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GEOCHEMICAL CHARACTERISTICS OF TROPICAL SALT LICKS IN SEGALIUD LOKAN FOREST RESERVE, SANDAKAN, SABAH MALAYSIA

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***ABSTRACT*:** Mineral licks are important for animals, especially wildlife, to nourish their diets, not only in terms of supporting their mineral intake deficiencies but also in regulating toxins in their bodies. This study characterised the geochemical properties of salt licks located in Segaliud Lokan Forest Reserve (SLFR). Soil samples were collected from five selected salt licks in the study area. The physico-chemical results show that the pH of the salt-lick soil varied from slightly acidic to slightly alkaline. The percentage of moisture content and organic matter ranges from 25.22% to 44.78% and 0.95% to 7.83, respectively. The electrical conductivity reading ranges from 48.59 µS/cm to 260.88 µS/cm. The soil samples were digested using aqua regia and analysed using inductively coupled plasma-optical emission spectrometry (ICP-OES). The concentrations of Ca (1101.92 mg/kg–11551.64 mg/kg), K (910.27 mg/kg–2355.41 mg/kg), Na (106.36 mg/kg–727.34 mg/kg), and Mg (1442.14 mg/kg–5305.13 mg/kg) in the five salt licks varied considerably and were higher than in the control soil samples. High chemical concentrations in salt licks are due to the pH of soils, which ranges from slightly acidic to slightly alkaline.

KEYWORDS: Salt licks, soil, physico-chemical, geochemical, tropical forest

INTRODUCTION

Salt licks are a location that is frequently visited by animals. It is a place rich in minerals animals seek to supplement their diets and regulate their body function (Parker et al., 2004; Blake et al., 2011; Lazarus et al., 2019). Salt licks can be identified from traces of animals, such as footprints on soil or bite marks on rock walls (Lameed & Adetola, 2012; Molina et al., 2014). There are two types of salt licks that exist naturally, known as hydromorphic licks and lithomorphic licks (Panichev et al., 2013). According to Panichev et al. (2013), hydromorphic licks are formed by running water springs where clay rocks saturated with chemical concentrations become licks in water discharge areas, whereas lithomorphic licks are an exposure of rocks searched for and consumed by animals. Chong et al. (2005) divide the natural salt licks found in Peninsular Malaysia into two groups known as spring salt licks and dry land salt licks, whose local names vary according to location.

Salt licks can provide resources for animal nutrient deficiency that are difficult to obtain (Hon & Shibata, 2013; King et al., 2016; He et al., 2022); thus, they have been classified as important places within landscapes (Montenegro, 2004; Tawa et al., 2021). Salt licks are an important source of minerals for many species of mammals and birds in the lowland forests of Malaysia (Magintan et al., 2015).

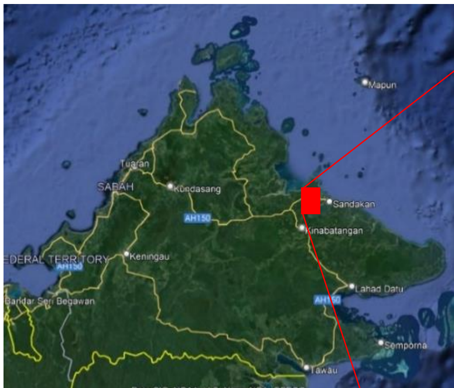
Previous studies of salt licks have mostly focused on the chemical properties, patterns of use, and interpretations of why the salt licks are frequently visited (Matsubayashi et al., 2007; Tobler et al., 2009; Elyau et al., 2012; Matsuda et al., 2015; Razali et al., 2020). Typical results for geochemical analysis studies found in salt licks content is abundant in essential elements such as calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg) (Brightsmith & Muñoz-Najar, 2004; Lizcano & Cavalier, 2004; Lameed & Jenyo-Oni, 2012; Wahab et al., 2020; Sitienei et al., 2012; Griffiths, 2022).

