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Conservation of Heritage Sites in Kathmandu, Nepal: Assessing the Corrosion Threat from Pigeon Excreta on Metal Monuments

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Abstract: Pigeons have long been a common nuisance at numerous cultural sites in the Kathmandu Valley. Besides the health, economic and aesthetic issues caused by the pigeon excreta, this waste may also result in damaging effects to the materials used in Nepalese architecture, including metals such as copper and its alloys. This study assessed the impact of pigeon excreta on the metal-based monuments of cultural importance in the Kathmandu Valley. To test the corrosive effects of the excreta, fresh pigeon excreta were collected from three world heritage sites located around the Kathmandu Valley: Kathmandu, Bhaktapur, and Patan Durbar Squares. Additionally, metal samples, like those used in the monuments (including copper and its alloys bronze and brass), were obtained from metal shops in the surrounding area of Patan Durbar Square. The metal samples were cleaned, weighed, and immersed in pigeon excreta and placed in covered beakers for a duration of 122 days. During this study period, the metal samples were cleaned and weighed at multiple intervals during three designated exposure periods: Short-term duration (<10 days), Medium-term duration (10–42 days) and Long-term duration (42–122 days), to evaluate the degree of corrosion. Analysis of the metal samples showed a significant corrosion loss in copper but not in the alloys bronze and brass, thus indicating a stronger negative impact of pigeon excreta on copper compared to its alloys. Therefore, the use of copper-alloys instead of pure copper in monument renovation could serve as a useful alternative to help minimize the adverse effects of pigeon excreta. These findings provide an important insight in helping to promote the long-term preservation of cultural heritage sites.

Keywords: corrosive effects; Kathmandu Durbar Square; UNESCO heritages; uric acid

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1. Introduction

Outdoor buildings and monuments are exposed to a range of physical, chemical, and biological elements that can degrade the aesthetic and material integrity of the structures [1,2]. Ongoing anthropogenic climate change, natural hazards and human-induced coercions are creating significant problems for the conservation and management of such architectural structures [3–5]. In lower economy countries, because of resource limitations, cities are often overcrowded and human-induced alterations are more intense, thus posing significant threats to important archaeological resources [3,6,7]. Apart from direct and indirect effects of anthropogenic pressures, population explosions of urban-exploiter pests such as pigeons, rodents, ants, fungi, etc. have also become a threat to heritage sites [8–10].

Pigeons are well adapted to living in an urban environment and have become a serious nuisance, resulting in a significant negative impact on an area's ecology, economy, and health [11]. Pigeons can also impact the aesthetics of cultural sites where a buildup of their excreta may damage the materials used in monuments [1,2]. In the Kathmandu Valley, for example, there are a wide variety of cultural heritage sites with temples, stupas, and monasteries, where pigeons have become a problem. The availability of building ledges for roosting with overhangs offering protection from predators and readily available food sources (due in part to human provisioning) has helped in creating an ideal place for a pigeon to live [12]. Pigeon excreta contains highly acidic material and microorganisms which attack metal objects, accelerating corrosion and damage [2,13–15].

In Kathmandu and other locations, copper and its alloys, especially bronze and brass, are known to be very good metals for the construction of statues and cultural monuments [16]. Copper is a very malleable and ductile metal, and its alloys are used for the making of pinnacles, statues, idols, and roofs of many of the cultural sites of Nepal. Pigeons can damage the copper structures in many ways, such as visual staining of the surfaces, chemical damage by acids and soluble salts, and nutrient deposition aiding in biodegradation through different microorganisms [17]. There is mixed opinion regarding pigeon excreta as the agent responsible for damage to the building materials [1]. Experimental studies have shown that bird excrement has a deleterious impact on metals such as copper, bronze, zinc, and other alloys used in monuments [1,17,18]. The damage is seen mostly in the form of metal corrosion [17,18], structural and textural damage, and tarnishing of the metal [1], all leading to a degradation in visual appearance and corrosion loss of the metal.

