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Properties and indigenous knowledge of soil materials used for consumption, healing and cosmetics in KwaZulu-Natal, South Africa

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Abstract

Ethnopedological studies focus on agricultural soils resulting in undervaluation of non-agricultural soil materials during land classification. In this study, ethnographic and ethnopedologic methods were used to obtain local knowledge and gain in-depth understanding of non-agricultural soils, their mineralogical and elemental composition relating to application in geophagy, healing and cosmetic purposes in two villages in KwaZulu-Natal, South Africa. In each village a questionnaire was administered to fifty randomly selected individuals from which ten knowledgeable volunteers (including eight geophagists from two villages) provided details on the selection criteria, the desired properties and why the soils performed the claimed role. Users based their selection on macromorphological features (e.g. colour, texture and location within the soil) and indigenous knowledge. Geophagic materials were mainly sourced from C horizons. They were mostly fine-grained with mica, kaolinite and quartz, and elements such as copper (Cu), zinc (Zn), cobalt (Co) and lead (Pb). Natural pigments, such as iron oxides in highly weathered soils, were recognised as sunscreen materials. Although the mechanisms were not understood by users, laboratory analyses showed that the mineralogical and chemical properties of the soil materials played a crucial role. The sunscreen and healing capabilities of these soils were related to high contents of titanium (TiO_2) and iron (Fe_2O_3) and the presence of kaolinite. Further appraisal of these soil materials is necessary for their conservation and inclusion in land classification.

1. Introduction

Most ethnopedological studies have focused on agricultural soils with less attention paid to non-agricultural soil materials and their possible uses (Cabral et al., 2015). This can result in the disregard of soils with low agricultural potential but considered by some users as suitable for other purposes. Thus, understanding ethnopedological knowledge associated with non-agricultural uses of soil materials as well as their defining properties is necessary to achieve sustainable and unbiased land use and management.

Soil can be a raw material for various goods and services owing to their structural and chemical properties (Carretero and Pozo, 2010). For example, the use of clayey soils for cosmetic purposes and for sun protection is common in many indigenous African communities (Matike et al., 2010; Molefe, 2015; Morekhure-Mphahlele et al., 2017), suggesting local understanding of the properties of soil materials.

Some properties of soil materials such as viscosity, consistency, texture, and clay mineralogy are essential for their cosmetic suitability (Carretero, 2002; López-Galindo and Viseraz, 2004; Carretero and Pozo, 2010; Matike et al., 2011; Ngomo et al., 2014). Clay particle size and chemical composition are of great importance regarding UV-reflection and UV-absorption functions, respectively (Hoang-Minh, 2006). Many studies (Carretero, 2002; López-Galindo and Viseraz, 2004; Carretero et al., 2020) have shown that clay minerals such as kaolinite, smectite, and talc as well as rutile provide protection against external physical and chemical agents due to their ability to adhere to the skin forming a film. However, these studies have focused mostly on commercial products while little attention has been paid to soil materials used traditionally in many rural communities. While soil materials used for healing/cosmetic purposes relate more to external injuries, others are ingested (geophagy).

Geophagy has been recorded in numerous African traditional communities (Diko and Ekosse, 2014; Ekosse et al., 2017; Kambunga et al., 2019). The ingested material is generally selected based on colour and texture (Nchito et al., 2004; Ngole et al., 2010) with a preference for red clayey soils (Diko and Diko, 2013). Geophagy has been associated with advantages relating to mineral supplementation, especially iron (Harvey et al., 2000) as well as copper (Cu), magnesium (Mg), selenium (Se), zinc (Zn) and iodine (I) (Abrahams et al., 2006; Rifkin, 2012). However, some geophagic materials have been reported to affect dental enamel and increase prevalence of anaemia and helminth infection (Geissler et al., 1999; Ngole et al., 2010) and may contain heavy metals such as Pb and Cd (Orisakwe et al., 2020). Effects of geophagy vary depending on the physicochemical properties, mineralogy and geochemistry of the ingested soil material. Studies have been undertaken in South Africa to characterise geophagic materials and understand possible implications for geophagists (George and Ndip, 1997; Ekosse and Ngole, 2012; Diko and Diko, 2013; Sumbele et al., 2014, Mashao et al., 2021). These and other studies on healing/cosmetic soil materials (Matike et al., 2010; Mpako et al., 2011; Dlova et al., 2013; Mashao et al., 2021) have however been focused on the Eastern Cape, Free State and Limpopo Provinces, with little data from KwaZulu-Natal (KZN) (Saathoff et al., 2002; Msibi, 2014; Morekhure-Maphahlele et al., 2017).

This study thus investigated some geophagic, cosmetic and healing soil materials of KZN. The aim of the study was to (i) examine the physicochemical and mineralogical properties of geophagic materials and their possible implications for the health of the users and (ii) characterise healing, sunscreen and cosmetic soil materials to establish possible explanations for their effectiveness.

