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Original Research

Characterisation of morphological and geochemical properties of lick soils for animals

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Abstract

The main aim of the study was to investigate the morphological and geochemical properties of mineral licks formed in various landscapes and climatic conditions. The properties of lick soils were greatly influenced by parent materials and climatic conditions. The pH of the lick soils varied between 8.83 and 9.54. The licks identified in semi-arid climatic conditions exhibited higher concentrations of calcium (Ca), potassium (K), sodium (Na), sulfur (S), iron (Fe), boron (B), and total nitrogen (TN) than other sites. For instance, S concentrations was as high as 17.57 g kg^{-1} *soil in semi-arid areas of Dire district, making them ideal sources of S. Manganese (Mn) and silicon (Si) levels were high in lick soils found in humid climates. The variation in nutrient concentrations between lick soils suggests that each lick site can provide different nutrients to herbivores. Toxic heavy metal concentrations such as cadmium (Cd), mercury (Hg), and lead (Pb) were below the maximum allowable limits in all mineral licks. Our findings suggest that lick soils require protection as they play an important role in maintaining ecosystem services and integrity.*

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INTRODUCTION

Soil is one of the most valuable earthly resources. Soils have many functions, including biomass production, biodiversity pool, a source of raw materials, a source of energy, an archive of geological and cultural heritages, storage and transformation of substances, and rarely animal feed (Brady and Weil, 2002; Bhattacharyya and Pal, 2015). Soil contains important nutraceuticals that are essential for plant growth and animal production (Auchter, 1939). As a result, soil controls food production and thereby regulates ecosystem functions (Silver et al., 2021). Soils are heterogeneous in nature, and this soil hetrogeneity governs the potential use of the soils (Mommer et al., 2012; Wallor et al., 2018). Variations in soil properties lead to the use of soils for various purposes (Xue et al., 2016), the most important of which is nutrient supplementation for plants and animals (Poole et al., 2009; Ghanem et al., 2013).

In a complex food web, herbivores consume lick soils (Voigt et al., 2008; Ghanem et al., 2013), representing a direct flow of nutrients and energy from soils to large animals living outside the soils. The main reasons for soil consumption among herbivores are to obtain essential minerals that are lacking in their diet, to get relief from toxic elements or indigestion problems caused by plant-based alkaloids via adsorption with clays, and to develop animal behaviours that aid in survival and reproduction (Brightsmith et al., 2008; Voigt et al., 2008; Gilmore et al., 2020). Many species of wild herbivores travel long distances away from their natural habitats or live near mineral lick sites and consume it whenever they need it, making the licks important hotspots for ecological conservation (Poole et al., 2009; Blake et al., 2011). Thus, lick soils are relevant for ecosystem integrity and sustainability (He et al., 2022).

Lick soils are widely distributed across the world. The nature and properties of lick soils are mainly influenced by variations in landscape, climate, and geological conditions (Ramachandran et al., 1995; Molina et al., 2013). Geological processes such as volcanic eruptions can destructively change the landscape pattern and are also responsible for bringing mineral-rich deposits to the earth's surface (Amaral et al., 2006; Fabricio Neta et al., 2018), where they weather to form soil distinct from the majority of surrounding areas. Similar to spatial variability in ordinary soils (Gessler et al., 2000; McBratney et al., 2003; Birhanu and Chalsissa, 2018), lick soils can also inherit their properties from the in-situ weathering of rocks and subsequent pedological processes. Variation in the properties of mineral licks caused the constituents of the licks to vary even at local scales. This leads to the formation of licks with distinct morphological and geochemical properties across the landscape.

Understanding the properties of lick soils can aid in lick classification and the selection of a specific lick for the management of specific nutrient deficiencies in herbivores. Therefore, the study was aimed at investigating the selected morphological and geochemical nature of lick soils that occur in different landscape and climatic conditions.

MATERIALS AND METHODS

Study Sites

The study was carried out in the southern and western compartments of Oromia Region in Ethiopia, specifically different districts of Borana, Wollega, and Jimma Zones (Table 1). Lick soils are identified at elevations ranging between 1000 and 1700 metres above sea level. They were observed in a wide range of agro-ecologies across the study sites (Table 1). Borana Zone, for example, has a semi-arid climate with mean annual rainfall ranging between 285 and 740 mm (Worku et al., 2022). Limu Saqa, Amuru, and Ababo Guduru districts, on the other hand, are located in humid areas with an average annual rainfall of more than 1500 mm. As a result, the formation of lick soils is not limited by climate, though their characteristics differ depending on the climatic conditions. Furthermore, the lick soils are found on various topographies, implying that landscape patterns can only influence the type, morphological, and chemical characteristics of the licks.

