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Soil Quality Impacted by Brick Kilns in the Agriculture Fields of Kathmandu Valley

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Abstract

Brick kilns are causing environmental concerns due to their emissions and potential negative impacts on soil health and heavy metal accumulation in the agricultural soils. However, there are limited studies reflecting the impacts on agricultural soils due to the operation of brick kilns in the Kathmandu Valley, Nepal. Therefore, this study aims to assess the impact of the kilns on soil quality in Lalitpur and Bhaktapur districts of Kathmandu Valley, focusing on soil parameters pH, nitrogen, phosphorus, potassium, moisture content, organic carbon, and heavy metals (Pb and Zn). Standard methods were followed for the determination of soil quality parameters. Twelve brick kilns (six from each district) were studied, with 36 soil samples (0-15 cm depth) collected at 100 m, 200 m, and 300 m from each kiln. Results showed low levels of organic matter, carbon, nitrogen, potassium, and moisture near the proximity of the brick kiln areas, i.e., in most of the 100 m distance sites compared to 300 m sites. Soil excavation for brick production and kiln emissions are degrading agricultural land, gradually deteriorating key soil fertility over time. Lead (not detectable-32.04 mg/kg) and zinc (22.44-143.16 mg/kg) concentrations in the soil samples were in the commonly observed natural range, and the geo-accumulation index indicated low lead and high zinc contamination. Soil quality parameters were in improved conditions moving the distance from the kilns, suggesting the impact of emissions and nearby soil excavation for brick production. Alternatives to brick uses need to be identified for conserving the fertile top soils of the agricultural lands.

Keywords: *Geo-accumulation index, Kathmandu Valley, Physicochemical parameters, Soil fertility*

Introduction

Soil consists of minerals, organic matter, air, water, microorganisms, fractured rocks, and other constituents shaped by environmental reactions (Edori & Iyama, 2017). It serves as both sink and source for metals and other pollutants, making an essential indication of environmental quality (Karim et al., 2014). Apart from water and air, soil quality is one of the three components of environmental quality (Andrews et al., 2002). Soil is not only the key nutrient-bearing environment for plant life (Bradl, 2004) but also a supplier of many pollutants to plants because plants can uptake toxic substances through their roots from soils (Youssef & Chino, 1991). As the world's population grows, so does the demand for bricks for construction, establishing the brick business as a thriving industry (Skinder et al., 2014). Brick kilns reduce soil fertility by removing topsoil, directly impacting crop productivity and increasing nutrient restoration costs (Bisht & Neupane, 2015). Brick kilns deteriorate soil's physical, biological, and chemical properties, reducing fertility and productivity while depleting organic matter, making it unsuitable for farming (Thapa, 2011). Brick kilns release toxic gases that disrupt natural cycles, like the nitrogen cycle, leading to reduced fertility and nutrient depletion in the soils (Krishna & Govil, 2007). Pollutants like heavy metals, CO, CO_2, SO_2, nitrogen oxides, and VOCs are especially concerning due to their toxicity, non-biodegradability, and buildup over time (Kayastha, 2014). Metals from bottom ash and fly ash around brick kilns spread to nearby soil, altering its structure (Sikder et al., 2016). In recent years, the number of brick kilns in the Kathmandu Valley has grown significantly due to urbanization and higher demand for building materials (Thapa, 2011). Improved knowledge of the soil mining system used to supply brick kilns may reveal options for minimizing the impact on yields from agriculture (Biswas et al., 2018).

Brick kilns have become a serious environmental issue especially in developing countries (Dey & Dey, 2017). In Nepal, 96% of kilns are outdated and use energy intensive and highly polluting technologies causing harmful impacts on health and agricultural yields (from nitrogen oxide) locally and contribute to global warming (Vista & Gautam, 2018) and are mainly concentrated around Kathmandu Valley and in Terai regions. Few studies have been conducted in Nepal to show that brick kilns are responsible for contaminating the environment, the majority of which are based on the measurement of air polluting elements. This study aims to understand the impact of brick kilns on agriculture soils, focusing on soil quality parameters, in the Lalitpur and Bhaktapur districts of Kathmandu Valley.