2. Materials and Methods

2.1. Site description

The study was conducted at Potshini and Khokhwane villages (Fig. 1) in KZN. Potshini (28.8145°S, 29.3679°E) is located in the foothills of the Drakensberg Mountains, north-western KZN at about 1300 m a.s.l. The geology is a horizontal succession of Permo-Triassic fine-grained sandstone which is interbedded with shale, siltstone and mudstone of the Beaufort and Ecca Groups of the Karoo Supergroup (Dlamini and Chaplot, 2012) with soils dominetd by Acrisols, gleysols and ferralsols (Buthelezi-Dube et al., 2018). This area is characterised by Northern KwaZulu-Natal Moist Grassland (Mucina and Rutherford, 2006) and recieves a mean annual rainfall of 700 mm with 34°C and −4°C as maximum and minimum annual temperatures, respectively (Kongo et al., 2010). Khokhwane (29.7014°S, 30.1039°E) is located in central KZN about 53 km north of Pietermaritzburg at about 1 300 m a.s.l. Shale of the Ecca Group dominates the underlying geology and the vegetation is Moist Midlands Mistbelt with species including *Alloteropsis semialata*, *Aristida junciformis*, *Digitaria eriantha* (tall form), *Digitaria tricholaenoides*, *Harpochloa falx*, *Acacia dealbata*, *A. Mearnsii* (Mucina and Rutherford, 2006; Camp and Hardy, 1999). Khokhwane receives an average annual rainfall of 750 mm with maximum and minimum annual temperatures of 22.8°C and 9°C, respectively. The areas is dominated by ferralsols (Buthelezi-Dube et al., 2018).

2.2. Ethnographic and ethnopedological study

Ethnographic and ethnopedological investigations were conducted in both villages to obtain knowledge relating to non-agricultural soils and their uses. Ethnographic techniques employed were questionnaires and interviews (Oudwater and Martin, 2003). The questionnaires were administered to 50 ran-

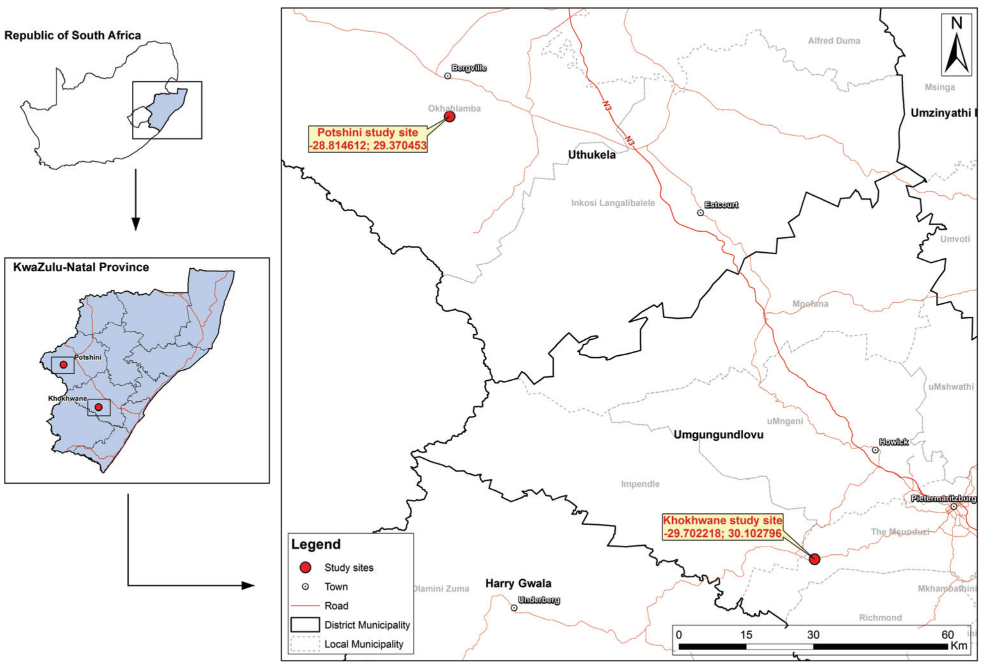

Fig. 1. Location of Potshini and Khokhwane in KwaZulu-Natal, South Africa

domly selected individuals from each village to ascertain general information on existing non-agricultural soils as well as their uses. Ten of the 50 individuals were then chosen for detailed semi-structured interviews to gain more information regarding the selection criteria for the non-agricultural soils used, their desired properties, possible mechanisms through which they performed the claimed function, their locations and sampling. Only eight of these were geophagists (five from Potshini and three from Khokhwane) from which in-depth information about the habit of ingesting soil was obtained. Although this was only a small number of people, they were knowledgeable and had first-hand experience in geophagy. They were thus used as key informants about geophagic soil materials. The individuals were chosen for interviews based on their willingness and depth of knowledge shown during the questionnaire stage. Interviews consisted of both closed and open questions to allow respondents to give detailed information.