Table 1

Locations and environmental conditions where the lick soils form

Site code	Location		Formation (location)	Agro-ecology
	District	Zone		
Dire	Dire	Borana	Lake	Semi-arid
Liban	Liban	East Borana	Inland	Semi-arid
Amuru	Amuru	Horro Guduru Wollega	Stream bank	Humid
Ababo Guduru	Ababo Guduru	Horro Guduru Wollega	Stream bank	Humid
Limu Saqa	Limu Saqa	Jimma	Stream bank	Humid

Survey, Sampling, and Characterization of Lick Soils

Combinations of information gathered from local people and a reconnaissance survey were used to identify five lick sites across different agro-ecologies. The lick soils in the Dire district are associated with specific mini lakes known as Ela-sooddaa, which form only in closed depressions with evidence of historic volcanic eruptions. The licks occur at the bottom of the lakes (i.e., *Ela-sooddaa*) *(Figure 1a, Table 1).* The lick soils identified in Liban district (Figure 1b, Table 1) form on flat to gently sloping inland terrain. They had no discernible relationship with water bodies or vegetation cover. The red-coloured mineral licks in Amuru, Ababo Guduru, and Limu Saqa districts, where the Ababo Guduru lick is shown in Figure 1c, are all associated with stream banks.

Samples of lick soil at the Dire site were collected from the bottom of the lake, as shown in Figure 1a. The remaining licks were found only in the subsoil and were thus assessed using profile sampling. Thus, samples of mineral lick in Liban were collected at 0.9–1.2 m depth from a profile dug to a depth of 1.3 m to expose the parts of the soil consumed by animals (Figure 1b, Table 2). Soil samples of mineral licks in Amuru, Ababo Guduru, and Limu Saqa districts were collected from the vertical segment that was exposed spontaneously during animal licking at depths between 0.7 and 1.2 m (Figure 1c, Table 2). In the field, selected morphological and physical properties of lick soils were characterised using FAO (2006) guidelines. Quantitative and qualitative data about the lick soils, including data on the colour, depth of occurrence, landscape configuration, presence of rock fragments, and water, were collected for each site.

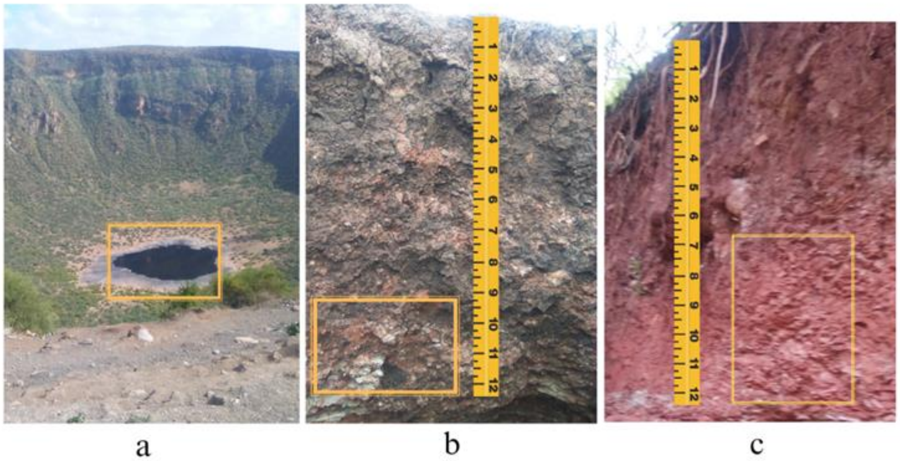

Figure 1 *Lick soils identified in (a) Dire, (b) Liban, and (c) Ababo Guduru districts. The lake shown in Figure 1a is the source of mineral lick at Dire 1. The pits used for characterization of mineral licks in Liban district (Figure 1b) was dug to 1.3 m, whereas that of Ababo Guduru district (Figure 1c) was exposed by animals' consumption.*

