement of the oxidation–reduction potential (ORP) of soils is significant to explain the soil corrosivity towards the buried–structural materials, because it determines partially the stability of the materials. In general, an anaerobic soils having low ORP less than about 100 mV vs SHE are not helpful for formation of rust/oxide layer on the surface of the materials (Jones 1996). The ORP value of all thirty soil samples collected from the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur is in the range of 307- 490 mV vs SHE as shown in Table 1. Among these soil samples, seventeen samples had ORP values in the ranges of 300-400 mV vs SHE and other remaining thirteen samples had more than 400 mV vs SHE ORP. These results revealed that all soil samples collected from the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur are belonged to mildly corrosive to non-corrosive for the buried-structural materials based on the Johes' classification (also given in Table 3) (Jones 1996).

Chloride content in soil

The contribution of chloride ions to soil corrosivity towards the buried-materials is very significant. The chloride ions also participate directly in pit initiation on the surface of stainless steels. They are not only promoting the pitting corrosion of stainless steels, but also inhibit the passivity of the buried-structural materials (Uhlig & Revie 1991). The chloride content in all thirty soil samples collected from the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur is found to be in the range of 13-92 ppm as shown in Table 1. Among these soil samples, ten samples had less than 50 ppm, while remaining twenty samples had between 50-100 ppm chloride content as presented in Table 1. These results revealed that soils of the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur are considered to be mildly corrosive to non-corrosive towards the galvanized and cast-iron pipelines used to supply the drinking water in the areas, because the soils containing less than 100 ppm chloride content and more than 5000 ohm.cm soils resistivity are categorized as the mildly corrosive to non-corrosive soils towards the buried-structural materials (Robinson 1993, Escalante 1989, NACE 1993).

Sulfate content in soil

Sulfate content in soil is generally harmful for the buried-structural materials, because it participates directly in pit initiation of stainless steels and also increases the soil conductivity. It is reported that soils containing less than 200 ppm of sulfate is considered as "mildly corrosive" (Robinson 1993, Escalante 1989, NACE 1993). Table 1 shows sulfate content in all thirty soil samples which is found less than 200 ppm. Among these soil samples, seven soils contained between 50-100 ppm sulfate, ten samples contained between 101-150 ppm, six samples contain 151-200 ppm, while remaining seven soil samples contained more than 200 ppm sulfate. These results revealed that all soil samples of the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur are considered to be mildly corrosive to non-corrosive towards the galvanized steels and cast-iron pipelines.

In summary, Most of soils of the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur are sandy or mixture of sand and clay which are assumed to be mildly corrosive to non-corrosive in nature towards the buried-galvanized steels and cast-iron pipes. The soil pH value is found to be within the limits of 7.0-7.9 pH for showing mildly corrosive to non-corrosive towards the buried-galvanized steels and cast-iron pipelines.

A very high soil resistivity (i.e., > 5000 ohm.cm) of all thirty soil samples supports the moderately corrosive to essentially non-corrosive nature of soils of the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur. All soil samples have the oxidation–reduction potential values above 300 mV vs SHE, which shows the mildly corrosive to non-corrosive nature of soil towards the buried-galvanized steels and cast-iron pipelines.

All examined soil samples contained less than 100 ppm chloride, less than 200 ppm sulfate and more than 5,000 ohm.cm soil resistivity and hence showed mildly corrosive to essentially non-corrosive nature towards the buried-galvanized steels and cast-iron pipelines used to supply the drinking water in the Tanglaphant-Tribhuvan university campus-Balkhu areas of Kiritpur.

Table 2. Relationship between soil resistivity, chloride and sulphate content and soil corrosivity towards the buried–structural materials (Robinson 1993, Escalante 1989, NACE 1993).

Soil Parameter	Soil Corrosivity Rate
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 (Jones 1996).

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

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