JNCS Journal of Nepal Chemical Society July 2025, Vol. 45, No. 2, 147-156

ISSN: 2091-0304 (print)
DOI: https://doi.org/10.3126/jncs.v45i2.83064
RESEARCH ARTICLE

Durability Judgment of Reinforced Concrete Infrastructures around Butwal Sub-metropolitan City Areas with Corrosion Potential Mapping Method

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(Received: June 20, 2025 revised: August 1, 2025 accepted: August 7, 2025)

Abstract

Reinforced concrete is a commonly used construction material in the modern age; however, premature corrosion of the embedded steel poses a significant challenge. This corrosion can lead to the premature deterioration of structures, including buildings, pillars, bridges, and drainage systems. This study evaluates the corrosion risk of fifty-three steel-reinforced concrete infrastructures (S-RCIs) in Butwal Sub-Metropolitan City, Nepal, using the corrosion potential mapping (CPM) technique. The CPM is a non-destructive, cost-effective electrochemical method that complies with ASTM C876-22b standards. It measures in-situ open-circuit potential (OCP) values of the S-RCIs) to qualitatively categorize the probability of corrosion into three levels: low corrosion risk (LCorR, i.e., <10%), moderate corrosion risk (MCorR, i.e., 10-90%), and high corrosion risk (GCorR, >90%). The findings indicate that the roof samples of residential buildings predominantly fall into the low-risk category, suggesting satisfactory durability. In contrast, fencing pillars, bridges, and drainage pipes show a high likelihood of corrosion, with OCP values indicating a probability of over 90%. Furthermore, the study emphasizes that structures exhibiting visible cracks, signs of delamination, and prolonged exposure to moisture are significantly more susceptible to reinforcement corrosion.

Keywords*:* Concrete infrastructure, Open-circuit potential, Reinforced concrete, Reinforcement corrosion.

Introduction

Concrete remains the most widely used construction material worldwide, appreciated for its high compressive strength and design versatility [1]. Regardless, it lacks adequate tensile capacity, which necessitates the use of steel reinforcement to enhance its structural performance [2]. Reinforced concrete plays a critical role in the construction of essential infrastructure, including buildings, bridges, highways, and marine structures. Yet, the embedded steel is prone to corrosion, a degradation mechanism involving electrochemical, chemical, and microbial interactions [3]. Environmental agents such as chlorides, carbon dioxide, sulfates, acidic water, and industrial pollutants typically trigger this process, which ultimately compromises structural durability through the formation and expansion of rust [4].

Various protection techniques have been developed to counteract reinforcement corrosion [5]. These include cathodic protection, which neutralizes anodic reactions through impressed current or sacrificial anodes, and anodic protection, which is suitable for passivating metals in highly acidic environments [6]. Additionally, surface treatments such as electroplating, galvanizing [7], synthetic chemical pretreatments [8], plant-based phyto-compounds admixtures [9, 10] improve corrosion resistance of reinforced metals in concrete by enhancing surface stability and coating adhesion. Despite concrete consumption exceeding 25 giga-tonnes annually [11], regions like Nepal remain vulnerable to corrosion-related deterioration, particularly in rapidly urbanizing and seismically active areas.

Before the NBC 105:2020 standard practices in the construction of reinforced infrastructures [12], the lack of sufficient durability of many reinforced infrastructures in Nepal necessitated targeted assessments and maintenance. It means NBC 105, which focuses on construction, should consider whether the location is in a seismic zone or not. Steel corrosion in concrete begins at anodic regions where iron atoms oxidize, releasing electrons, and produce ferrous ions. The releasing electrons flow to cathodic zones, where oxygen reduction reactions produce OH^- ions in the presence of moisture.

The ferrous ions produced react with hydroxide ions to form hydrated ferric hydroxide (rust) [13]. This rust increases internal stresses, leading to surface cracking and spalling of the concrete cover of the reinforced concrete infrastructures [14].

Therefore, we can guide on whether the reinforcing metals in concrete structures are corroded or not from simple field observation. Corrosion conditions on the surface of the reinforcing metal in concrete infrastructures can assured from the recorded potential values of the reinforced concrete infrastructures using a simple, easy, and cost-effective corrosion potential mapping (CPM) method.