There hasn't been much research done on the physico-chemical and chemical composition of the important elements in salt lick soil in SLFR. Thus, the study was conducted to determine the geochemical composition of salt lick soil from Segaliud Lokan Forest Reserve (SLFR), Sandakan Sabah.

MATERIALS AND METHODS

Study Area

Segaliud Lokan Forest Reserve is located in Sandakan, on the eastern side of Sabah. The study area lies within a latitude of 05026'N to 05036'N and a longitude of 117030'E to 117036'E. The sampling stations for the different forest zones and compartments are given in Figure 1. This forest reserve is a logging area managed by KTS Plantation Sdn. Bhd. and covers approximately 57,247 hectares of land. It was zoned into a Natural Forest Management and Industrial Tree Plantation area. The SLFR was gazetted as a timber production forest in 1955 and has been managed by a few private companies to date (Wilting & Mohamed, 2010). The SLFR is divided by Sungai Lokan in the north, Sungai Tabalion in the south, and Sungai Rawog in the center, whereas the eastern area of the forest consists of part of the basin formed by three rivers: Sungai Lokan to the north, Sungai Rawog Besar, and Sungai Tabalion Besar to the south (Hasmat et al., 2020).



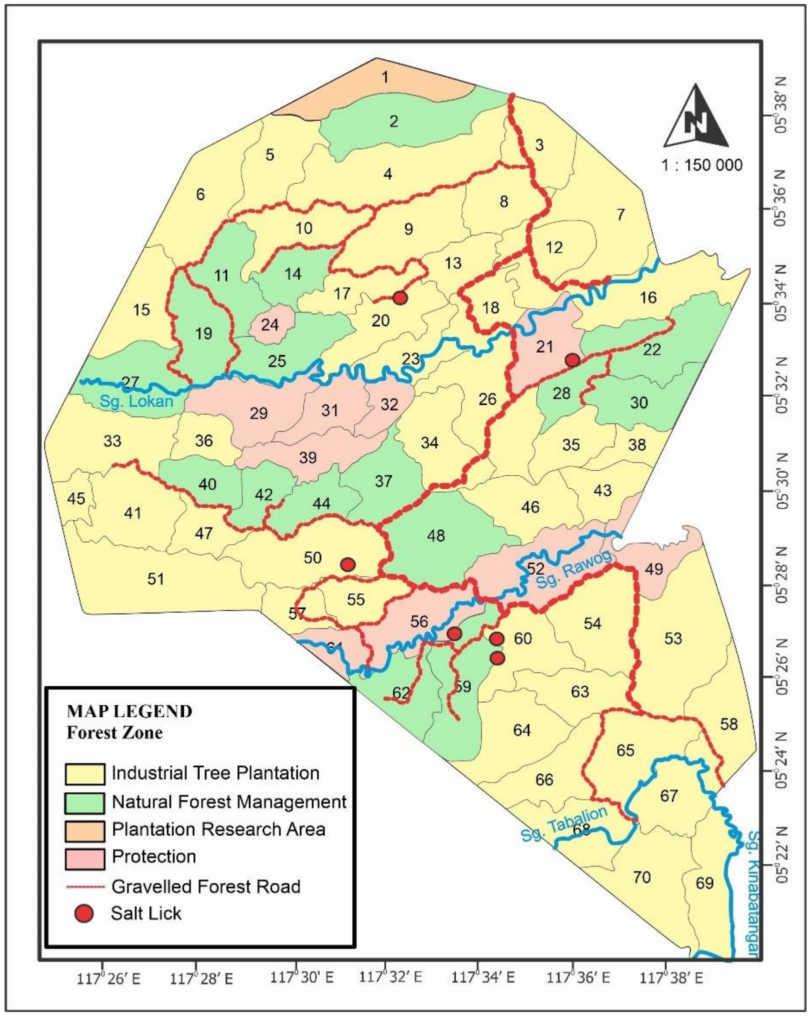


Figure 1 Map of Segaliud Lokan Forest Reserve, Sabah showing the forest zones and numbers of compartments.