Materials and methods

Study area

This study was carried out in Kathmandu Valley which lies in Bagmati Province, Nepal. For this study, Lalitpur District and Bhaktapur District of Kathmandu Valley were selected as the study sites (Fig. 1). Lalitpur District is situated in the south-central part of Kathmandu Valley at an altitude of about 1,400 m. It spans 385 km^2 and experiences a relatively moderate temperature with evenly distributed precipitation (MoHA, 2025a). Bhaktapur District, located in the eastern part of Kathmandu Valley, is the smallest district in Nepal, covering an area of 119 km^2 (MoHA, 2025b). The climate in Bhaktapur is characterized by subtropical and temperate conditions.

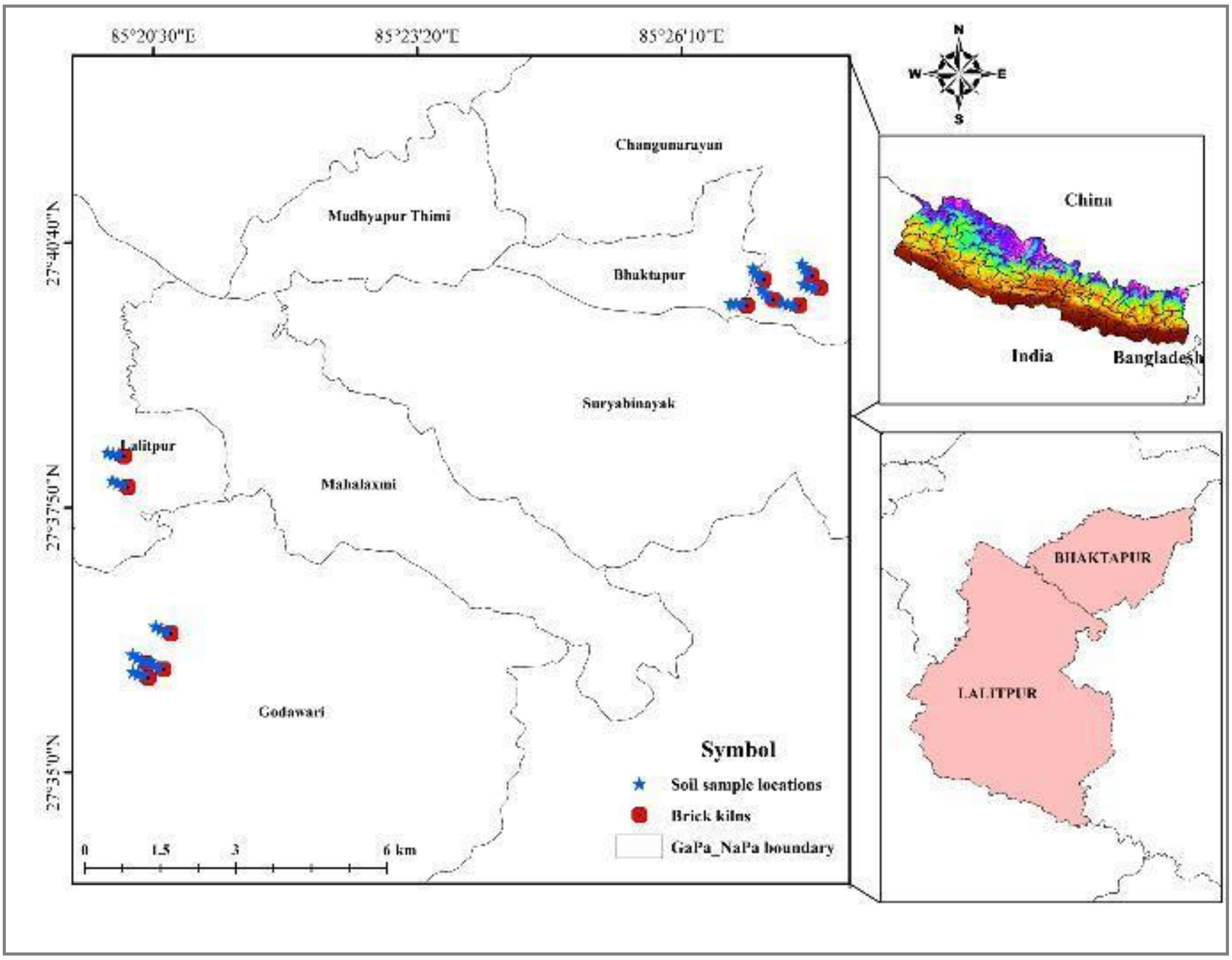

Figure 1: Study area map showing the locations of brick kilns and sampling points