The CPM method recommends understanding the likelihood of different corrosion conditions of the reinforcing metals from the recorded open circuit potential (OCP) values, as per ASTM C876-22b standard [15]. Although these techniques are largely qualitative, they are effective in preliminary corrosion assessments and are influenced by factors like moisture, oxygen diffusion, and concrete conductivity [16].

Earlier studies had examined the corrosion risk levels of various reinforced concrete infrastructures (i.e., building roofs, building pillars, fencing pillars, sewage pipes, and concrete bridges) of some selected areas of the Kathmandu Valley [17] and the Pokhara Valley [18]. The conditions of the reinforced infrastructures available in other urban cities of Nepal (Butwal, Bhairahawa, Narayanghat, Biratnagar, Janakpur, Bhaktapur, Banepa, and so on) remain under-investigated due to their high exposure to environmental pollutants and rapid urbanization or the process of concrete jungle.

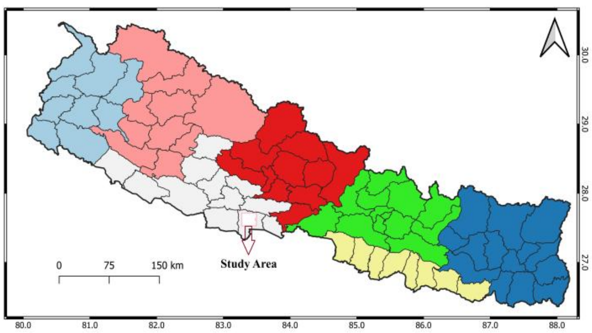
In this context, this research study focused on the application of the CPM method, combined with field observations, to assess the OCP values of reinforced mild steel within various concrete infrastructures (mild steel-reinforced building roofs of residential buildings, fencing pillars, house pillars, concrete bridges, drainage pipes, and safety tanks) situated in the Butwal Sub-Metropolitan city areas of Rupendehi district of Nepal. The primary objective was to ascertain the severity and progression of corrosion, as well as to identify the factors that contribute to it. Prior investigations conducted by Phulara & Bhattarai [17], Laudari *et al.* [18], and Duong *et al.* [19] concluded that specific recommendations are essential for the effective maintenance and retrofitting of corroded reinforced concrete structures. The results of this research aim to bridge existing knowledge gaps and provide valuable insights for the development of more resilient infrastructure designs and management strategies in Nepal.

Materials and Methods

Fifty-three MS-RCIs, available in the Butwal Sub-Metropolitan city areas **(Figure 1)**, were selected for the study and were meticulously assessed by recording their OCP values for forecasting the corrosion probability of reinforcing mild steel rebars in concrete foundations (buildings, bridges, pillars, drainage pipes, and safety tanks). After a careful visual inspection of the physical and morphological characteristics of the samples and sampling sites, the OCP values of four points of each MS-RCI sample surface were recorded using a digital voltmeter (UNI-T model, Hong Kong) under ASTM C876-22b standard [15].

A saturated calomel electrode (SCE) and a reinforced mild steel surface act as a reference and a working electrode, respectively, which were connected to the negative and positive terminals, respectively, of the voltmeter for recording the OCP values, as described elsewhere [20]. Hence, the unit of the recorded OCP is expressed as SCE hereafter.

These fifty-three (53) MS-RCIs were selected and systematically categorized into six primary types based on their structural foundations. These categories comprise steel-reinforced residential building roofs (BuRs), fencing pillars (FnPs), house pillars (HoPs), concrete bridges (CoBs), drainage pipes (DrPs), and safety tanks (SaTs). An investigation managed to assess the corrosion levels of the 53 MS-RCIs by analyzing the recorded OCP associated with each type: 19 BuRs, 9 FnPs, 8 HoPs, 5 CoBs, 9 DrPs, and 3 SaTs. The main aim of present work was to evaluate the likelihood of mild steel corrosion in these reinforced concrete infrastructures and to examine how environmental exposure influences corrosion susceptibility.