(Source: https://www.segaliudlokan.com/)

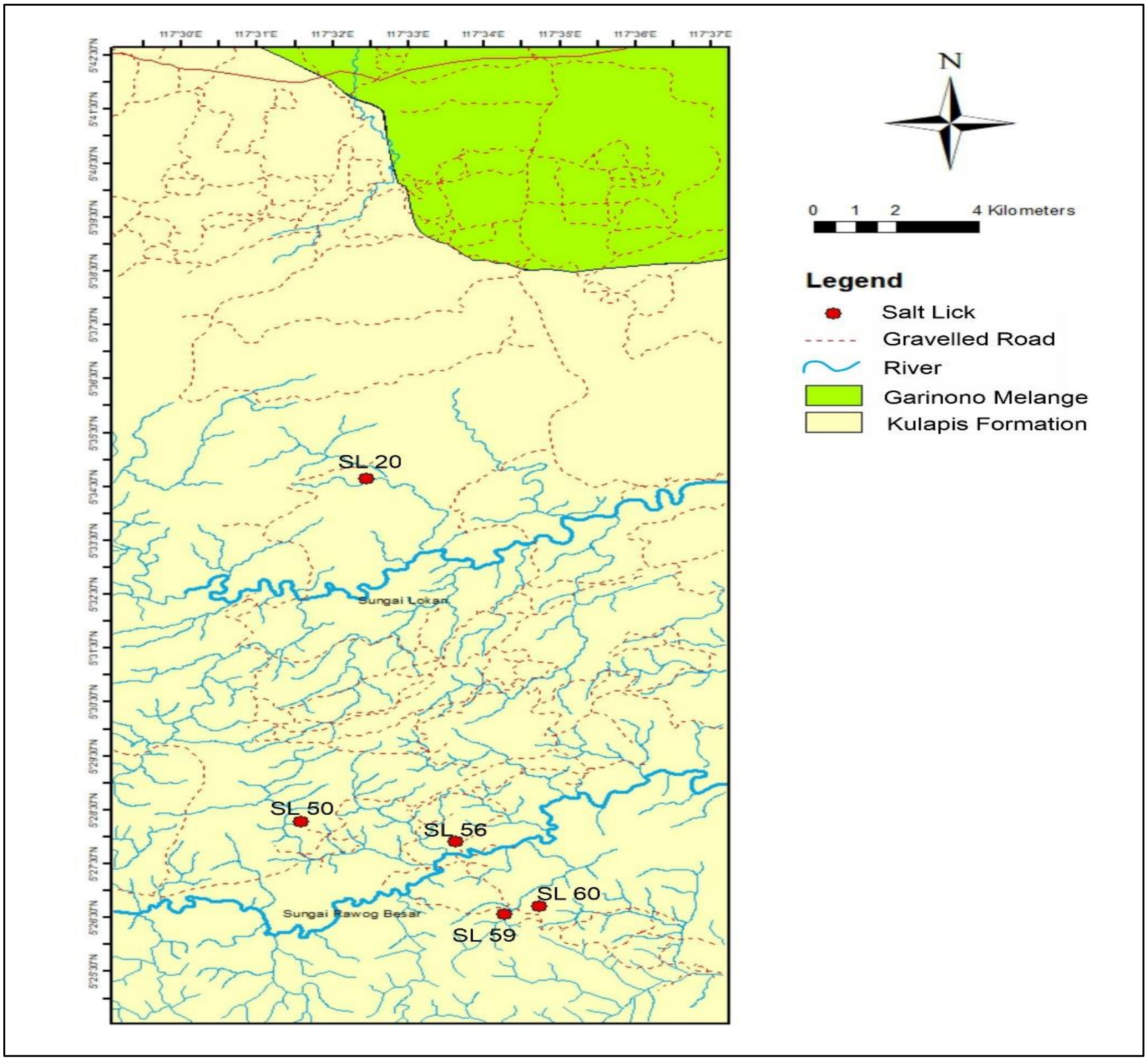


Figure 2 Geological map of Segaliud Lokan Forest Reserve
(Mineral and Geoscience Department of Malaysia, 2015)