Bhaktapur and Lalitpur districts of Kathmandu Valley have large number of brick kilns along the highly agricultural fields. Sampling sites were in Chapagaun and Harisiddhi of Lalitpur District, as well as Tathali and Faidhoka of Bhaktapur District. The selection of brick industries for this study was done based on the presence of agricultural land nearby the kiln area. Twelve brick kilns were selected for the study i.e. six brick kilns each from Lalitpur and Bhaktapur districts.

Methods

Soil samples collection

Soil samples were collected nearby the brick kilns areas, which were in operation for more than ten years, and are in operation in present condition for at least one month. Soil samples from Lalitpur District were collected in January, 2023 whereas, samples from Bhaktapur District were collected in March, 2023 which is the peak period of brick production. Thirty-six (eighteen samples from each district) soil samples (0-15cm depth) were collected from twelve different brick kilns from three points of each kiln area to see the changes with distance to agriculture field. The distances are approximately 100 m, 200 m, and 300 m from the kilns toward the agricultural field (Bisht & Neupane, 2015; Ismail et al., 2012; Rajonee et al., 2018). Each of the samples collected at the site were placed in a closed plastic bag and labeled as needed and the GPS location was taken. External contaminants were removed and the samples were air-dried in room temperature for further laboratory analysis. The soil sample was collected in the west direction from each kiln sites according to the wind direction shown in the wind rose diagram of Kathmandu Valley (Aryal et al., 2008). The collected soils were air dried for one week in room temperature and grinded to a fine powder which were later sieved through 250 µm stainless steel mesh wire. The samples were then stored in a polythene container to make ready for the analysis.

Soil analysis

The collected soils were air dried for one week in room temperature and grinded to a fine powder which were later sieved through 250 µm stainless steel mesh wire. The samples were then stored in a polythene container ready for the analysis. The soil samples were further analyzed using standard methods (Table 1).

Statistical and geo-accumulation analysis

Statistical analyses for this study were one-way ANOVA, Tukey HSD as a post hoc test, and Pearson's correlation. The significance level considered for this study was 0.05. The purpose of the one-way ANOVA was to assess the variability of soil quality parameters across different distances. Similarly, the Tukey HSD test was used to examine the mean differences in the concentration of soil quality parameters between distances. Additionally, Pearson's correlation test was performed to investigate the relationships between the soil quality

Table 1: Methods and instruments used for the analysis of soil samples

S.N.	Parameter	Method	Instrument	References
1	pH	Electrometric method	pH meter YSI 1200 (China)	Jackson (1973)
2	Electrical conductivity	Electrometric method	Conductivity meter 4200 Jenway 4200 (UK)	Jackson (1973)
4	Potassium	Flame photometry	Flame photometer model 1382 (India)	Toth and Prince (1949)
5	Phosphorous	Spectrophotometric Brays II method	Spectrophotometer model SSI UV 2102	Olsen et al. (1982)
6	Nitrogen	Kjeldhal method		Jackson (1973)
7	Organic matter	Walkley-Black method		Walkley and Black (1934)
8	Lead, Zinc	Wet digestion and Atomic Absorption Spectrometry	AAS, HG 3000 (Australia)	USEPA (1986)
9	Moisture	Gravimetric	Digital weighting balance	Weight of fresh and dry soil samples

parameters. The data collected were analyzed using Microsoft Excel 2013 and R (R Core Team, 2016).

The geo-accumulation index (Igeo) was calculated using the following formula developed by Muller (1969).

$$Igeo = \log_2 \frac{Cm}{1.5Bm}$$

Where Cm is the concentration of the studied metals in the soil and Bm is the background value of the same metal. Factor 1.5 is used to account for the possible variations in the background values. The world average concentration of metals reported for shale served as a background value in this study (Turekian & Wedepohl, 1961). For the not detectable value of lead in soils samples, to calculate Igeo, we have considered 0.05 as a reference minimum value. Different values of the Igeo indicate a total of seven grades or classes of contamination level: Class 0 (nearly uncontaminated): Igeo< 0; Class 1 (uncontaminated to moderately contaminated): 0 <Igeo< 1; Class 2 (moderately contaminated): 1 <Igeo< 2; Class 3 (moderately to severely contaminated): 2 <Igeo< 3; Class 4 (severely contaminated): 3 <Igeo< 4; Class 5 (severely to extremely contaminated): 4 <Igeo< 5; and Class 6 (extremely contaminated): 5 <Igeo.