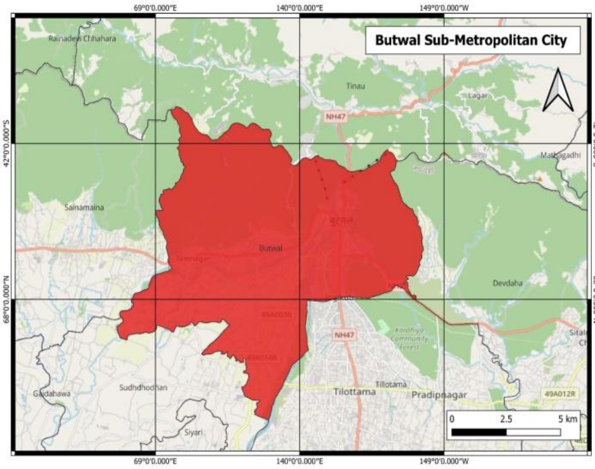


Figure 1: Map of sampling sites around Butwal sub-metropolitan city of Nepal.

Four surface points—labeled SP-1, SP-2, SP-3, and SP-4 were identified on each MS-RCI to achieve a consistent analysis. These predefined sampling surface points allowed for systematic monitoring of potential variations across the surface area of each concrete structure. The use of multiple measurement locations enhanced the reliability of the corrosion assessment, as demonstrated in **Figure 2.**

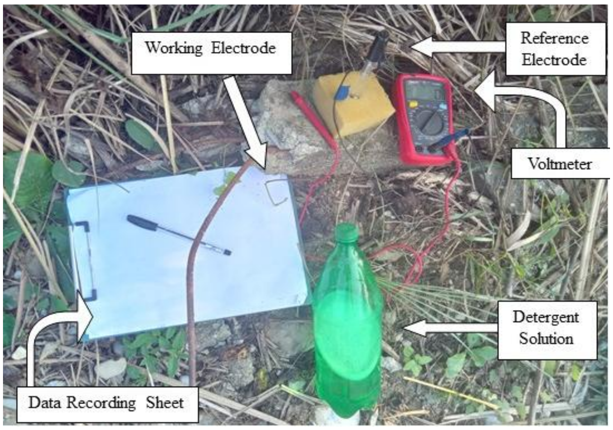


Figure 2: Experimental setup for the measurements of OCP of the reinforced-steel corrosion.

The CPM technique was applied to assess the corrosion probability of MS-RCIs with the measured OCP values as recommended by ASTM C876-22b standard [15], as summarized in **Table 1.**

Table 1: Qualitative prediction of corrosion probability condition of steel-reinforced concrete infrastructures (MS-RCIs), dependent on OCP value [15]

Average OCP (mV vs SCE)	Corrosion Probability Condition of MS-RCIs
More + ve value than -126	Low or <10% corrosion probability (LCorR)
276 -126	Moderate or 10-90% corrosion probability (MCorR)
More - ve than -276	> 90% corrosion probability (GCorR)

Accordingly, the OCP values more positive than −126 mV (SCE) indicates a lesser probability of active corrosion—typically less than 10% (categorized as LCorR). The OCP value within the intermediate OCP range of −276 mV to −126 mV for SCE falls into an uncertain or moderate zone (categorized as MCorR), where the presence of corrosion cannot be definitively confirmed or ruled out. OCP reading more negative than −276 mV suggests a high probability of corrosion activity, with a likelihood exceeding 90% corrosion ((categorized as GCorR).

The corrosion risk of all fifty-three (53) mild steel-reinforced concrete samples based on purposive random sampling techniques was evaluated in the study area using this protocol. The results categorized each structure into one of three levels of corrosion risk. This classification provided a foundational understanding of the severity of corrosion, which will help guide future maintenance strategies and durability assessments for reinforced concrete infrastructure.

Results and Discussion

A total of fifty-three MR-RIC samples were selected from the Butwal sub-metropolitan area to investigate their corrosion probability conditions. This selection was conducted using a non-probability sampling method, specifically convenience or purposive sampling. Detailed information regarding the physical and morphological properties of these MS-RCIs, including their OCP, is presented in **Tables 2, 3, and 4.**

Out of nineteen selected roof samples from urban sub-metropolitan cities (see **Table 2**), most exhibited a low likelihood of corrosion (LCorR) with less than a 10% probability since their average values were more positive than -126 mV. Only three samples (BuR-15, BuR-16 & BuR-17) showed signs of susceptibility to corrosion, likely due to pollution and exhaust emissions, which introduce aggressive pollutants that can cause more corrosion with the appearances of rust staining.