This forest reserve is made up of the Kulapis Formation, as shown in Figure 2 (Clennell, 1991; Hutchison, 2005). According to Noad (1998), Kulapis Formation lithofacies consist of thick massive pink coarse-grained sandstone grading up to fine-grained, thick beds of featureless red mudstone, thin dark-red sandstone, and thin interbeds of very fine-grained red sandstone and thicker mudstone. Kulapis Formation is a distinctive wholly red bed formation where all the rocks have a red colour varying from pink sandstones to chocolate-brown shales, probably indicating an iron-rich source, perhaps from the nearby uplifted ophiolite (Hutchison, 2005).

The location of the salt licks is approximately 500 metres from the nearest gravel road. Researchers went by foot through the forest to reach the salt licks area, as no open access was provided. Each salt lick is named after the forest's compartment where they are located. The salt lick's site description is shown in Table 1.

Table 1: Licks, GPS coordinates, and site description.

Licks	Coordinate	Site Description
SL20 (n=11)	N 05^{O} 34’ E 117^{0} 32’	It is the farthest from other licks and located at the north of the research area. This salt lick is situated right next to an unpaved road. The slope height is approximately 2 to 3 metres from the road surface. Mud puddles can be seen on the surface of lick soils, as well as boulders scattered around the lick. The soil is dark in colour with no vegetation. Animal footprints were found in the lick. 
SL50 (n=5)	N 05^{O} 28’ E 117^{0} 31’	The salt licks are situated in the western part of the study area. This lick shows a flat and rocky area. Shrubs and low-canopy plants grow in the vicinity and are covered with vegetation. A tiny stream flows through seasonally, depending on the total rainfall. Gravel-sized rocks and shells are also present in the soil, as are weathered leaves. The soil is dark in colour. Animal footprints were found nearby, and leeches were also present in the area. 

SL56 (n=3)	N 05^{O} 27’ E 117^{0} 33’	The salt lick area is small compared to other licks and rocky. The size of the rocks in the locality varies with each other. Water puddles exist on the soil surface as well as animal waste products. A small pool can also be seen forming in one place. Soil is dark in colour and available in small amounts with no vegetation. 
SL59 (n=14)	N 05^{O} 26’ E 117^{0} 34’	The small river stream flows through, dissecting the licks into two parts. The flow rate of the stream depends on the rainfall. During the summer season, the stream dries up, and water puddles form on the lick soil surface. This lick is situated near the Rawog River branch. The depth of the salt lick is approximately 2–3 m from the slope. Soil colours range from yellowish to darker brown. Greyish-black soil is also present within the lick, indicating the presence of carbon. Flocks of butterflies are observed, as are vegetation and animal footprints. 

SL60 (n=11)	N 05^{O} 26’ E 117^{0} 34’	It takes a hike to get to the salt lick spot. Outcrops were spotted before being crushed by animal activities. Large boulders made up the lick vicinity, and puddles of water were spotted on the soil surface with no vegetation. The lick is approximately 2–3 m deep and darker. 

Sampling

A total of five (5) natural mud from salt licks were found scattered in the forest. Soil sampling was collected using the horizontal (Photo 1) and vertical (Photo 2). Horizontal sampling is carried out by taking out a thin layer of the topsoil. Vertical sampling was collected using PVC pipes with a diameter of 10 cm and a length of 100 cm. The pipes were closed tightly using styrofoam cork to avoid contamination. Once the samples arrived in the laboratory, the core samples were sliced and divided 10 cm thick accordingly. Controlled soil samples were also collected approximately 500 m away from the salt lick location for comparison. The control site is soil taken underneath shades of trees with zero influence of water. A total of forty-four (44) salt lick soil and eight (8) control soil samples were obtained.

Photo 1 (a) Horizontal sampling was carried out by clearing the top layer of the soil surface before taking soil samples. (b) Vertical soil sampling was carried out using PVC pipe hammered into the soil profile.