Most public areas in the Kathmandu Valley, including the UNESCO heritage sites such as Kathmandu Durbar Square, Patan Durbar Square, Bhaktapur Durbar Square, Pashupati Nath Temple, Syawambhu Nath Temple, etc., are densely populated by pigeons. Given that pigeons have become a major pest in the urban areas of Kathmandu and that their abundance is highly concentrated in its heritage sites, it is essential to know the effects of their excreta on the metals used in the monuments and architecture at these sites and the extent of the deterioration it could cause in the future. This study assessed the effects of pigeon excreta on the exposed metal materials used in many of the cultural monuments in the Kathmandu Valley. We hypothesized that the corrosive effects of pigeon excreta is not the same on copper and its alloys; further, the corrosive effects vary with the exposure duration. This study provides a better understanding regarding the extent of the danger that pigeon excreta poses to copper monuments.

2. Materials and Methods

2.1. Sampling Sites

Three cultural sites within the Kathmandu Valley were selected for collecting fresh pigeon excreta: Kathmandu Durbar Square, Bhaktapur Durbar Square, and Patan Durbar Square (Figure 1). A preliminary survey was then conducted at each site to identify optimal collection spots—those areas where the maximum number of pigeons were located (typically where feeding often occurred) (Figure 2). Once the collection spots were confirmed (several at each site), collection of excreta samples commenced for a two-week period, during October 2020. Fresh excreta samples were collected at each spot several times a week for a 30-min period between 9 a.m. and 4 p.m. A plastic spatula was used to scoop up the sample, which was immediately stored in a closed plastic container [1]. A total of 800 g of fresh excreta was obtained. Fresh excreta were used to ensure the validity of the results, as suggested by Balogh, Slížková, and Kreislová [18].

Figure 1. The UNESCO heritage sites within the Kathmandu Valley from where pigeon excreta were collected.

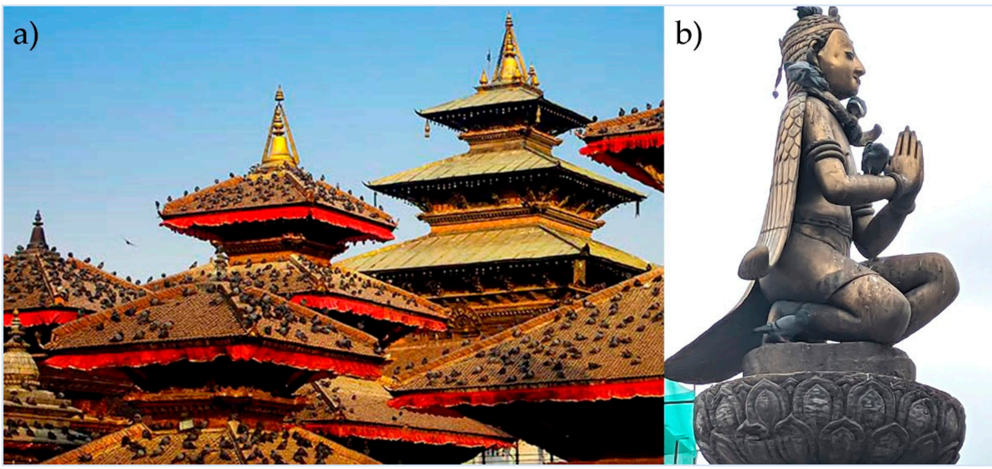

Figure 2. Photos showing pigeons at two of the study sites: (**a**) pigeons on the roof of temples at the Kathmandu Durbar Square; (**b**) pigeons on a metal statue at the Patan Durbar Square, Kathmandu, Nepal (Photos: S. Shrestha; 2020).

2.2. Experimental Design

The experiments (outlined in the Figure 3) were performed in the laboratory of the Central Department of Zoology, Tribhuvan University, Kathmandu from 5 October 2020 to 1 February 2021. The 800 g of pigeon excreta was homogenized in 400 mL of distilled water and 100 mL of the prepared excreta mixture was placed in each of nine clean beakers.