2.3. Soil sampling

Five samples used for geophagy were collected from Potshini (samples G1 to G5) and two from Khokhwane (samples G6 and G7) (Fig. 2). The number of samples was determined by the sites identified by geophagists. One type of soil material (locally referred to as *ukhethe* – rocky soil, leptosol) is consumed in both villages. All the samples were collected either from below the solum in the unconsolidated material of ferralsols (Potshini) or from partially weathered rock or bedrock of leptosols (Khokhwane) (Fig. 2). The soils were classified according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014).

The preliminary questionnaires revealed another non-agricultural soil type (locally known as *ibomvu* – red, clayey soil) classified as a ferralsol that is used for healing, cosmetic and sunscreen purposes (Fig. 3). Some respondents in Potshini referred to the same material as *umadilika* (Fig. 3a). One sample of *ibomvu* was thus collected from each of the two villages near the lower boundary of the B horizon in a ferralsol (H1 and H2). In addition, two soil samples with healing properties, also from the subsoil of ferralsols, were obtained from rural locations near Louwsburg – H3 (27.5762°S, 31.2798°E) and Nkandla – H4 (28.6223°S, 31.0894°E) in northern KZN. All studied healing soil samples were collected from soils derived from dolerite parent material. These locations were chosen because of the prominent use of *ibomvu* for both healing and cosmetic purposes (Siphindile Sibiya, pers. comm., January 2016). Red soils respondents described as unsuitable for healing and cosmetic purposes during interviews were collected as comparison samples for each of the healing/cosmetic soils from Potshini (C1) and Khokhwane (C2). Similar to sampled healing/cosmetic soils, the comparison samples were red but not from the same depth as healing/cosmetic soils.

Geophagic and healing/cosmetic samples were collected using a geological pick or knife. All samples were air-dried, ground and sieved to pass a 2 mm mesh prior to laboratory analysis.

Fig. 2. (a) Examples of some geophagic materials from Potshini (G1, G2 and G3) and Khokhwane (G6 and G7) and (b) the geophagic soil (Glenrosa – Soil Classification Working Group, 1991; Leptosol-IUSS Working Group, WRB, 2014) in Khokhwane from which G6 was collected.

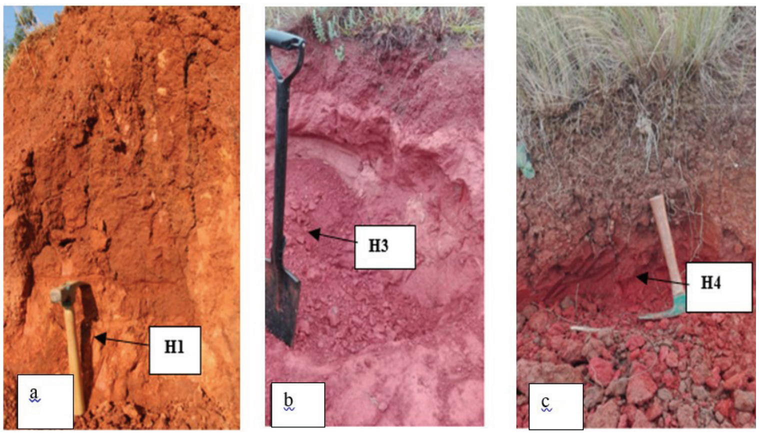

Fig. 3. Oxidic soils (Ferralsols) at (a) Potshini, (b) Louwsburg and (c) Nkandla from which healing materials (H1, H3 and H4, respectively) were collected.

2.4. Soil analysis

All the samples were analysed for pH (1:2.5 ratio of soil:1M KCl) using a pH meter, exchangeable calcium (Ca), magnesium (Mg) and acidity (extracted with 1M KCl) and potassium (K), zinc (Zn), copper (Cu) and manganese (Mn) extracted with ammonium bicarbonate solution (Manson and Roberts, 2000) and analysed using the inductively coupled plasma-optical emission spectroscopy. Both major and trace elements were determined using X-ray fluorescence spectrometry on a PANalytical Axios Wavelength Dispersive spectrometer. Particle size distribution was determined using the pipette method (Gee and Bauder, 1986). Soil colour was determined using Munsell colour charts (Firm) (2010). Powder X-ray diffraction (XRD) of bulk samples was carried out using a back-loading preparation method. The analysis was performed with a PANalytical Empyrean Diffractometer with an X'Celerator detector operated at 40 kV and 30 mA, with monochromated Co-Kα radiation (XRD, PANalytical X'PRO Pert). Fluka quartz standard was used as a reference materials. The diffractograms were interpreted semi-quantitatively using X'Pert HighScore Plus software (The HighScore suite, 2014). Two of the healing samples (H1 and H2), that were also used for cosmetic purposes and their comparison, non-healing samples (C1 and C2), from Khokhwane and Potshini, were analysed in their natural state with an Optometrics SPF 290 Analyser (Optometrics Corporation, Ayer, MA, USA) and a Multiport Solar Simulator to estimate their UV protection efficiency. The in vitro sun protection factor (SPF) testing procedure developed by Diffey and Robson (1989) was used according to the sunscreen standard (SANS 1557) of South Africa.