Physico-chemical analysis

The physico-chemical parameters were pH, moisture content (MC), organic matter (OM), and electrochemical conductivity. The pH analysis was conducted shortly after the samples arrived in the laboratory (BS 1377-3: 1990). The samples were air dried at 1050 for 8 hours in an oven (BS 1377-2: 1990). The sample preparation for organic matter was conducted according to BS 1377-3:1990, where the samples were left overnight in a furnace at 4000 °C with the dry combustion method. Electrical conductivity analysis for the soil samples was determined using a 1:5 suspension of soil in water (BS 7755-3.4:1995).

Geochemical analysis

Geochemical analysis for calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg) in soil was determined by using inductively coupled plasma-optical emission spectrometry (ICP-OES) with the Perkin Elmer Optima model 5300DV. For the sample preparation, the soil was air dried, ground until powdered, and sieved through a 0.063-micrometre sieve for easier metal digestion. About 1 gramme of soil is weighed, added to 14 ml of aqua regia solution, and left overnight. The aqua regia were produced by mixing hydrochloric and nitric acid in a 3:1 ratio. The solution is then heated for 90 minutes and cooled down before adding 4 ml of aqua regia and heating again for 30 minutes (USEPA, 1996). The solution is then left to cool to room temperature, filtered through a 0.45-micrometre membrane filter, and diluted to 50 mL with deionized water.

RESULTS AND DISCUSSIONS

Results

Physico-chemical properties

Table 2 shows the soil physico-chemical properties of soils in five salt licks from the study area. The result for pH is slightly acidic to slightly alkaline, with an average of 7.30 ± 0.08. Muddy environment licks (SL20 and SL60) are slightly alkaline, whereas gravelled licks are slightly acidic (SL56 and SL59). The SL50 lick shows an almost neutral soil pH. The moisture content, organic matter, and electrical conductivity were (33.88 ± 1.67%), (4.12 ± 0.30%), and (177.46 ± 4.76 uS/cm), respectively. Generally, silt percentage (44.79 ± 21.15%) is the main component that makes up the salt lick soil, followed by sand (31.66 ± 22.97%) and clay (23.45 ± 11.95%), whereas sand percentage (47.69 ± 10.28) is the highest particle detected in the control soil.

Table 2 Physico-chemical properties (average values) of licks and control soil.

Sampel	SL20 (n=11)	SL50 (n=5)	SL56 (n=3)	SL59 (n=14)	SL60 (n=11)	Salt Lick Mean ± SD (44)	Range	Control (n=8)	Control SD (8)
pH	8.58	7.13	6.04	6.06	8.03	7.30 ± 0.08	4.69-9.49	4.90	± 0.07
MC (%)	26.04	38.36	36.00	44.78	25.22	33.88 ± 1.67	4.84-61.65	13.99	± 0.74
OM (%)	0.95	3.80	5.27	7.83	2.41	4.12 ± 0.30	0.08-12.11	3.05	± 0.23
EC (uS/cm)	260.88	243.32	224.39	48.59	100.69	177.46 ± 4.76	14.12-375.04	38.05	± 1.53
Sand (%)	33.56	42.79	66.79	30.73	16.29	31.66 ± 22.97	4.41-80.08	47.69	± 10.28
Silt (%)	40.88	34.83	14.69	46.43	59.36	44.79 ± 21.15	2.89-82.94	28.81	± 6.90
Clay (%)	25.56	21.48	18.53	22.84	24.35	23.45 ± 11.95	4.98-78.48	23.50	± 7.29
Texture	Loam	Sandy Loam	Sandy Loam	Silty Clay Loam	Silt Loam			Sandy Loam	

Essential element concentration

The geochemical concentration of essential elements in each lick's soil varies with each other (Table 3). Generally, lick soils contain a higher nutrient composition compared to control soil. Calcium (Ca) has the highest concentration in all salt-lick soils, followed by potassium (K), magnesium (Mg), and sodium (Na). The SL20 and SL60 show significantly higher concentrations of Na and Mg compared to other licks. SL20 and SL50 are rich in Ca.