Among the nineteen sampling sites belonging to the BuR category, three building roofs (BuR-15, BuR-16, and BuR-17) exhibited a moderate corrosion risk. The recorded OCP values for these roofs ranged from –126 mV to –145 mV vs. SCE, as detailed in **Table 2**. In contrast, the OCP values for the remaining fifteen BuR samples ranged from –33 mV to –75 mV (SCE), indicating low corrosion risk. According to the ASTM C786-22b (2022) standard classification, the public buildings included in this study have a corrosion damage risk of less than 10%, as illustrated in **Figure 3** also.

Nine fencing pillars (FnPs) and eight house pillars (HoPs) were analyzed using CPM methods to assess their corrosion risk conditions, as summarized in **Table 3.** The recorded OCP values for the eight fencing pillars, except one (FnP-1), are more negative than -125 mV (SCE). It indicates a corrosion probability that ranges from about 10% to over 90%. These results demonstrate that the fencing pillars are more vulnerable to concrete corrosion. In contrast, the HoPs should not have an intermediate or high corrosion risk, as their average OCP values are reported within the low corrosion risk (LCorR) regions, as shown in **Figure 4**. Outcomes suggest that fencing pillars are more susceptible to concrete corrosion compared to concrete house pillars. The increased vulnerability of the fencing pillars is attributed to their direct exposure to corrosive environmental agents, unlike the internal house pillars.

Out of 17 sub-metropolitan concrete structures, which include five bridges (CoBs), nine drainage pipes (DrPs), and three safety tanks (SaTs), only one bridge (CoB-4) and one drainage pipe (DrP-11) can classify as highly corrosion-prone. CoB-4 and DeP-11 have OCP values more negative than -275 mV (SCE), indicating they have a more than 90% probability of corrosion risk (**Table 4**). However, three concrete bridges (CoB-2, CoB-3, CoB-5), six drainage pipes (DrP-6, DrP-7, DrP-10, DrP-12, DrP-13, DrP-14), and two safety tanks (SaT-16, SaT-17) are considered moderately corroded with average OCP values ranging from -126 mV to -275 mV (SCE). The remaining CoB-1, DrP-8, DrP-9, and SaT-15 are in good condition with less than 10% possibilities of corrosion risk, as illustrated in **Figure 5**.

Table 2: *In-situ* measurement of mean OCP, standard deviation (n=4), and corrosion probability of the reinforced building roof (BuR) specimens along with physical observations around the Butwal sub-metropolitan city.

Sampling Site Name	**Physical Description**	OCP-Values		**Corrosion Probability**
		Mean	**SD**	
BuR-1	New; smooth & dry surface; no rust staining; no cracking and spalling	-44.0	2.6	LCorR
BuR-2	New; smooth & dry surface; rust staining; no cracking and spalling	-36.0	5.3	LCorR
BuR-3	New building; rough & dry surface; no rust staining; no cracking and spalling	-56.5	5.0	LCorR
BuR-4	New; smooth & wet surface; no rust staining; no cracking and spalling	-42.8	1.7	LCorR
BuR-5	New; smooth & wet surface; no rust staining; no cracking and spalling	-74.8	2.6	LCorR
BuR-6	New; smooth & dry surface; no rust staining; no cracking and spalling	-69.0	7.3	LCorR
BuR-7	New; smooth & dry surface; no rust staining; no cracking and spalling	-22.0	4.2	LCorR
BuR-8	New; smooth & dry surface; no rust staining; no cracking and spalling	-21.5	6.2	LCorR
BuR-9	New; smooth & dry surface; no rust staining; no cracking and spalling	-75.3	1.7	LCorR
BuR-10	New; smooth & wet surface; no rust staining; no cracking and spalling	-51.8	4.6	LCorR
BuR-11	New; smooth & wet surface; no rust staining; no cracking and spalling	-32.0	4.2	LCorR
BuR-12	New; smooth & wet surface; no rust staining; no cracking and spalling	-66.5	3.4	LCorR
BuR-13	Old; smooth & dry surface; no rust staining; no cracking and spalling	-47.8	5.7	LCorR
BuR-14	Newly; smooth & dry surface; no rust staining; no cracking and spalling	-13.3	3.3	LCorR
BuR-15	Old; rough & wet surface; rust staining; no cracking and spalling	-126.0	4.2	MCorR