Geochemical Analysis

Lick soil samples brought from the field were air dried and then sieved with a 2 mm sieve. Particle size distribution was determined by the Bouyoucous hydrometer method (Bouyocous, 1962). The pH was determined in H_2O using a 1:2.5 soil-to-water ratio using an ELMETRON pH metre (Black, 1965). The electrical conductivity of saturated extract (ECe) was determined in a soil/water ratio of 1:5 using a conductivity metre (van Reeuwijk, 1993). The amount of $CaCO_3$ was determined using an acid neutralisation method as described by Allison and Morse (1965). The OC content of the lick soils was determined by the Walkley-Black oxidation method (Walkley and Black, 1934). Total N was determined by the Kjeldhal method (Bremner and Mulvane, 1982). Cation exchange capacity (CEC) was determined using ammonium acetate extract (Page et al.,1982). Mineral elements such as Ca, Mg, K, Na, P, S, Fe, Zn, Cu, Mn, CoMo,Cr, Sn, Si, Ni, and heavy metals such as cadmium (Cd), mercury (Hg), and lead (Pb) were determined using the Mehlich-III soil test extraction procedure (Mehlich, 1984).

Statistical Analysis

Mean comparisons of the chemical properties of lick soils were carried out using one-way ANOVA. The mean comparisons and tests of significance were conducted at $p \leq 0.05$ using IBM-SPSS version 28.0.1.0. Principal component analysis (PCA) was carried out using OriginPro Lab version 2022 (9.95). The PCA was used to identify the nutrient data pattern and the geochemical properties that represent each lick site.

RESULTS AND DISCUSSIONS

Genesis and Geomorphology of Lick Soils

The morphological features of lick soils in the present study sites varied dominantly with climatic conditions and parent materials. The variation in morphological properties of lick soils along the climosequence assisted in classifying the licks in the present study sites into three district classes, each with its own vernacular name (Table 2). The lick soil identified in Dire Lowland is locally known as *Booqee*. This lick soil commonly forms in lakes that were formed in closed depressions with evidence of past volcanic activities. It showed dark grey and very dark grey clours, respectively (Table 2), likely caused by the reduction of Fe and Mn compounds in the waterlogged condition and the result of past geological processes. The dark grey and very dark grey colours could also be due to high organic materials washed into the lakes by erosion. Furthermore, the surfaces of these lick soils showed bluish casts, which could be attributed to the high sulphur content.

Table 2

Indigenous classification and morphological properties of lick soils

Site code	Vernacular name	Depth of occurrence (m)	Particle size distribution			Color (moist state)
			Clay	Silt	Sand	
Dire	*Booqee*	Lake bed	33	25	42	10YR 2/1
Liban	*Haaya*	0.9-1.2	31	17	52	5YR 4/4
Amuru	*Boojjii*	0.7-1.2	69	23	8	7.5YR 2.5/2
Ababo Guduru	*Boojjii*	0.7-1.2	55	29	16	10R 3/4
Limu Saqa	*Boojjii*	0.7-1.2	37	23	40	2.5YR 3/4

The second category of lick soil identified in Liban is referred to as *Haaya*. This lick soil was most abundant on well-drained, flat to gently sloping inland terrain in semi-arid regions. It showed a reddish brown colour when moist (Table 2), probably due to the mixture of oxidised iron and high $CaCO_3$. Other lick soils identified in Amuru, Ababo Guduru, and Limu Saqa districts all develop under humid climatic conditions (Table 1) and are thus referred to as *Boojjii* (Table 2). These licks commonly occur along river or stream banks. The *Boojjii* lick soils showed a light to dark reddish brown colour (Table 2). At depths greater than 0.7 m, the profiles of *Boojjii* lick soils comprised many red contours (Figure 1c), which could be due to the illuviations of iron and clay minerals. The proportions of sand, silt, and clay varied across the licks. Clay fractions of up to 69% were found in the lick soils at Amuru and sand fractions of up to 52% in Liban (Table 2). This implies that lick soils are not associated with a specific soil fraction. Mineral soils appear very hard when dry and soft when wet. As a result, animals prefer to consume mineral licks when they are moist. In many locations, in-situ consumption of the lick soils by wild and domestic animals resulted in the formation of holes or caves.