Results and discussion

Soil pH

pH value of soils from agricultural fields ranged from 5.2 to 8.5 (Fig. 2), describing that samples are acidic to alkaline in nature (NARC, 2013). Bisht and Neupane (2015) studied the soil around brick kilns of Bhaktapur District and found that pH values range from 5.8 to 7.6 which was consistent to our study. Akter et al. (2016) showed that the pH values of the samples ranged from 4.9 to 7.7 represents that the samples in the studied area were very strongly acidic, slightly acidic, neutral, and slightly alkaline in nature. Higher pH values represented the appropriate range for plant growth, while lower pH levels prevented proper plant growth (Yaseen et al., 2015). The one-way ANOVA revealed that there is an increasing trend ($p < 0.05$) in soil pH as the distance from the brick kiln increases. A study conducted by Rajonee et al. (2018) found that pH values of the samples ranged from 6.9 to 8.8 indicating very slightly acidic to strongly alkaline (Rajonee et al., 2018).

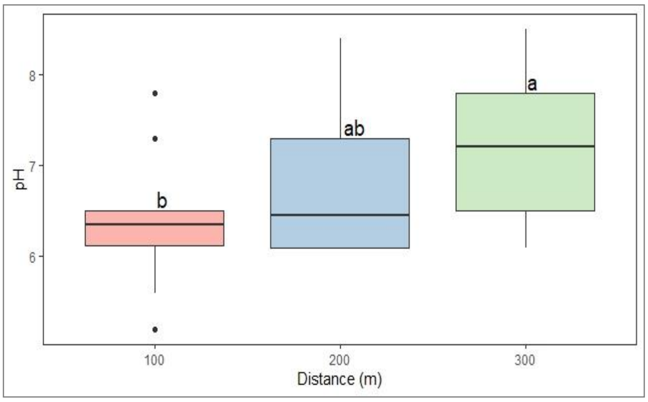

Figure 2: Variation in soil pH with distance from brick kilns where the letters 'a' and 'b' indicate significant differences between groups as determined by the Tukey HSD test

The results for electrical conductivity ranged from 43 µS/cm to 579 µS/cm in the study area. Cations can be accumulated in farm soils due to various agricultural techniques like irrigation, fertilizer, and other practices. However, the brick dust produced by the brick kiln activities decreased the soil's cationic composition (Saha et al., 2021). The analysis results obtained by Yaseen et al. (2015) showed that the EC were found to be ranged 120 µS/cm –527 µS/cm in different sites of Raniganj Coal Field. Saha et al. (2021) found that the EC of collected farm soil samples ranged from 165 to 391 µS/cm in Rajshahi and 222 to 453 µS/cm in Gazipur.

Soil organic matter

The organic matter content ranged from 0.4% to 2.8% in this study (Fig. 3). The mean value of organic matter in study area showed low concentration in comparison with NARC (2013). Burning of organic carbon in the brick kiln, the intense heat in the kiln area, and the topsoil removal practices could be the contributing factors for the low organic matter (OM) content (Saha et al., 2021). A study conducted by Yaseen et al. (2015) revealed that the organic matter of soil in the studied areas varied between 0.5% to 3.5% with an average value of 1.76% (Yaseen et al., 2015). Chowdhury and Rasid (2021) found that organic matter ranged from

0.60% to 1.67% respectively under agriculture soils near the brick kilns. The reduced cation exchange, water retention capacity and buffering abilities of the soil are due to lower levels of organic matter. It is subject to decreased biological activity and soil degradation (Van Loon, 2007).

The one-way ANOVA suggests that there is an increasing trend ($p < 0.05$) in organic matter as the distance from the kiln area increases. This trend could be attributed to factors such as soil excavation from the nearby area for brick production and the emissions released by the brick kilns affecting the agricultural land in close proximity. A study from Bhaktapur revealed that the organic matter of soil in the studied area were varied between 0.47% and 1.60% (Bisht & Neupane, 2015). Likewise, the organic matter content in the collective farm soil samples was ranged from 0.58% to 3.21% in Rajshahi and 0.34% to 1.47% in Gazipur (Saha et al., 2021).