BuR-16	Old; smooth & wet surface; rust staining; no cracking and spalling	-135.5	4.4	MCorR
BuR-17	Old; smooth & dry surface; rust staining; no cracking and spalling	-144.5	6.6	MCorR
BuR-18	New; smooth & dry surface; no rust staining; no cracking and spalling	-43.0	4.3	LCorR
BuR-19	Old; smooth & dry surface; no rust staining; no cracking and spalling	-72.5	4.4	LCorR

Table 3: *In-situ* measurement of mean OCP, standard deviation (n=4), and corrosion probability of the reinforced fencing pillar (FnP) and house pillar (HoP) specimens along with physical observations around the Butwal sub-metropolitan city.

Sampling Site	**Physical Description**	OCP-values		**Corrosion Probability**
		Mean	**SD**	
FnP-1	Old; rough & moist surface; rust staining; cracking and spalling	-124.0	3.7	LCorR
FnP-2	Old; rough & moist surface; rust staining; cracking and spalling	-225.0	9.9	MCorR
FnP-3	Old; rough & moist surface (porous); rust staining; cracking and spalling	-205.5	6.6	MCorR
FnP-4	Old; rough & moist surface; rust staining; cracking and spalling	-297.5	2.6	GCorR
FnP-5	Old; rough & moist surface; rust staining; cracking and spalling	-258.5	7.0	MCorR
FnP-6	Old; rough & moist surface (porous); rust staining; cracking and spalling	-210.0	7.0	MCorR
FnP-7	Old; rough & moist surface (porous); rust staining; cracking and spalling	-277.3	7.8	GCorR
FnP-8	Old; rough & moist surface (porous); rust staining; cracking and spalling	-210.3	7.7	MCorR
FnP-9	Old; rough & dry surface (porous); rust staining; cracking and spalling	-163.0	4.3	MCorR
HoP-10	Old; smooth and dry surface; rust staining; no cracking and spalling	-68.0	1.4	LCorR
HoP-11	New; smooth and dry surface; no rust staining; no cracking and spalling	-46.3	1.7	LCorR
HoP-12	New; smooth and dry surface; no rust staining; no cracking and spalling	-75.3	3.1	LCorR
HoP-13	New; smooth and moist surface; rust staining; no cracking and spalling	-64.3	2.2	LCorR
HoP-14	Newly constructing; smooth and dry surface; no rust staining; no cracking and spalling	-64.0	2.6	LCorR
HoP-15	New; smooth and moist surface; rust staining; no cracking and spalling	-63.8	1.7	LCorR
HoP-16	Old; smooth and dry surface; rust staining; no cracking and spalling	-94.0	2.6	LCorR
HoP-17	Old; rough and dry surface (porous); rust staining; cracking and spalling	-184.0	2.6	MCorR

Table 4: *In-situ* measurement of mean OCP, standard deviation (n=4), and corrosion probability of the reinforced concrete beam (CoB), drainage Pipe (DrP) and Safety tank (SaT) specimens along with physical observations around the Butwal sub-metropolitan city.