Chemical Properties of the Lick Soils

All the lick soils had a strongly alkaline reaction, with pH ranging from 8.83 in a lick at Dire to 9.54 at Liban Saqa (Table 3). The last three lick soils were identified in highly leached, humid lowland soils in western Ethiopia (Table 1). However, they showed a strongly alkaline reaction, regardless of the agroclimate. The EC values of the lick soil in Dire district were 13.75 ds/m1, indicating the presence of high concentrations of soluble salts. The remaining licks exhibited very low EC values (< 2 dS m^{-1}) (Table 3). The lick soils in Dire and Liban showed a higher $CaCO_3$ content than other lick soils (Table 3). This could be attributed to aridity and associated weak pedologic processes. The remaining lick soils could have been subjected to intensive weathering or leaching, resulting in low carbonates.

Table 3

Chemical properties of the lick soils

Site code	pH (H_2O)	EC (dS m^{-1})	$CaCO_3$ (%)	CEC	ECEC	PBS (%)	OC (%)
				cmol (+) kg^{-1} soil			
Dire	9.00^{b}	13.75^{b}	10.79^{b}	57.07^{b}	175.21^{a}	307.01^{b}	9.39^{b}
Liban	8.83^{a}	1.34^{c}	9.79^{b}	40.99^{a}	57.20^{b}	139.55^{c}	0.20^{ac}
Amuru	9.08^{b}	0.81^{c}	0.61^{c}	18.74^{c}	34.24^{c}	182.71^{d}	0.18^{c}
Ababo Guduru	9.27^{c}	1.33^{c}	2.60^{d}	31.02^{d}	29.43^{c}	94.87^{e}	0.16^{c}
Limu Saqa	9.54^{d}	0.37^{c}	0.52^{c}	30.06^{d}	28.73^{c}	95.58^{e}	0.18^{ac}

EC: electrical conductivity; $CaCO_3$: calcium carbonate; CEC: cation exchange capacity; ECEC: effective cation exchange capacity; PBS: percent base saturation; OC: organic carbon. Different letters indicate significant differences at $\alpha = 0.05$.

The CEC ranged from 18.74 cmol (+) kg^{-1} in the lick soil at Amuru to 57.07 cmol (+) kg^{-1} in a lick at Dire. Except for the lick soil in Amuru district, all the licks had very high CEC and effective CEC (ECEC). The entire lick soils, but Ababo Guduru and Limu Saqa licks, exhibited percent base saturation (PBS) > 100% (Table 3). All lick soils had very low OC (< 2%) except for licks at the Dire site. The relatively high OC in the lick soil in Dire district is due to the erosion of organic materials from the hills to the depression (i.e., lakes) where mineral licks form. The concentrations of heavy metals such as cadmium (Cd), mercury (Hg), and lead (Pb) in the entire licks were lower than the critical concentrations, so they pose no risk to animals (Figure 2).

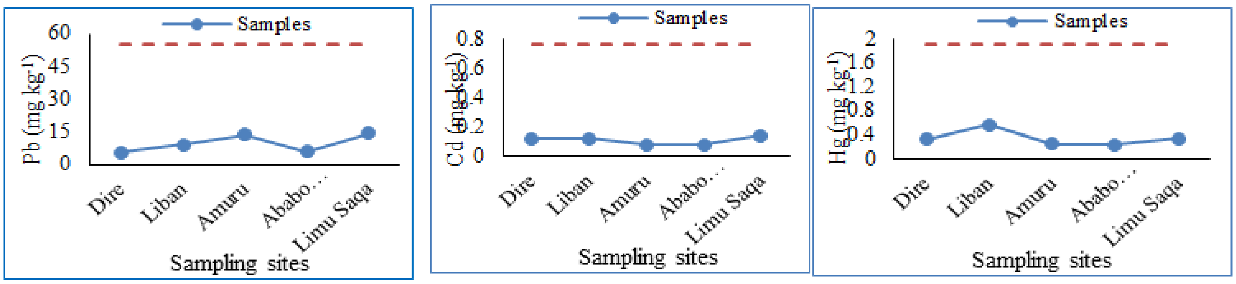

Figure 2 *Concentrations of heavy metals including cadmium (Cd), mercury (Hg), and lead (Pb) in the mineral licks. Critical limits indicate the maximum permissible concentrations of heavy metals in soils.*