2.5. Data analysis

Qualitative data collected were coded and subjected to descriptive analysis using SPSS version 24 (IBM SPSS Statistics, 2016).Open ended questions from interviews were analysed informally using themes developed from word-based techniques, *viz*. word repetition and key indigenous terms (Ryan and Bernard, 2003). Words, synonyms and phrases that respondents used repeatedly were noted and later used to identify recurring themes related to questions asked.

3. Results

3.1. Data obtained from questionnaires and interviews

Questionnaires (n = 50 in each village) revealed that 74% and 35% of respondents mentioned geophagy as one of the non-agricultural uses of soils in Potshini and Khokhwane, respectively. However, according to respondents this was perceived as an aberrant behaviour and rarely openly practised. All eight of the key informants were females of childbearing age. The individuals collected the soil in its original state and/or sun dried for consumption. When asked why they ingest soil they gave a number of reasons including desirable sour taste (7), craving (6), pregnancy (4) and smell (4). Interviewed geophagists would consume a quarter to a full 250 mL cup (between about 62 and 246 g) from once daily (4) to once a week (2) or not often (2). They preferred soils that had a soft and smooth feel in the mouth.

Preliminary questionnaires revealed that *ibomvu* (ferralsol) is used in cultural rituals associated with female traditional initiations (60%, n=100) and clan identification (64%, n=100). For example, in preparation for *umemulo* (a ceremony through which a young female is initiated into womanhood) *ibomvu* is used for cosmetic purposes to cleanse and lighten a girls' skin prior to the actual ceremony. The clan identification ceremony involves face scarification or cutting of the small index finger performed mostly on infants with surnames such as Zuma, Mchunu and Zondi. According to respondents, *ibomvu* paste is applied onto the cut to facilitate healing and prevent infection of the scars as the wound dries and heals faster. The interviews further revealed that *ibomvu* is only used for topical application. Respondents also indicated that *ibomvu* has become a common sun protectant, particularly for women.

3.2. Physical and chemical properties of soil samples

All geophagic samples were partially weathered with easily disaggregated rock found at the base of soil profiles developed by in situ weathering. The physical and chemical properties of the geophagic samples are given in Table 1. All the samples were loamy with higher content of medium and coarse sand in Khokhwane samples (G6 and G7) compared to those from Potshini. Of the five samples from Potshini, one had red coloration, one yellow and three were brownish, similar to the two from Khokhwane (Table 1). All samples were characterised by a strongly acidic reaction (pH < 4.0) with higher concentration of exchangeable Mg^{2+} (1.13–2.71 $cmol_c\ kg^{-1}$) compared to Ca^{2+} (0.33–1.63 $cmol_c\ kg^{-1}$) and K^{+} (0.27–0.53 $cmol_c\ kg^{-1}$).

The healing soil samples had a pH ranging from 3.91 to 4.21 (Table 2). Both H1 and H2 samples had a similar pH to their respective comparison samples (C1 and C2). All healing soils had low concentration of exchangeable cations (Table 2). The comparison samples had higher concentration of Ca than all the healing soil samples. The silt content in all the healing soil samples was high and ranged from 51% to 66%. Sample H3 had the lowest clay content (15%) while the other three healing soil samples had similar clay content (between 33 and 36%). The comparison samples had higher clay (>40%) and lower silt fraction (<30%) contents. All soils had reddish brown colours.

3.3. Mineral composition of soil samples

All geophagic materials consisted of both clay and non-clay minerals (Table 3; Fig. 4 and 5). The most dominant mineral phases were quartz (30–60%) and mica (40–80%) in all samples. Except for G1 and G2 samples, the other samples also contained kaolinite. In addition, G2 sample had residual anatase (a form of titanium dioxide) at 0.35 nm while G2 and G5 samples had trace quantities of a 1.4 nm clay mineral.

Table 1
Physical and chemical properties of the geophagic soils from Potshini (G1 – G5) and Khokhwane (G6 and G7).