Table 3 Chemical concentration (average values) of soil from salt licks.

Sample	Concentration (mg/kg)			
	Ca	**K**	**Na**	**Mg**
SL20 (n=11)	7966.03	2355.41	615.09	5305.13
SL50 (n=5)	11551.64	1456.29	199.60	2501.74
SL56 (n=3)	1101.92	980.54	154.56	1442.14
SL59 (n=14)	1914.28	910.27	106.36	1446.85
SL60 (n=11)	3288.95	2053.73	727.34	5208.01
Controls (n=8)	1470.31	1102.05	186.73	1692.65

Discussions

Physico-chemical properties

The slightly alkaline soil observed in muddy salt licks is associated with high-soluble salts. According to Ardahanlioglu et al. (2003), the high sodium concentration affects the soil's overall pH value, which otherwise explains the lower sodium concentration in slightly acidic licks.

The moisture content in the lick soil is also higher than in the control soils. The presence of seasonal small streams and water seepage cutting through the lick promotes a high percentage of moisture content, apart from soil texture parameter influence. Fine-textured soils have higher water retention ability compared to coarse-textured soils (Tufaila et al., 2016) because fine-textured soils have more pore space (Zacharias & Wessolek, 2007; Eluozo, 2013; Mairghany et al., 2019) and an absorptive surface, thus having better water holding capacity (Nurhayati, 1986; Marakkala et al., 2018). The high percentage of moisture content in SL50, SL56, and SL59 is presumably affecting the high organic content in the licks. According to Bot and Benites (2005), soil conditions that are continuously saturated with water will cause poor aeration in the soil, thus causing low oxygen availability. This environment will result in low mineralization, where organisms become less active or dead. A prolonged water-saturated environment in the soil and a low decomposition rate could produce considerable organic matter. Low organic matter was observed in SL20 and SL60 compared to control soils. These may be due to the direct effect of the ungulates using the licks (Walters & Deluca, 2007), and active activities such as trampling in these areas cause soil compaction and further degrade soil physical properties (Greene et al., 1994).

Othaman et al. (2020) state that the soil's electrical conductivity values reflect the soil salinity (salt concentration), where the higher the electrical conductivity value, the higher the salt concentration in the soil, and vice versa. The SL59 shows lower electrical conductivity values, suggesting less soluble salts are readily available in the soil. The low electrical conductivity value was perhaps due to good drainage conditions, which favoured the removal of bases by percolation (Rao et al., 2017). A small seasonal stream cutting through the soil affects the dilution process of mineral concentration in the soil (Anderson et al., 1997; Anderson & Dietrich, 2001).

Textural variances were also observed between salt lick soils and control soils. The differences were influenced by the nature of the source materials and some geomorphological events that occurred at these locations (Molina *et al.*, 2014). The mud salt licks show geochemical characteristics like weathering of rocks and other origins such as erosion of surface soil or sediments transported by water that are associated with the salt licks. The dissimilarities in grain size and particle content could be a result of the mixed structure of the mud salt licks, which continuously receive eroded materials from other components of the habitat both in and above the surface soil (Molina et al., 2014).

Essential element concentration

The salt lick SL50, which is almost neutral soil, shows a high concentration of calcium. This is due to the fact that the parent rock that made up the study area is calcareous lithic arenite sandstone (Hutchison, 2005), which is rich with calcium. According to Hutchison (2005), calcitic concretions are common in the thicker sandstone beds of Kulapis Formation. He also states that the sandstones are quartz-rich and contain plagioclase and chert grains. Thus, the co-existence of calcium elements and quartz in equilibrium may give rise to the neutral soil pH obtained in SL50. The existence of high calcium content in alkaline soils is influenced by the decomposition processes of animals, microorganisms, and plants. The decomposition process will cause calcium to be mineralized and released back into the soil (Attiwill & Adams, 1993). Mineralization rates are large and differ significantly among tree species, affecting the spatial pattern of soil acidity and calcium availability in a mixed-species forest stand (Dijkstra, 2003). A greater calcium concentration also indicates a higher clay content in the soil (Espinoza et al., 2012).