Sampling Site	Physical Description	OCP-values		Corrosion Probability
		Mean	SD	
CoB-1	New; smooth and wet surface; no rust staining; no cracking and spalling	-115.0	4.0	LCorR
CoB-2	Old; rough and dry surface (porous); no rust staining; cracking and spalling	-150.5	5.3	MCorR
CoB-3	Old; rough and dry; surface (porous); rust staining; cracking and spalling	-163.5	3.9	MCorR
CoB-4	Old; rough and wet surface (porous); rust staining; cracking and spalling	-295.8	4.1	GCorR
CoB-5	Old; rough and dry surface (porous); rust staining; cracking and spalling	-197.3	4.3	MCorR
DrP-6	Old; smooth and moist surface; rust staining; no cracking and spalling	-193.5	7.0	MCorR
DrP-7	Old; rough and moist surface (porous); rust staining; no cracking and spalling	-128.0	2.2	MCorR
DrP-8	Old; rough and moist surface (porous); rust staining; cracking and spalling	-118.5	4.4	LCorR
DrP-9	Old; rough and moist surface (porous); rust staining; cracking and spalling	-122.5	7.6	LCorR
DrP-10	Old; rough and wet surface (porous); rust staining; cracking and spalling	-244.3	6.5	MCorR
DrP-11	Old; rough and wet surface (porous); rust staining; cracking and spalling	-284.0	2.6	GCorR
DrP-12	Old; rough and moist surface (porous); rust staining; cracking and spalling	-259.5	5.9	MCorR
DrP-13	Old; smooth and dry surface rust staining; no cracking and spalling	-127.0	5.9	MCorR
DrP-14	Old; rough and moist surface (porous); rust staining; cracking and spalling	-135.8	4.8	MCorR
SaT-15	New; smooth and moist surface; no rust staining; no cracking and spalling	-27.0	14.5	LCorR
SaT-16	Old; smooth and moist surface; rust staining; no cracking and spalling	-171.8	2.9	MCorR
SaT-17	Old; smooth and moist surface; rust staining; no cracking and spalling	-152.0	2.6	MCorR

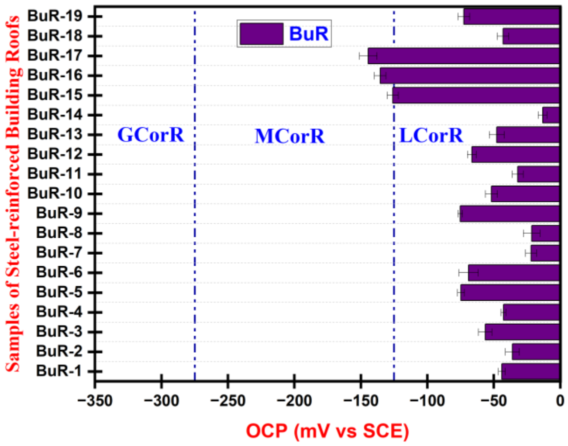


Figure 3: Mean OCP values showing corrosion probabilities of the building roof samples.

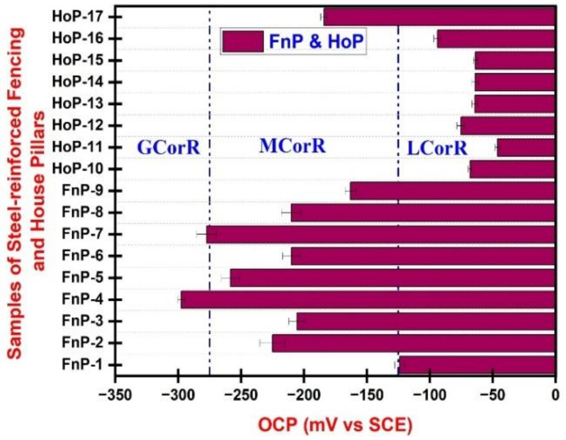


Figure 4: Mean OCP values showing three corrosion probabilities of the fencing and house pillar samples.

These outcomes are summarized in the pie diagrams, as shown in **Figure 6**. Among the nineteen-building roof (BuR) samples, about 84% of samples are considered to be safe with less than 10% corrosion probability, and only 16% of the BuRs are in a moderate corrosion probability zone **(Figure 6(a)).** Similarly, among nine fencing pillars (FnPs) investigated in this study, about 11%, 67%, and 22% of the FnPs are at low (LCorR), medium (MCoR), and greater than 90% (GCoR) probabilities of corrosion risk, respectively, as illustrated in **Figure 6(b).** Furthermore, among the total nine house pillars (HoPs), five concrete bridges (CoBs), nine drainage pipes (DrPs), and three safety tanks (SaTs), about 20% of concrete bridges (CoBs), and about 22% of drainage pipes (DrPs) are at high corrosion risk zone (GCorR) with a greater than 90% probability of corrosion occurs, as displayed in **Figure 6(d) and 6(e)**, respectively. The remaining HoPs (~89%), CoBs (60%), DrPs (~56%), and SaTs (~67%) are located within the MCorR zone with the corrosion risk probabilities between 10% to 90%, except about 11% of HoPs, 20% of CoBs, about 22% of DrPs and about 33% of SaTs, as demonstrated in **Figure 6 (c-f)** respectively.