Parameters	G1	G2	G3	G4	G5	G6	G7
pH (1M KCl)	3.68	3.65	3.81	3.85	3.81	3.75	3.91
Exchangeable acidity ($cmol_c kg^{-1}$)	4.52	5.00	4.63	5.35	7.90	2.71	3.40
K^+ ($cmol_c kg^{-1}$)	0.33	0.36	0.33	0.28	0.33	0.53	0.27
Ca^{2+} ($cmol_c kg^{-1}$)	1.60	0.79	1.23	0.85	0.33	1.30	0.87
Mg^{2+} ($cmol_c kg^{-1}$)	2.71	1.88	2.03	2.87	1.13	2.65	1.97
Zn ($mg kg^{-1}$)	1.40	0.57	0.49	0.43	0.21	0.37	0.93
Mn ($mg kg^{-1}$)	24.8	59.6	85.4	21.5	6.45	17.6	37.1
Cu ($mg kg^{-1}$)	1.00	0.96	1.10	1.80	0.64	0.55	0.82
Clay (<0.002 mm) (%)	34.3	25.2	47.3	17.7	19.3	12.1	15.4
Silt (0.05–0.002 mm) (%)	57.4	27.1	49.5	57.0	42.3	16.5	23.9
Fine sand (0.25–0.1 mm) (%)	2.50	5.40	1.00	8.00	9.20	8.00	7.50
Medium sand (0.5–0.25 mm) (%)	0.30	7.00	0.10	2.60	4.80	10.8	11.0
Coarse sand (2.0–0.5 mm) (%)	0.00	31.5	0.30	0.40	11.5	47.7	39.0
Texture	silty clay loam	sandy clay loam	silty clay loam	silt loam	loam	sandy loam	sandy loam
Munsell notation (colour)	2.5YR 6/6 (LR)	2.5YR 3/4(DRB)	5YR 6/6 (RY)	7.5YR 5/8 (SB)	10YR 5/8 (YB)	10YR6/4 (LYB)	10YR 6/8 (BY)

LR= light red; DRB = dark reddish brown; RY = reddish yellow ; SB = strong brown; YB = yellowish brown; LYB = light yellowish brown; BY= brownish yellow

Table 2
Physical and chemical properties of healing and non-healing soils from Potshini (H1 and C1), Khokhwane (H2 and C2), Louwsburg (H3) and Nkandla (H4).

Parameters	H1	H2	H3	H4	C1	C2
pH (1M KCl)	3.91	4.09	4.05	4.21	3.88	4.05
Exchangeable acidity ($cmol_c kg^{-1}$)	0.99	1.99	1.64	1.34	2.38	1.48
K^+ ($cmol_c kg^{-1}$)	0.23	0.08	0.21	0.04	0.19	0.22
Ca^{2+} ($cmol_c kg^{-1}$)	0.57	0.72	0.66	0.46	1.70	1.30
Mg^{2+} ($cmol_c kg^{-1}$)	0.65	0.80	4.70	0.69	1.20	0.63
Zn ($mg kg^{-1}$)	1.30	0.00	1.50	0.10	4.00	0. 11
Mn ($mg kg^{-1}$)	127	133	81.5	0.20	0.98	9.57
Cu ($mg kg^{-1}$)	4.81	3.78	3.33	1.25	2.36	0.95
Clay (<0.002 mm) (%)	32.6	35.9	14.6	33.1	41.0	54.3
Silt (0.05–0.002 mm) (%)	61.2	51.4	66.1	62.1	26.4	28.9
Very fine sand (0.1–0.05 mm) (%)	3.10	6.00	13.7	3.10	16.9	4.40
Fine sand (0.25–0.1 mm) (%)	2.70	4.90	4.90	1.40	14.0	3.30
Medium sand (0.5–0.25 mm) (%)	0.40	1.30	0.30	0.30	1.60	1.80
Coarse sand (2–0.5 mm) (%)	0.00	0.50	0.40	0.00	0.00	7.30
Texture	silty clay loam	silty clay loam	silt loam	silty clay loam	clay loam	clay
Munsell notation (colour)	2.5YR4/8 (RB)	5YR4/6 (DRB)	5YR 3/6 (DRB)	2.5YR3/6 (DRB)	5YR 2/4 (RB)	5YR 4/6 (VDRB)

RB = reddish brown; DRB = dark reddish brown; VDRB= very dark reddish brown

Table 3
Minerals identified (X) in the geophagic soils from Potshini (G1 – G5) and Khokhwane (G6 and G7).

Mineral	Geophagic samples						
	G1	G2	G3	G4	G5	G6	G7
1.4 nm		X**			X*		
Anatase	X	X	X				
Goethite							X*
Hematite			X*	X*			
Kaolinite			X*	X*	X*	X*	X*
K-feldspar	X					X	
Magnetite				X			
Mica/illite	X***	X**	X***	X**	X***	X**	X**
Quartz*	X***	X**	X**	X**	X***	X**	X**

*5–20%; **21–60%; ***>60%. No asterisk is added to minerals present as traces.