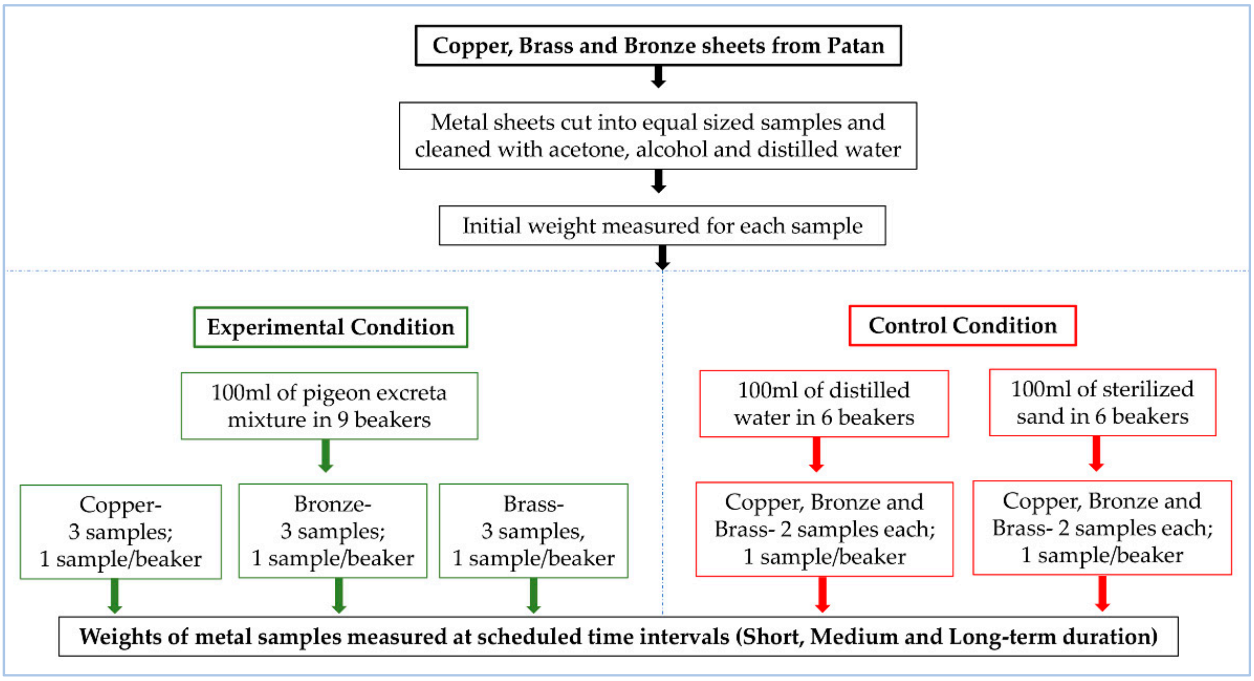

Figure 3. A schematic flow chart summarizing the experimental design.

Sheets of metal, like those used in the local monuments (including copper and its alloys bronze and brass), were obtained from metal shops in the surrounding area of Patan Durbar Square. This area is known for the local craftsmen who still construct monuments using ancient techniques. The metal sheets were cut into small samples of approximately equal dimension (16 mm × 16 mm) and weight (approx. 5 g). They were cleaned with acetone, ethanol, and distilled water to remove external contaminates [19]. The samples were then air-dried, and initial weights were measured using a digital balance (Radwag Wagi Electroniczne, AS 220.R2; [d] = 0.1 mg).

The metal samples were then immersed in the excreta solution in the beakers, as suggested by Balogh, Slížková, and Kreislová [18]. The samples were suspended in the beakers using thread tied to a bamboo stick that was placed across the top of the beaker to prevent the metal samples from making contact with the glass. The beakers were sealed with aluminum foil and left at room temperature throughout the duration of the study. At scheduled intervals of exposure (i.e., 3 days, 7 days, and 10 days—"Short-term duration"; 17 days, 24 days, and 42 days—"Medium-term duration"; and 66 days, 94 days, and 122 days—"Long-term duration"), the metal samples were removed individually from the beakers using tweezers and cleaned by dipping in distilled water followed by rinsing with ethanol to remove any substrate remaining on the metal sample [1,20]. The samples were then air-dried, and weight measurements were taken using the digital balance. Once the measurements were completed, the metal samples were re-immersed in their original beakers.