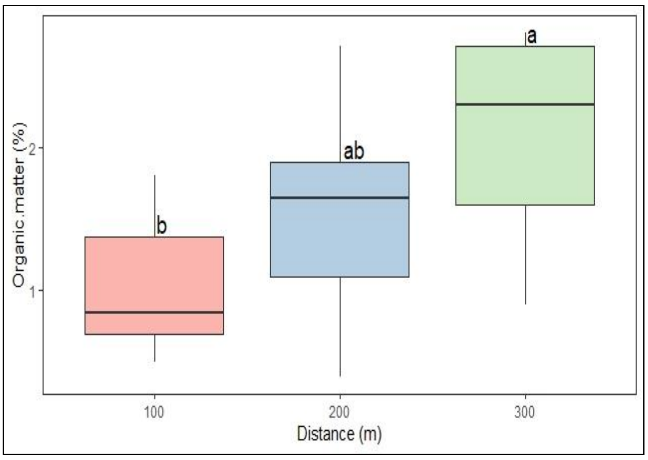

Figure 3: Variation in organic matter concentration with distance from brick kilns where the letters ‘a’ and ‘b’ indicate significant differences between groups as determined by the Tukey HSD test

Soil organic carbon

Good fertility is indicated by an organic carbon concentration more than 0.75% (Yaseen et al., 2015). The soil organic carbon in our study ranged from 0.2% to 1.6% with a mean concentration of 0.9% (Fig. 4). The range of organic carbon were nearly similar to the study conducted by Rajonee et al. (2018), with the range from 0.2% to 1.4%. The one-way ANOVA test suggests that as the distance from the kiln area increases, there is an observed increase in organic matter ($p < 0.05$), which in turn influences the concentration of organic carbon in the soil. According to Akter et al. (2016), organic carbon enhances soil structure, improves aeration and water absorption, increases the capacity for water retention, and provides essential nutrients for plant growth. Organic carbon of the soil ranged from 0.13% to 1.15% in a study done by Akter et al. (2016), whereas it ranged from 0.28% to 0.93% in the study conducted by Bisht and Neupane (2015).

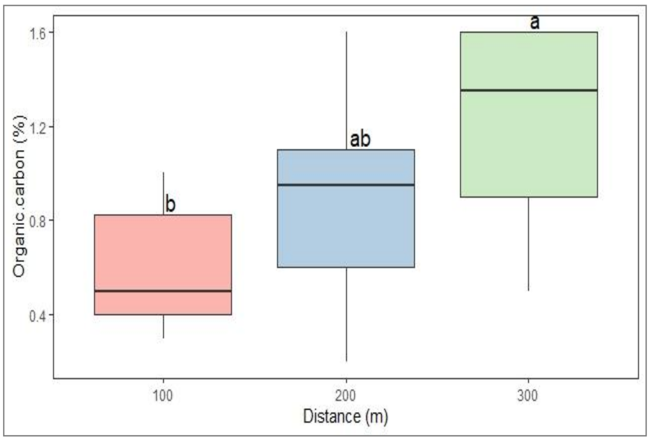

Figure 4: Variation in organic carbon concentration with distance from brick kilns where the letters ‘a’ and ‘b’ indicate significant differences between groups as determined by the Tukey HSD test

Soil moisture

The soil moisture ranged from 10.8% to 43.6%, with a mean value 21.47% (Fig. 5) in our study. The mean values of soil moisture were observed higher than the value revealed by Yaseen et al. (2015) which was 4.2%. The one-way ANOVA suggests that there is an increasing trend in soil moisture as the distance from the kiln area increases ($p < 0.05$). According to Mazumdar et al. (2018), the heat released during brick burning lowers the soil moisture in adjacent areas. A similar scenario may have occurred in our study as well. In a study conducted by Rajonee et al. (2018) revealed that soil moisture content ranges from 18.77% to 56.49%. The amount of moisture in the soil contributes to determining the soil’s quality. Crop development, decaying patterns, and a soil’s ability to deliver water to crops throughout dry spells are all influenced by its water holding capacity (Debnath et al., 2012).