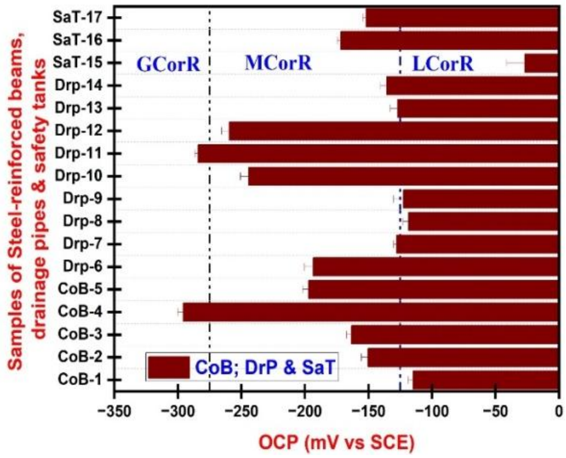


Figure 5: Mean OCP values showing three corrosion probabilities of the MS reinforced concrete bridge, drainage pipe and safety tank samples.

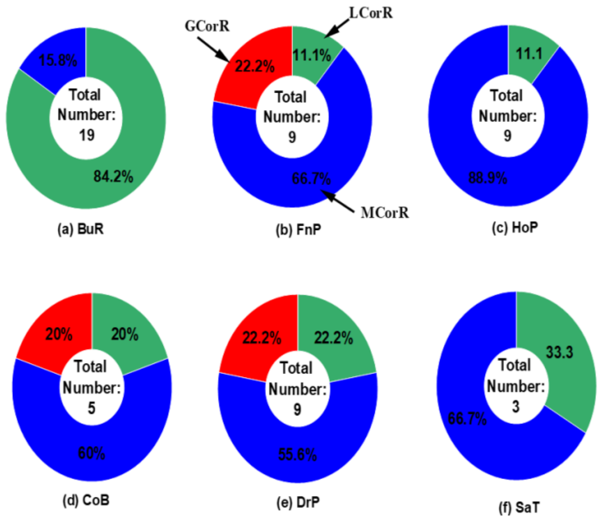


Figure 6: Charts showing three different corrosion probabilities of different categories of S-RCIs around Butwal sub metropolitan city.

These results are in agreement with the result of previous studies by Phulara & Bhattarai [17], and Laudari *et al.* [18], they similarly assessed the durability characteristics of reinforced concrete structures using corrosion potential mapping methods. The research supports the conclusion that this approach of CPM is effective in evaluating structural integrity and identifying potential damage risks.

Conclusion

The corrosion potential of fifty-three MS-reinforced concrete infrastructures (MS-RCIs) located in the Butwal Sub-metropolitan area of Nepal was evaluated utilizing the corrosion potential mapping (CPM) method following ASTM standards. The analysis indicated that fencing pillars are particularly susceptible to corrosion, with a significant number classified as high corrosion risk and uncertain corrosion zones, thereby underscoring the immediate action for protective measures. Furthermore, concrete bridge structures present considerable corrosion concerns, necessitating regular inspections to avert potential structural degradation. Drainage pipes exhibited a high prevalence of uncertain corrosion risk, suggesting the need for continuous monitoring. Safety tanks revealed mixed corrosion levels, indicating that while certain areas may demonstrate stability, others require focused attention in corrosion management planning. In contrast, house roofs and pillars displayed minimal corrosion activity, reflecting enhanced durability and a reduced likelihood of immediate deterioration. The findings of this study suggest that concrete house pillars are more susceptible to corrosion compared to the corrosion risk associated with reinforced concrete house roofs.

Author's Contribution Statement

K. T. K. Magar: Sample preparation, Experiments, Data analysis, Writing: original draft, **Y. Paudel:** Sample preparation, Experiments, Data analysis, Writing: review & editing, **M. Gautam:** Data analysis, Writing: original draft, Writing: review & editing, **N. P. Bhattarai:** Experimental design, Data analysis, Supervision, Writing: review & editing, **J. Bhattarai:** Experimental design, Data analysis, Supervision, Writing: review & editing

Conflict of Interest

The authors claim that they have no competing interests.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding authors upon reasonable request.

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