In addition to the experimental manipulation using the pigeon excreta, a control condition was also implemented, which involved immersing metal samples in two types of control media: (1) a solution of distilled water, and (2) in sterile fine sand. All sampling procedures involving the control samples were the same as in the experimental condition. The experimental condition was replicated three times and the control condition twice.

2.3. Data Management and Analysis

All the metal samples and the beakers were clearly labelled. Initial weights and weight measurement taken at scheduled exposure intervals were recorded and maintained in an excel database. At the completion of the study, the data were summarized and the metal sample weight loss was calculated. For medium-term duration, the final weight of the 10th day was considered as the initial weight, and for the long-term duration, the weight of the samples on 42nd day was considered the initial weight. The percentage loss for each measurement was calculated as follows:

$$\text{Weight loss} = \text{Initial weight of the sample} - \text{Weight of the sample at the time of measurement}$$

$$\text{Weight loss percentage} = \frac{\text{Weight loss}}{\text{Initial weight of the sample}} \times 100$$

The percent weight loss versus exposure duration was graphed for both the metal samples immersed in the pigeon excreta and those in the control conditions with distilled water and sterile fine sand. An analysis of variance (ANOVA, Kruskal-Wallis one-way) was used to compare the weight differences of the metal samples in the experimental and control conditions [19].

3. Results

3.1. General Pattern of Weight Loss in Metal Samples

The rate and amount of weight loss for the copper and its alloy samples (brass and bronze) immersed in the pigeon excreta and control media (distilled water and sterile sand) varied. Weight loss of all metal samples was observed in all media conditions, but the copper samples immersed in the pigeon excreta showed the greatest percent weight loss. Specifically, the copper samples immersed in fresh pigeon excreta showed the greatest loss, with a 0.21% average weight loss compared to only a 0.0019% loss for the copper samples placed in the distilled water. Further, the weight loss in the copper samples was greater than that observed in the brass and bronze samples.

3.2. Weight Loss Patterns among Metal Samples by Study Conditions and Exposure Time

The weight loss of the metal samples immersed in pigeon excreta and control conditions as a function of the exposure time is shown in Figure 4. Maximum corrosion and weight loss were seen in copper, while alloy brass and bronze showed lesser weight loss. Sharp weight loss was seen during the initial time duration of experimentation compared to the later stages of the exposure, but the copper samples showed consistent weight loss in the medium-term exposure duration and a sharp decline during the long-term exposure duration, as shown in (Figure 4a).

In the control medium of sterile fine soil, there was limited change in the weight of metal samples but, compared to bronze and brass, copper showed less weight loss (Figure 4b). Similarly, the change in weight in distilled water was also comparatively less, but bronze showed the greatest weight loss among the samples (Figure 4c). Assessing the statistical significance for the final weight loss of the metal samples in the test for equal means revealed a significant difference among three different metal samples in pigeon excreta and control media (df = 2, 18; F = 6.17, $p < 0.05$).