Level of Nutrients in the Lick Soils

The concentrations of essential animal nutrients varied among lick types. The total concentrations of Ca in the lick soils ranged from 0.99 in Ababo Guduru to 7.77 g kg^{-1} in Liban district (Table 4). The amounts of K varied between 0.20 (Ababo Guduru) and 9.74 g kg^{-1} (Dire). The lick soil formed at Dire depression contained the highest concentrations of Na (26.39 g kg^{-1}). The elevated Na concentrations in the lick soil could help to balance the high K intake in forage. The S content was consistently high (> 0.10 g kg^{-1}) for all the sampled sites (Table 4), with S levels in the lick soil at Dire district being significantly higher than in other types of licks. Most mineral nutrients were found in high concentrations in the lick at Dire Depression, most likely due to the deposition of mineral-rich parent materials by past volcanic activity. Except for the lick at Ababo Guduru, which had a high P value (in the range of 80-150 mg kg^{-1}), the other licks had low P concentrations, resulting in very high Ca:P ratios. Silicon was abundant in all the lick soils ranging from 0.38 g kg^{-1} in Dire 1 to 1.13 g/ kg in Limu Saqa, whereas Fe was highest in a lick at Dire 2 (0.69 g kg^{-1}). The manganese content of the lick soils was higher than other micronutrients. The concentration of Zn ranged from very low (0.23 mg kg^{-1}) in a lick at Liban district to optimum (5.54 mg kg^{-1}) at Limu Saqa (Table 4). The Cu contents of most licks were within the optimum range, with values comparable to agricultural soils. Except for lick sites at Amuru and Limu Saqa, the B concentrations in the licks were very high (> 4 mg kg^{-1}). Lick soil in Liban district had the highest Mo level, which also had the highest level of most essential elements. In general, different lick sites had elevated levels of some essential elements and lower levels of others. The variation in essential nutrient amounts with consumed soils suggests that different lick soils may aid animals in obtaining a specific nutrient from each site. The association between essential elements (variables) and lick sites was described using a box plot (Figure 3). The variables outlined closest to a given lick site on the box plot were found to be the most representative of that site.

Table 4

The mean concentration of essential nutrients in the mineral licks

Sampling sites	g kg^{-1}							mg kg^{-1}								
	Ca	K	Na	Mg	S	Si	Fe	P	Zn	Cu	Mn	Mo	Cr	Ni	As	B
Dire	5.84	9.74	26.39	0.78	17.57	0.66	0.69	27.19	4.35	1.91	80.83	0.31	0.32	3.42	0.52	143.84
Liban	7.77	0.34	2.36	0.88	0.25	0.64	0.04	10.66	0.32	2.97	9.56	0.39	0.16	0.49	2.04	5.42
Amuru	4.00	0.25	0.96	1.15	0.33	0.38	0.08	8.79	0.77	2.15	77.38	0.21	0.18	0.58	0.52	0.73
Ababo Guduru	0.99	0.20	4.18	0.70	0.37	0.71	0.09	85.72	1.10	1.28	375.46	0.22	0.12	1.77	0.33	1.59
Limu Saqa	1.89	0.27	2.72	0.82	0.20	1.13	0.23	25.42	5.54	2.40	178.25	0.32	0.20	2.33	0.52	T

TN: total nitrogen; Ca: calcium; K: potassium; Na: sodium; Mg: magnesium; P: phosphorus; S: sulfur; Fe: iron; Zn: zinc; Cu: copper; Mn: manganese; Mo: molybdenum; Cr: chromium; Si: silicon; Ni: nickel; As: arsenic; B: boron; T: trace