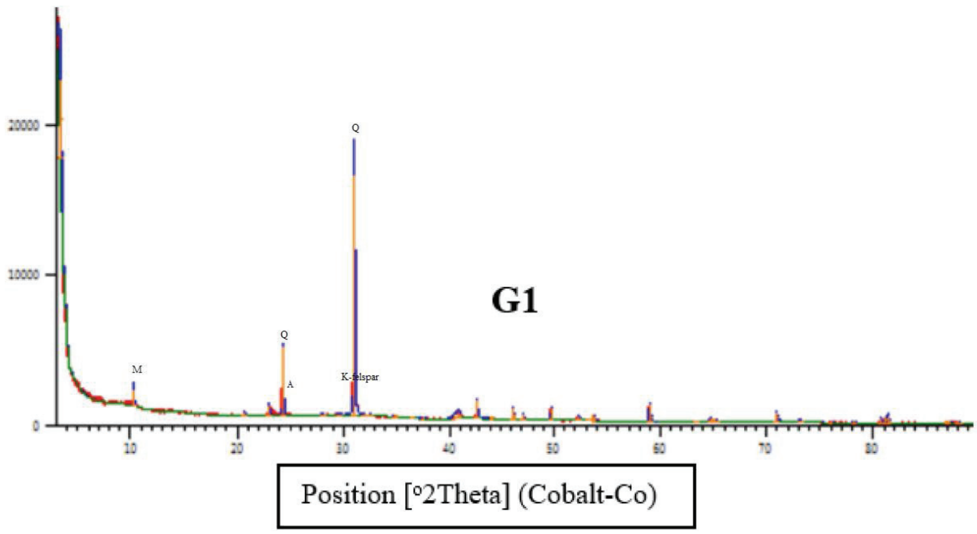

Fig. 4. Powder X-ray diffractogram of geophagic sample G1 from Potshini.

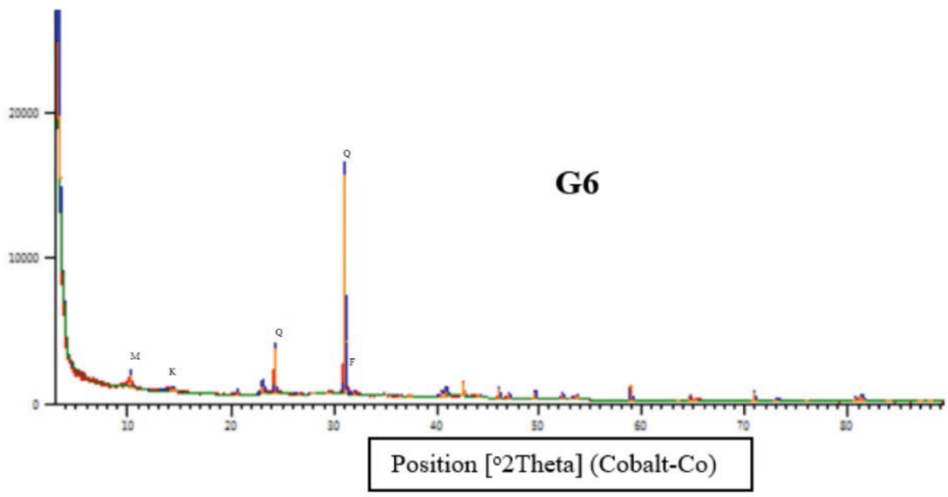

Fig. 5. Powder X-ray diffractogram of geophagic sample G6 from Khokhwane.

All healing and comparison samples had both kaolinite and quartz (Table 4; Fig. 6–8). Kaolinite was the dominant phase (≥70%) in H1 and H2 samples which had only minor quantities of quartz (<6%). Samples H3 and H4 had quite high content of both kaolinite (>20%) and quartz (>40%). Only the comparison samples contained a 1.4 nm clay mineral and K-feldspar. Hematite (0.27 nm) and trace amount of anatase occurred in healing samples H2 and H3 as well as in both comparison samples. Samples H2 and H4 contained gibbsite (0.44 nm), which was also present in both comparison samples. Goethite (0.42 nm) only occurred in samples H1 and H4.

Table 4
Minerals identified (X) in the healing and non-healing soils from Potshini (H1 and C1), Khokhwane (H2 and C2), Louwsburg (H3) and Nkandla (H4).

Mineral	Healing soils				Non-healing soils	
	H1	H2	H3	H4	C1	C2
1.4 nm					X**	X**
Anatase		X	X		X	X
Gibbsite		X**		X*	X**	X*
Goethite	X**			X**		
Hematite		X*	X*		X	X**
Kaolinite	X***	X***	X**	X**	X	X
K-feldspar					X	X
Mica/illite						X
Quartz	X	X	X*	X*	X**	X**

*5–20%; **20–60%; ***>60%. No asterisk was added to minerals present as traces.

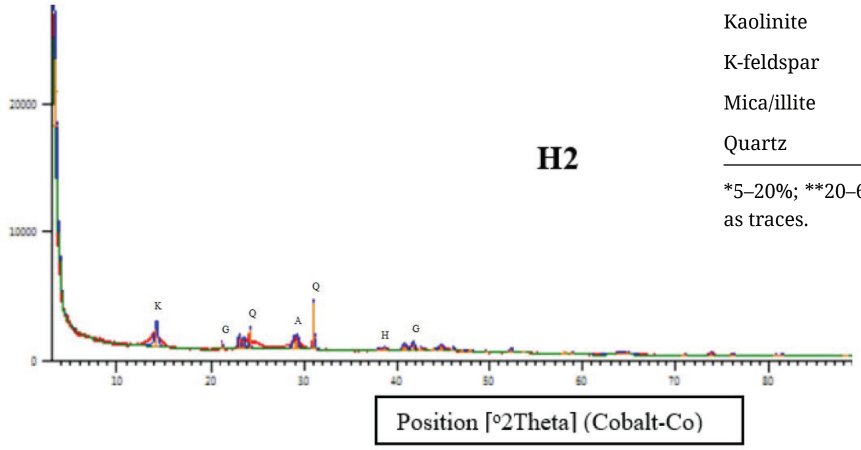

Fig. 6. Powder X-ray diffractogram of healing soil sample H2 from Potshini.