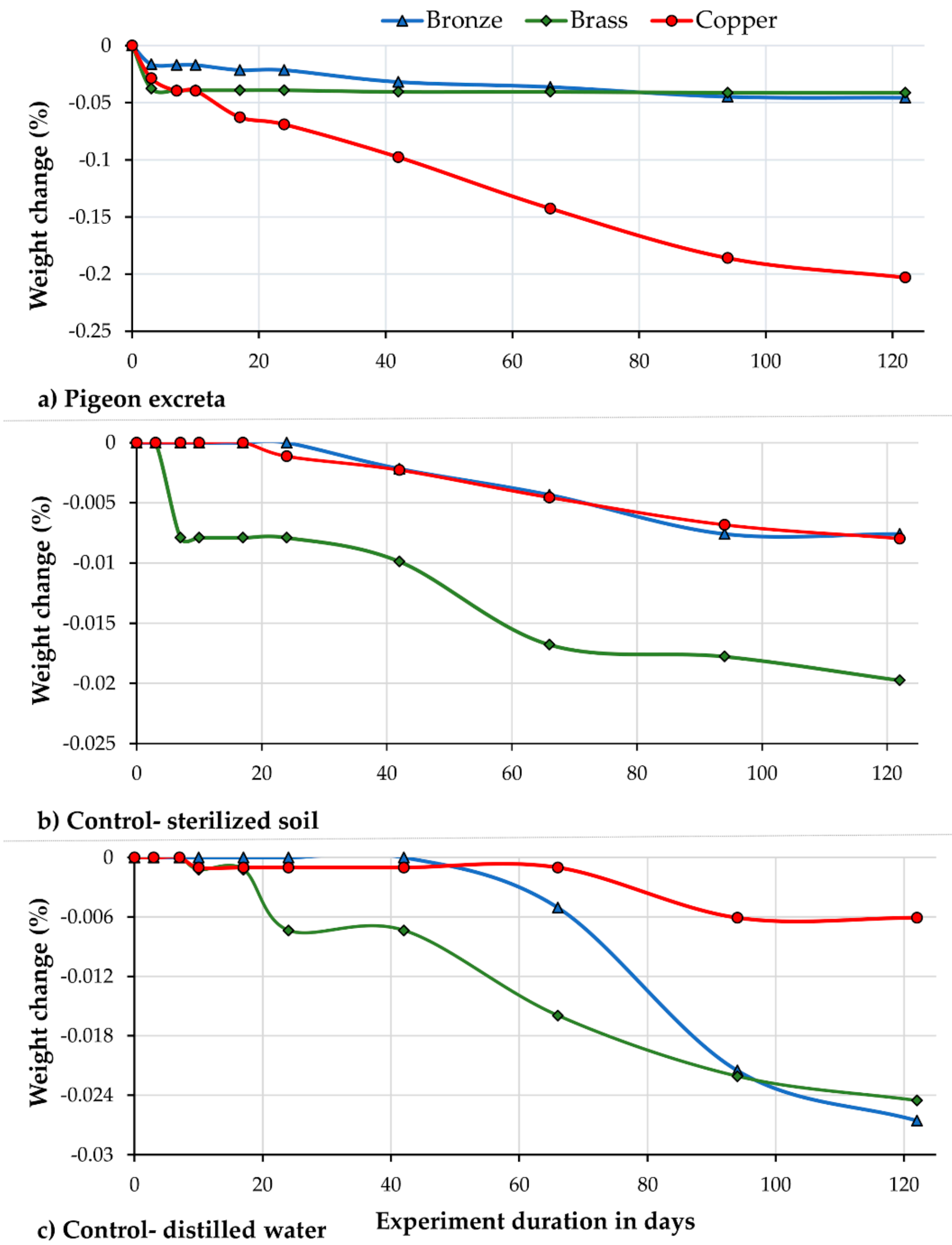

Figure 4. Variation in the average weight loss of the metal samples under different experimental conditions with exposure time in days; (**a**) metal samples immersed in pigeon excreta, (**b**) metal samples immersed in control soil samples, and, (**c**) metal samples immersed in distilled water.

3.3. Weight Loss Pattern of Metal Samples in Pigeon Excreta as a Function of Exposure Duration

In the short-term versus the medium- and long-term exposure of metal samples to the excreta, the results showed a consistent weight loss in all metal samples in the 3rd day, and the weight slowly decreased up to the 10th day (Figure 5a). The loss was greatest in the copper compared to bronze and brass. Compared to the initial weights of the metal samples, copper showed a maximum loss of 0.057%, followed by bronze and brass, with weight losses of 0.045% and 0.44%, respectively.