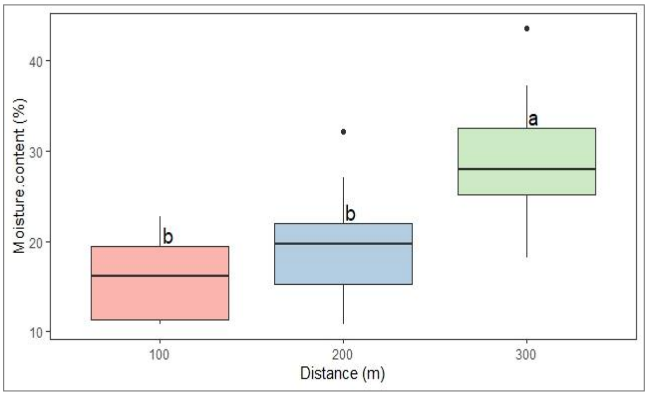

Figure 5: Variation in moisture content with distance from brick kilns where the letters 'a' and 'b' indicate significant differences between groups as determined by the Tukey HSD test

Total nitrogen in soil

The value of total nitrogen ranged from 0.01% to 0.13% with the mean value of 0.02%, 0.035% and 0.04% at distances of 100 m, 200 m and 300 m, respectively (Fig. 6) which lies in very low concentration in comparison to NARC (2013). Low value of organic matter in the study area may be the cause of the low nitrogen content. In the farming soils adjacent to the cluster of brick kilns, total nitrogen levels varied from 0.10% to 0.23%, respectively as studied by Chowdhury and Rasid (2021) which was higher than our study.

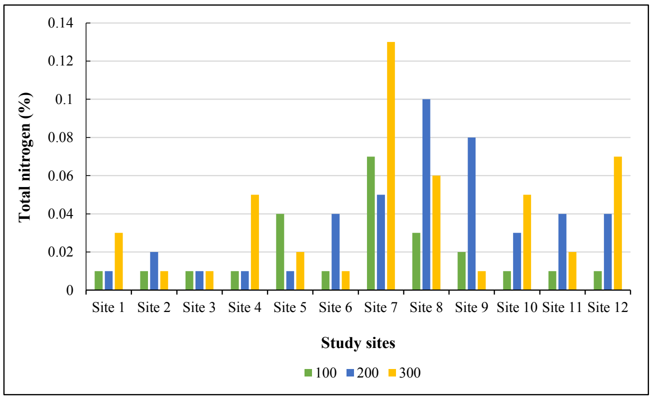

Figure 6: Variation in nitrogen concentration with distance from brick kilns

Available phosphorous in soil

The concentration of phosphorous was ranged from 13.99 kg/ha to 59.06 kg/ha with the mean concentration of 35.26 kg/ha, 39.26 kg/ha, 35.86 kg/ha at distances of 100 m, 200 m and 300 m, respectively in our study (Fig. 7). The mean concentration of phosphorous in study area showed medium concentration in comparison to NARC (2013). The value of available phosphorus ranged from 13.23 kg/ha to 43.3 kg/ha in a study conducted by Dey and Dey (2017) which was slightly lower in comparison to our study. Phosphorus has been regarded as 'Master Key to Agriculture' (Dey & Dey, 2017).

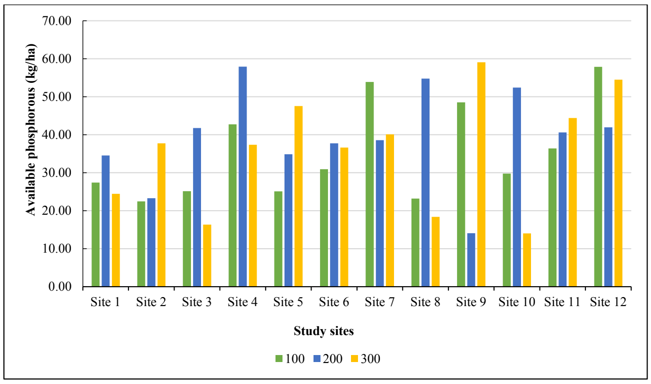

Figure 7: Variation in available phosphorous with distance from brick kilns

Available potassium in soil

The concentration of potassium ranged from 29.57 kg/ha to 220.42 kg/ha with the mean concentration of 62.50 kg/ha, 94.75 kg/ha, 100.58 kg/ha at distances of 100 m, 200 m and 300 m, respectively in our study (Fig. 8), which showed the low concentration in comparison to NARC (2013). The value of available potassium ranged from 49.7 to 170 kg/ha in a study conducted by Dey and Dey (2017).