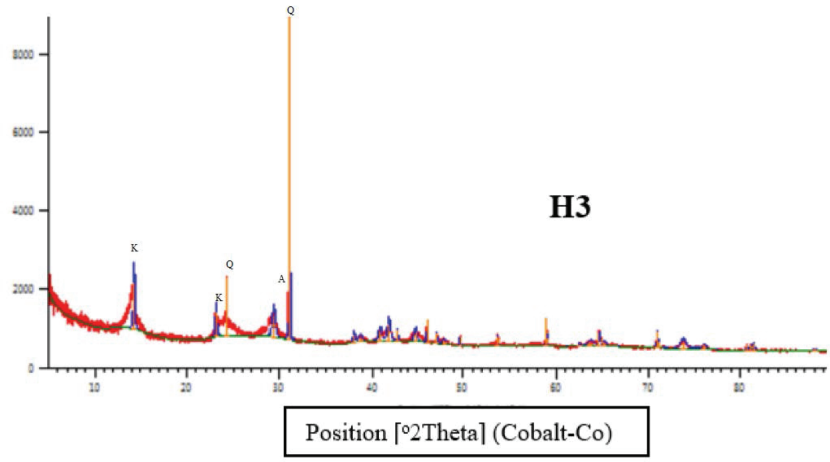

Fig. 7. Powder X-ray diffractogram of healing soil sample H3 from Khokhwane.

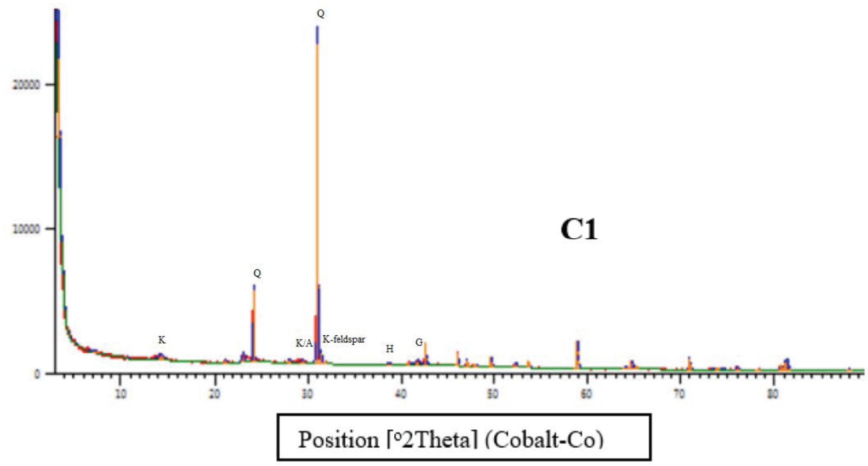

Fig. 8. Powder X-ray diffractogram of comparison soil sample C1 from Potshini.

3.4. Chemical composition of soil samples

Silica (SiO_2; 60–70%), Al_2O_3 (16–21%) and Fe_2O_3 (4–9%) were the main components of the geophagic materials (Table 5). All geophagic samples generally had low alkali and alkaline oxides except for K_2O (2.10–3.75%). The concentrations of Co, Cu and Zn, considered as essential nutrients for humans, and concentrations of Pb, Ni and Ba that are associated with toxicity are given in Table 6. Samples had variable concentrations of these trace elements, especially Zn which was higher in Khokhwane (G6 and G7 samples) compared to all Potshini samples. Sample G2 had markedly higher Ni (224 mg kg^{-1}) while sample G7 had the highest Pb content (51 mg kg^{-1}). Barium content varied between 322 mg kg^{-1} and 644 mg kg^{-1}.