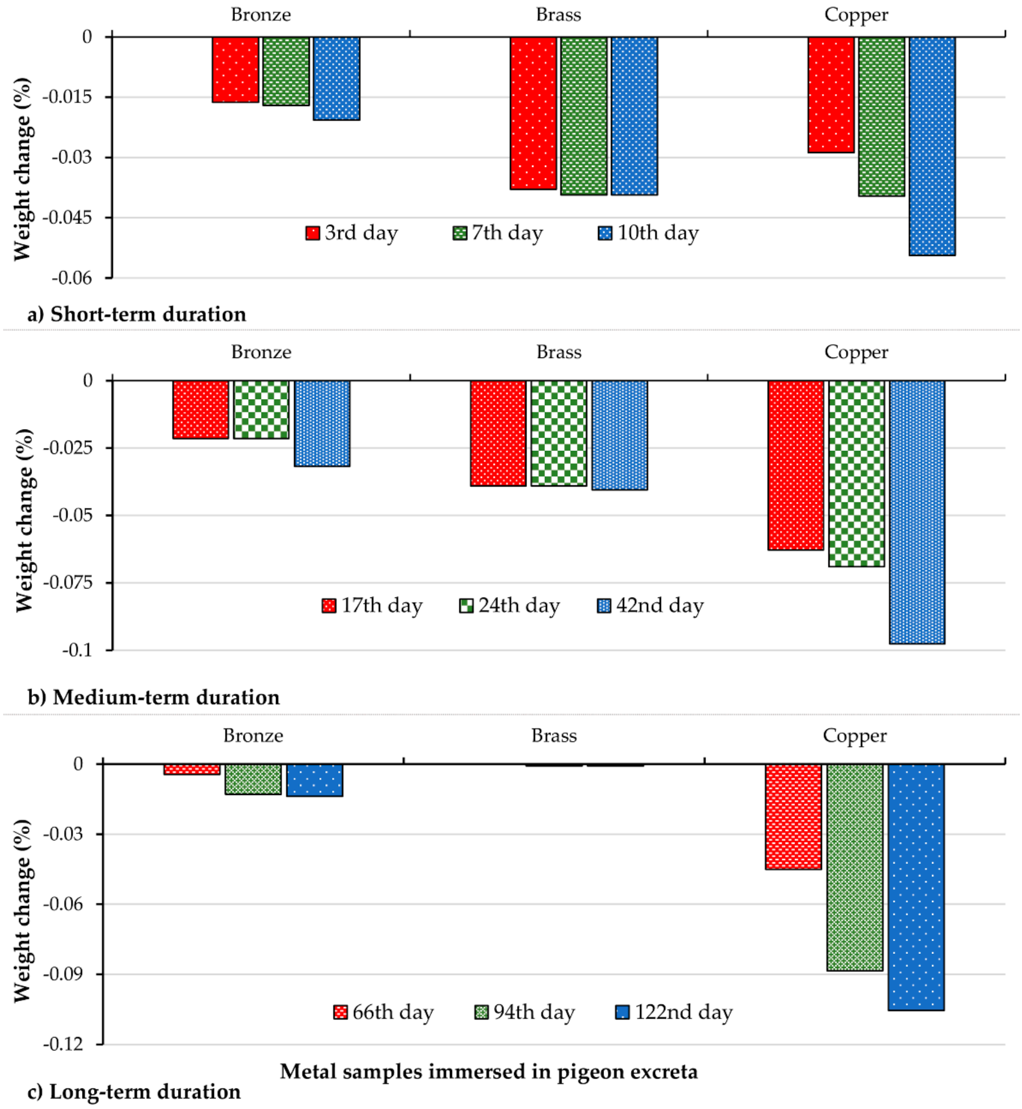

Figure 5. Variation in the average weight loss of the metal samples immersed in the pigeon excreta for different experimental durations; (**a**) for short-term (0–10th day), (**b**) medium-term (10th–42nd day), and (**c**) long-term (43rd–122nd day).