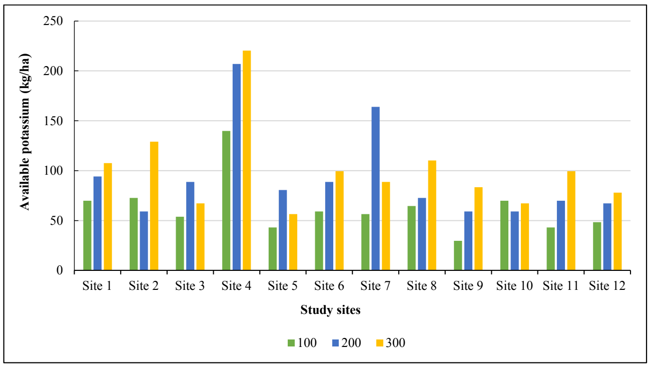

Figure 8: Variation in available potassium with distance from brick kilns

Lead concentration in soil

The Pb concentration ranged from not detectable to 32.04 mg/kg range in the sites, reflecting the maximum concentration observed within the limit for the common range of soils (2-200 mg/kg) (Lindsay, 1979). The extremely hazardous heavy metal lead (Pb) disrupts a number of physiological processes in plants, destroys lipid membranes, which in turn harms chlorophyll and the photosynthesis process while also inhibiting plant growth (Najeeb et al., 2014). A study conducted by Saha et al. (2021) revealed that the Pb concentration in farm soil ranged from 9.53 to 31.27 mg/kg in Rajshahi and 9.54 to 23.86 mg/kg in Gazipur. The concentration of lead ranged from 19.07 to 52.07 mg/kg in a study conducted by Chowdhury and Rasid (2021), whereas it was in a range of 5.45 to 11.82 mg/kg in a study conducted by Bisht and Neupane (2015) in Bhaktapur District which is higher in comparison to our present study of Bhaktapur.

Zinc concentration in soil

Zn is essential to function as a source of nutrition for both people and crop plants. However, it also performs extremely dangerous to plants and fauna when present in higher concentrations (Saha et al., 2021). It was observed that zinc concentration ranged from 22.44 to 143.16 mg/kg with the mean concentration of 49.47, 58.72, and 50.81 mg/kg at distances of 100 m, 200 m, and 300 m, respectively (Fig. 10), which is in limit compared to the content in the common range of soils (10-300 mg/kg) (Lindsay, 1979). Zn concentration in farm soil ranged from 12.68 to 79.34 mg/kg in Rajshahi and 11.24 to 78.51 mg/kg in Gazipur (Saha et al., 2021). The low pH might be responsible for increasing Zn concentration (Saha et al., 2021).

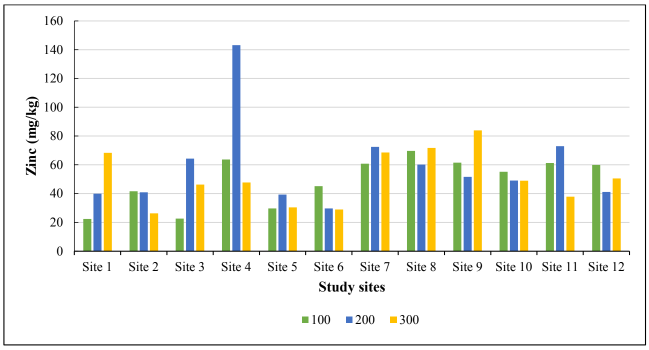

Figure 10: Variation in zinc concentration with distance from brick kilns

Correlation between physicochemical parameters including heavy metals

Pearson correlation analysis revealed that soil nitrogen positively correlates with electrical conductivity, organic matter, and organic carbon. Nitrogen boosts crop yields, increasing plant residues and enhancing soil organic carbon and organic matter (Powlson et al., 2011). Organic matter releases mineralizable nitrogen, creating a strong link between organic carbon and available nitrogen, resulting in a positive correlation (Kumar et al., 2014). Electrical conductivity influences crop yields, suitability, and nutrient availability, with soil salinity significantly impacting EC levels (Saha et al., 2021). Soil organic matter showed a strong positive correlation with organic carbon, meaning both increase together. Soil moisture also correlated positively with organic matter and organic carbon. Zinc was positively linked to phosphorus and potassium, while lead showed a negative correlation with nitrogen, indicating higher lead levels reduce nitrogen concentration (Table 2).