Potassium was found to be low in gravelled licks (SL 50 and SL 56) compared to muddy environments (SL 20 and SL 60). Mengel et al. (2001) state that the concentration of potassium in soil depends on the type of clay minerals present. In humid areas, illite was accompanied by vermiculite and smectite as the K+ (Shakeri & Abtahi, 2018). Potassium in acidic soil is low in concentration. Acidic soils are abundant with H+ and Al3+. During soil acidification, cations of calcium, magnesium, potassium, and sodium are leached out with rainwater and replaced by hydrogen and aluminium (Filipek, 2011).

According to Fang et al. (2021), high concentrations of salt and high pH often occur simultaneously in nature. Even though the soil contains a high concentration of soluble calcium, magnesium, and potassium salts, the predominant cause of salinity in soils is sodium salts (Rengasamy, 2006). Thus, the sodium concentration in SL20 and SL60 can be considered the predominant minerals in both licks, which are alkaline in nature. Acidic licks (SL56 and SL59) show almost similar nutrient concentrations to each other and are in the same range as control soils. Both of the salt licks are also influenced by water flows dissecting the licks. Continuous stream flows cause the elements to leach from soils to the water body (Addiscott & Wagenet, 1985; Roos & Åström, 2005; Saarinen & Kløve, 2012) and carry away, thus the relatively low nutrient concentration compared to other licks.

Magnesium concentrations are higher in salt licks SL20, SL50, and SL60 compared to other salt licks and control soils. Generally, magnesium and calcium share the same element reaction for ion exchange (Mikkelsen, 2010). According to Wang et al. (2020), exchangeable magnesium concentration in acidic soil were low. This is because, relative to base ions, hydrogen ions and aluminium ions were more prevalent in acidic soil and trapped there by the clay colloid. Noticeable variation in element concentration from the five licks suggests that each lick serves different purposes in supplying nutrients for animal usage (Ayotte et al., 2006; Molina et al., 2014).

Table 4 compares the mineral concentrations reported in previous studies with the present study. Overall, salt licks located in Sabah (Deramakot Forest Reserve and Segaliud Lokan Forest Reserve) are higher in mineral concentration compared to salt licks found scattered in Sarawak. A comparison within local salt licks shows that the mineral concentration found in this study is higher than the salt lick found in Deramakot Forest Reserve, with the exception of potassium and magnesium concentrations, which are a bit lower. Interestingly, both of these forest reserves are located in the same formation, which is the Kulapis Formation. This proves that although the area is made up of the same rock formation, the soil formed from the weathering processes varies with mineral concentration.

Table 4 Chemical concentration (average values) of soil from salt licks.

Salt Lick Location	**Concentration ranges (mg/kg)**			
	Ca	**K**	**Na**	**Mg**
Deramakot Forest Reserve, Sabah Matsubayashi et. al (2007)	700 - 4400	1300 – 10060	200 – 600	1200 – 8600
Central to interior parts of Sarawak (Siong, 2020)	Nd – 1017	454 - 1834	Nd - 136	450 - 3627
Segaliud Lokan Forest Reserve (This Study)	1101 - 11551	910 - 2355	106 - 727	1442 - 5305

Nd – not detected

CONCLUSION

It was found that each salt lick in Segaliud Lokan Forest Reserve (SLFR) varies in physico-chemical composition and geochemical concentration. The salt lick soil's pH ranges from slightly acidic to slightly alkaline. The high moisture content in the salt lick's soil is the result of the occurrence of a seasonal stream with the support of a fine-grained texture that has high water retention abilities. The prolonged condition of water-saturated soil will cause anaerobic reactions and yield a considerable amount of organic matter in the soil. The salt lick's soils also show a high electrical conductivity value, reflecting the abundance of salt found in the soil. The chemical concentration in Salt Lick's soils was higher compared to control soils. The abundance of calcium and magnesium, as well as elevated potassium and sodium concentrations in salt-licked soil, serve as sources of nutrients.

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