In the medium-term (up to 42 days) and long-term duration exposures (up to 122 days), maximum loss was observed in the copper samples (Figure 5b,c). During the long-term duration, copper showed a maximum loss of 0.094% (bronze 0.017% and brass with 0.002% loss) compared to the weight at the 42nd day. There was the maximum loss of the metal immersed in pigeon excreta in the initial shorter duration and then in the long-term duration compared to the medium duration. The test for equal means for final weight loss at the end of experiment for copper samples showed a statistical difference in different media (df = 2,4; F = 176.7, $p < 0.05$). However, there was no significant loss of weight in brass and bronze samples in different media used for experimentation. The overall weight loss was seen in every sample of metals, but there was a significant difference in the weight loss in copper samples placed in excreta compared to other control media.

4. Discussion

This study assessed the potential corrosion threats of pigeon excreta to the copper and its alloys used in the construction of metal monuments at heritage sites in Kathmandu Valley, Nepal. Our results revealed that the copper experienced the greatest loss of weight compared to its alloys- brass and bronze. This trend was comparable to that found in a past study by Vasiliu and Buruiana [14], who documented the greatest weight loss in copper samples immersed in the diluted pigeon excreta. They also reported a maximum change in mass percentage in copper when the study was conducted for 60 days [14]. The higher percentage weight loss in all samples during this study compared to the previous similar study [14] may be due to the use of fresh excreta samples compared to the dry pigeon excreta, better experimental conditions (enclosed beaker vs. open exposure), and longer exposure time (122 vs. 60 days) for the experiment. The copper samples immersed in the pigeon excreta had the greatest weight loss, but in the control media, copper showed much more resistance to the corrosion with lesser weight loss compared to the bronze and brass samples.

We observed fungal growth on the metal samples immersed in the pigeon excreta, which also was reported by other studies [17,18,21,22]. Such fungal growth is believed to enrich the nutrients in the excreta that facilitates the production of microbes, which in turn increases the acidity of the medium and contributes to acidification and more weight loss. Similar damage such as staining and weight loss seen with the metal sample has also been observed in other studies using different material samples, such as limestone, marble, concrete, wooden structures, automotive clear coat, and steel [23–29]. For example, the negative impact of bird excreta on building materials such as limestone has been reported in a number of studies [26,30,31]. Commonly observed damage includes staining, discoloration, and corrosion. Ramezanzadeh, Mohseni, Yari, and Sabbaghian [25] found that the simulated bird droppings on the protective coating of automobiles had an irreparable effect on appearance due to the etching mechanism of the excreta on the coating material.

Our results showed the greatest weight loss occurring during the short-term duration (0–10th days) and long-term duration (43rd–122nd days) of the study compared to the medium-term duration (10th–42nd days). All the samples immersed in the excreta showed considerable loss during the short-term duration, which contrasted with the results of Vasiliu and Buruiana [14]. They reported minimal change in the weight of the metal samples kept in excreta during the initial exposure duration. This may be due to the use of dry pigeon excreta in their study. For the medium and the long-term exposure duration, weight loss trends were similar to the previous study [13], although we observed a greater overall percentage loss. This might be explained by our experimental design, involving the use of fresh pigeon excreta, and our conducting the experiment for longer exposure durations. We believe it is important to know that the study on the long-term effects of pigeon excreta on the metals are not yet conclusive, as only a few experiments have been performed for longer durations. The visual impact of the excreta on the metal samples was similar to that reported by Balogh, Slížková, and Kreislová [18], where a darker brown color was seen on the copper and bronze. This observation is further supported by other laboratory tests where bird excreta showed a tarnishing of the metal surface of copper and bronze [1,24].