Table 2: Correlation of physicochemical parameters along with heavy metals

	pH	EC	OM	OC	N	P	K	SM	Zn
pH	1								
EC	0.083	1							
OM	0.207	0.154	1						
OC	0.198	0.13	0.997**	1					
N	-0.218	0.367*	0.367*	0.353*	1				
P	0.103	0.092	0.117	0.124	0.047	1			
K	0.073	-0.196	-0.044	-0.048	0.022	0.154	1		
SM	0.142	-0.125	0.561**	0.570**	0.16	0.084	0.24	1	
Zn	-0.142	0.107	-0.013	-0.022	0.155	0.357*	0.405*	-0.2	1

*** Correlation is significant at the 0.05 level (2-tailed).**

**** Correlation is significant at the 0.01 level (2-tailed).**

Table 3: Geo-accumulation index for lead and zinc

Igeo Value	Igeo Class	No. of samples for Lead	No. of samples for Zinc	Designation of soil
>5	6	_	4	Extremely contaminated
4-5	5	_	25	Heavily to extremely contaminated
3-4	4	_	7	Heavily contaminated
2-3	3	_	_	Moderately to heavily contaminated
1-2	2	_	_	Moderately contaminated
0-1	1	1	_	Uncontaminated to moderately contaminated
0	0	35	_	Practically uncontaminated

Contamination degree based on geo-accumulation index

The geo-accumulation index of overall study sites (i.e. sites from both Lalitpur and Bhaktapur) was prepared using Muller (1969) in which 35 soil samples showed practically uncontaminated status and only 1 sample showed uncontaminated to moderately contaminated status in terms of lead. In case of zinc, 4 samples showed extremely contaminated, 25 samples showed heavily to extremely contaminated, 7 samples showed heavily contaminated status.

Ravankhah et al. (2017) found that the Igeo value of Pb in soils were moderately contaminated by Pb. The Igeo value for Zn in soil samples were moderately polluted whereas in our study it was heavily contaminated in most of the samples. Fig. 12 shows the range and average value of Igeo values for lead and zinc, using background values.

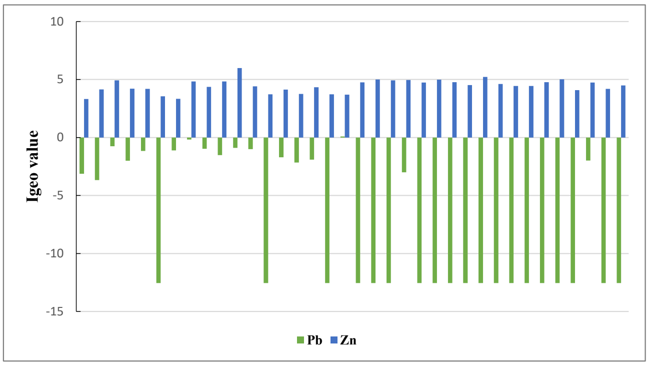

Figure 12: Range and average of Igeo value for lead and zinc.

Conclusion

The study determined that the soil in Lalitpur and Bhaktapur districts of Kathmandu Valley ranged from acidic to alkaline soils, with low fertility parameters and medium phosphorus levels. Soil pH, organic carbon, organic matter, and moisture varied significantly with distance from brick kilns. Lower values of these parameters were observed in most of the samples near the brick kiln areas. Most samples showed low lead contamination but high zinc contamination based on the geo-accumulation index. Lead and zinc were within common range for soils. Soil excavation for brick production and kiln emissions are degrading agricultural land, gradually harming the key soil fertility parameters over time. Comprehensive monitoring of brick kiln emissions and dispersion of pollutants are suggested for future assessments.

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