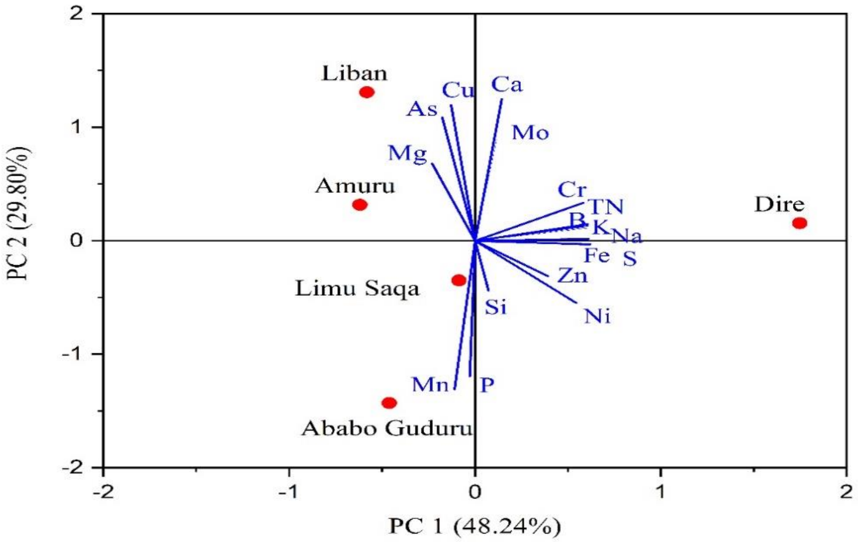

Figure 3 *Principal component (PC) analysis showing the abundance of essential elements at a specific lick site. Essential elements marked closer to a given lick site on the box plot indicates that the elements are abundant in that site.*

The lick soil at Ababo Guduru was represented by its high levels of Mn and P, making it an ideal location for farmers seeking to provide supplemental Mn and P nutrients to their cattle. The lick soil in the Liban district, on the other hand, was distinct from other licks due to higher concentrations of As and Cu. As shown in Figure 3, a lick at Limu Saqa was primarily explained by a higher concentration of Si elements than other licks. In general, each lick site has higher levels of one or more elements than other licks, demonstrating that different lick soils provide different services.

Geomorphology and Geochemistry of Lick Soils

Lick soils are formed by soil-forming factors similar to those of other soils, but their geophagial properties may have developed through distinct pedogenic processes that resulted in the accumulation of relevant mineral nutrients. Landform is the physical configuration of land that can shape the nature of the soils formed. The lick soils observed in the Dire district are formed in depressions bounded by hills. In addition to the uplifting of mineral-rich geological materials, surface geomorphic processes such as gravity and erosion may have caused materials to move down the hillside and deposit in the lakes where the mineral licks occur. The intensity of leaching also influences how parent materials behave and redistribute in lick soils. The relatively reddish subsoil in the lick soils at Amuru, Limu Saqa, and Ababo Guduru (Figure 1c), for example, indicates that there was intensive leaching and accumulation of Fe minerals in the subsoil where animals prefer to consume them. The results showed that soil particle distribution varies between lick sites. Most licks had less clay content than sand, indicating that clay fractions are not the determining factor for geophagia. However, consuming more clay fractions than sand can be beneficial due to the retention of more mineral nutrients and the adsorption of toxins from the animal body by their surfaces. Previous research has shown that negatively charged clay surfaces can hold cationic minerals such as Si, Ca, Mg, Na, K, Cu, and Zn (Callahan, 2003; Stankovic et al., 2014). The cations on the clay surfaces can then be used to exchange with heavy metals or organic toxins ingested with forages, flashing out harmlessly through the digestive system. Animals usually consume lick soils during the rainy season because the lick soils are soft only when wet, and there is a need for adequate drinking water after consumption.

According to Bruce and Rayment's (1982) soil pH classification, all lick soils in this study are strongly alkaline ($pH \geq 8.78$). The lick soils identified in the humid lowlands of western Ethiopia (i.e., Amuru, Ababo Guduru, and Liban Saqa) also had pH values greater than 7, despite the fact that soils in humid tropics are subjected to intensive leaching, which results in lower pH. This could be due to saline seeps caused by the continuous release of salts in low-lying areas. Previous research reports showed that some lick soils are alkaline ($pH > 7$) (Nderi et al., 2015) and other licks are acidic ($pH < 7$) (Ramachandran et al., 1995; Klaus et al., 1998), indicating that selection for soil licking by animals is not pH-dependent. The Dire lick soil had high EC values (> 4 dS m^{-1}). As a result, the high pH values in these two lick soils could be attributed to high concentrations of soluble salts and exchangeable Na. However, the high pH values of the remaining licks could be due to their high exchangeable Na content, as they exhibited low soluble salt concentrations (EC values $2 <$ dS m^{-1}). We found high $CaCO_3$ levels in lick soils in the Dire and Liban districts. Carbonates in mineral licks contribute to buffering capacity by neutralising acidity produced in the rumen (Bhattacharyya et al., 1999; Brightsmith et al., 2008).