The observed corrosive effects of pigeon excreta on metals and other building materials are mainly subjugated to the presence of various soluble inorganic and organic salts consisting of halite, sylvite, potassium/calcium sulphate, aphthitalite, apatite group minerals, weddellite, and gypsum [30]. The presence of uric acid also has been considered the prime factor for the degradation of building materials [1,14,22,32]. However, Ginez, Espinoza-Vázquez, and Rodríguez-Gómez [28] reported no relation of uric acid to the damaging of bronze. Other studies have acknowledged a relationship between pigeon excreta and the degradation of building materials where the acidity of excreta increased due to urban food sources compared to the natural diet of the birds [10,17]. Ramezanzadeh, Mohseni, Yari, and Sabbaghian [25] illustrated that the cause of damage to the automotive coating was due to hydrolytic reactions as a result of the catalytic effect of the enzymatic structure of the bird droppings. The natural protection layer formed on the surface of copper and its alloys reacts with the uric acid over time, even if it seemed to be protective during the initial phase of the bird droppings [14].

The experimental procedures of other studies, involving bird excreta and metal samples, provided some pieces of evidence regarding the negative influence of excreta on metals such as copper, bronze, zinc, brass, and other alloys used in the monuments [14,18,24,29,33]. Their experimentation used pigeon excreta as a paste rather than opting for immersion in a closed vessel; as a result, the weight loss could not be properly compared, but damage to the structural, textural, and visual appearance of the metal samples, as well as weight loss, were observed in those studies too. After reviewing the experimental design of related publications, we noted variations among the studies that could have affected the results. One of the major shortcomings was noted in collection of the bird excreta, where the samples were collected randomly without considering the species. As multiple species of birds may have lived on the sites and excreted, collecting old and dry droppings can be challenging in identifying the problematic species [1]. Some of the studies were conducted in 100 percent humid conditions [1,24], which does not occur in real-life conditions, especially in areas with distinct seasonality such as in Kathmandu. Apart from the humidity, other environmental factors like temperature, light, and bacterial growth, were also not taken into consideration, and no replication of the experiment was conducted [24]. The materials that were used in the experimentation were of different sizes, shapes, and weight, and the metals were also not cleaned before submerging them in the excreta sample [14]. The impurities in the metal surface might influence the result of corrosion. The experiments involving open exposure to air with no consideration of the evaporation loss in the excreta sample could alter the real results. Spennemann and Watson [17] suggested some extra precautions and measures by which further experimentation could be performed for a better understanding of the effect of bird excreta on building materials. Major past studies used fresh [1,24,26] as well as old, dry excreta [14,23,25,27] in the form of paste and immersion to see the damage it causes to metals, but mostly the immersive liquid form of the bird excreta was advised to perform the laboratory experiment in an enclosed environment [17,18]. For better results, the experiment should be conducted with identified fresh dropping samples of pigeon species, the samples and materials should be kept in the enclosed box with a built-in misting device to control humidity, temperature should be controlled with more control reagents, and there should be more replication of the experimentation for a longer duration of time.

The presence of the fungal, algal, and bacterial growth that helps to enrich the nutrient content in the excreta, which in turn facilitates the increase of acidity and of the staining and corrosion of building materials, is undeniable [15,16,19,20,31], representing a serious concern for the conservation of historical monuments. Very high levels of a single pollutant can lead to damage to these monuments, even if all other conditions are ideal [34]. Therefore, regular cleaning of the wet pigeon excreta and blocking the perching of pigeons represent simple steps in helping to mitigate corrosion effects on historical monuments. We suggest further efforts are needed to investigate, identify, and implement sustainable, bird-safe deterrent techniques to reduce the impact of pigeon excreta on metal monuments

5. Conclusions

The corrosion loss measurement in copper metal and its alloys due to pigeon excreta, investigated in an immersed condition, revealed that copper metal is more susceptible to damage from pigeon excreta exposure than its alloys-bronze and brass. The metal discoloration gave a good visual characterization of the impact of pigeon excreta on copper alloys. The significant difference exists in the final corrosion loss among the metal samples at different medium and exposure durations. Pigeon excreta is confirmed to be the cause of corrosion and damage in copper and its alloys that are used in cultural monuments in heritage sites. This answers the mixed opinion on the question of bird excreta harming different metal monuments.

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supervision, L.K.; project administration, L.K.; funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

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