The present lick soils had high CEC values, resulting in higher concentrations of essential nutrients. Similar to our findings, Montenegro (2004) found a percent base saturation (PBS) of 97.6% to >100% for soil licks in the Peruvian Amazon. The high base saturation in the licks could be due to high concentrations of exchangeable bases (Ca, Mg, K, and Na) and/or base-contributing minerals such as zeolites (Bhattacharyya et al., 1999). Heavy metal levels can have an impact on the quality of lick soils. According to Dutch standards (Crommentuijn et al., 1997), the concentrations of heavy metals such as Cd, Hg, and Pb in these licks were below the maximum permissible limits of 0.76, 1.9, and 55 mg kg^{-1}, respectively. As a result, they are safe for animal consumption. In general, lick soils varied across landscapes in terms morphological and chemical properties. Similar variation in lick properties with landscape was reported across the world (Montenegro, 2004; Powell et al., 2009).

Lick Soils as an Important Source of Essential Nutrients for Animals

Our results showed that lick soils vary in their nutrient content, implying that each lick soil supplies a sufficient quantity of a specific nutrient to herbivores. According to Karltun et al. (2013) classification, for example, the concentration of K was highest in the Dire lick soil, which is an ideal lick soil for supplementation of K nutrients for herbivores. This lick is also the major source of Na (26.39 g kg^{-1}). *Forages commonly* used in dry cow rations contain high K *concentrations* (Rerat et al., 2009). The ick soils of the present study sites, on the other hand, exhibited higher concentrations of Na than K. Thus, the intake of the licks could balance the K-to-Na ratios in the animal's body. Furthermore, forages often contain sufficient amounts of Ca and P, where the problem lies in the imbalance of ratios of these nutrients that could lead to a specific nutrient deficiency. For instance, the ideal Ca to P ratio for farm animals should be from *2.8:1 to 3.3:1, where* Ca:P ratio of > 7:1 or < 1:1 is critical (Prasad et al., 2015). However, lick soils of the present study sites exhibited much higher Ca:P ratio than the recommended ones, implying that the nutrient disorders caused by lower Ca:P ratios in forages can be corrected by the supplemental feeding of relevant lick soil.

Our results showed that the Dire lick site exhibited the highest S content. The local people use these high sulfur-containing licks to heal livestock infected by lumpy skin disease and manjimite, which could be because sulfur is the dominant component of many sulfur-containing drugs (Feng et al., 2016). The high sulfur content in the licks, when ingested by ruminants, could also help to synthesize sulfur-containing amino acids by rumen microbes, and this is an essential amino acid relevant for animal performance (Silva et al., 2014; Haro et al., 2019).

The entire lick soil of the present study sites contains high levels of most micronutrients. For instance, lick soils in the Dire and Limu Saqa districts exhibited high levels of Fe, and thus, consumption of these licks can help to produce adequate red cells in animals. In comparison to our findings, Montenegro (2004) reported higher Cu (3.08 mg kg^{-1}), a lower Mn (19.33 mg kg^{-1}), and a lower B (0.32 mg kg^{-1}) valuesfor Amazonian licks. Chromium is one of the essential mineral nutrients for animals. It is harmful to animals only when its amount in the feed exceeds the permissible limit of 3.8 mg kg^{-1} established by Vodyanitskii (2016). The lick soils at the present study sites were safe for consumption because their heavy metal content was less than the toxicity limit. The nutrient content of licks observed in this study differs from other licks reported for Amazonian licks (Montenegro, 2004), wet licks of North-Central British Columbia (Parker and Ayotte, 2004), and licks in Kenya (Nderi et al., 2015).

Lick soils play a significant role in maintaining ecosystem services and integrity. They are beneficial for animal nutrition and health, as well as biodiversity conservation (Parker and Ayotte, 2004; Molina et al., 2013). Lick soils are nutritionally and ecologically valuable resources that integrate living and non-living components of ecosystems. Our findings suggest that lick soils require protection as they play an important role in maintaining ecosystem services and integrity.

CONCLUSIONS

Lick soils serve a variety of functions, including animal nutrition and biodiversity preservation. Lick soils can form as a result of the uplifting of mineral-rich geological materials and the deposition of washed anthropogenic or natural parent materials in a specific landscape. The nutrient profile of lick soils was highly influenced by parent materials and climatic conditions. Landscape patterns showed a modifying effect on the formation of mineral licks. As a result, lick soils differ in concentrations of one or more mineral nutrients. The variation in nutrient concentrations between mineral licks indicates that each lick site can provide distinct nutrients to herbivores.

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DECLARATION

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

All data included in the article are available from the corresponding author upon request.

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