Healing soil samples had higher content of Al_2O_3 (22–29%) and Fe_2O_3 (11–18%) than comparison samples (C1 and C2) with about 17% and 8% Al_2O_3 and Fe_2O_3, respectively (Table 7). Both comparison samples contained about 66% of SiO_2, while healing samples had a lower content of SiO_2 (39–46%). All samples, including the comparison samples, had low (<1.0%) amounts of K, Ca, Mg, Na, Mn and P. Healing samples showed higher loss on ignition (mean of 12%) compared to an average of about 9% in the comparison samples. Titanium oxide was similar between healing soils and comparison samples. However, the highest concentration of TiO_2 (≥2%) was recorded for H1 and H4 with all other samples having <1.4% of TiO_2 content. All healing samples, except for H2, showed consistently high V, Co, Ni and Cu content compared to the comparison samples (Table 8). The highest V, Cr and Ni content were found in H3 sample. Except for H4 sample, healing samples had lower Zn content compared to the comparison samples. Sample H2 had the lowest concentrations of Co, Ni, Cu and Zn but the highest amount of Pb compared to all the other samples. The highest concentrations of Co and Ba

Table 5
Major chemical composition of the geophagic soils from Potshini (G1 – G5) and Khokhwane (G6 and G7).

Oxide (%)	Geophagic soils						
	G1	G2	G3	G4	G5	G6	G7
SiO_2	62.49	61.31	59.97	59.83	69.70	62.78	59.39
Al_2O_3	20.22	20.57	21.57	19.10	16.04	19.46	19.60
Fe_2O_3	6.83	5.90	7.24	7.99	4.18	5.71	8.75
CaO	0.04	0.03	0.06	0.05	0.07	0.06	0.06
MgO	0.60	0.96	0.48	1.00	0.77	1.20	1.01
K_2O	2.13	3.40	2.10	3.68	3.12	3.75	3.18
Na_2O	0.04	0.03	0.04	0.05	0.03	0.05	0.06
MnO	0.03	0.10	0.07	0.10	0.05	0.03	0.06
TiO_2	0.83	0.92	0.91	0.79	0.79	0.87	0.78
P_2O_5	0.06	0.04	0.04	0.20	0.03	0.07	0.10
LOI*	7.15	6.81	7.62	7.48	4.93	6.35	6.85
Total	100.36	100.07	100.09	100.26	99.71	100.30	99.87

* LOI – loss on ignition

Table 6
Selected trace element concentrations of the geophagic soils from Potshini (G1 – G5) and Khokhwane (G6 and G7).

Trace element (mg kg^{-1})	Geophagic soils						
	G1	G2	G3	G4	G5	G6	G7
Ba	322.2	510.1	404.8	643.7	603.7	546.3	616.9
Co	12.19	16.99	33.43	16.94	13.99	7.82	14.53
Cu	48.84	38.46	34.12	27.82	14.90	36.01	36.56
Ni	35.55	224.1	19.45	23.53	15.92	21.88	35.28
Pb	21.40	40.38	32.45	37.79	18.57	21.08	51.10
Zn	81.34	73.87	40.68	80.51	56.88	103.7	124.4

Table 7
Major chemical composition of healing and non–healing soils from Potshini (H1 and C1), Khokhwane (H2 and C2), Louwsburg (H3) and Nkandla (H4).

Oxide (%)	Healing soils				Non-healing soils	
	H1	H2	H3	H4	C1	C2
SiO_2	38.74	45.85	38.54	43.97	66.63	65.87
Al_2O_3	28.96	27.46	28.12	22.14	16.58	15.90
Fe_2O_3	17.4	11.1	18.4	20.4	8.17	8.20
CaO	0.02	0.03	0.02	0.03	0.03	0.03
MgO	0.49	0.24	0.18	0.73	0.13	0.21
K_2O	0.06	1.09	0.50	0.09	0.29	0.29
Na_2O	0.01	0.02	0.03	0.03	0.03	bdl#
MnO	0.20	0.05	0.06	0.30	0.02	0.02
TiO_2	2.01	1.34	1.27	2.28	1.15	1.21
P_2O_5	0.09	0.04	0.05	0.04	0.07	0.07
LOI*	12.3	13.0	13.3	11.8	8.52	8.80
Total	100.35	100.29	100.43	101.07	101.65	100.61

* LOI – loss on ignition; # bdl – below detection limit

Table 8
Selected trace element concentrations of healing and non-healing soils from Potshini (H1 and C1), Khokhwane (H2 and C2), Louwsburg (H3) and Nkandla (H4).

Trace element (mg kg^{-1})	Healing soils				Non-healing soils	
	H1	H2	H3	H4	C1	C2
Ba	72.23	277.9	104.9	500.6	78.15	72.08
Co	65.80	15.50	22.59	141.2	27.40	27.46
Cr	173.6	194.2	304.8	249.8	203.0	201.9
Cu	144.2	44.08	98.55	108.4	56.40	52.16
Ni	102.9	43.75	128.9	86.06	66.64	65.01
Pb	2.98	35.89	10.14	13.50	17.90	17.93
V	236.8	210.4	254.8	204.7	176.1	170.6
Zn	63.11	47.64	60.05	73.19	72.40	75.69

were recorded for sample H4. The trace element contents of the two comparison samples (C1 and C2) were very similar to each other.

3.5. UV-protection characteristics

All the samples had low SPF values (Table 9). Healing soils had SPF values similar to the comparison samples. Both the UVA/UVB ratio and the critical wavelength were similar between the cosmetic samples and comparison samples (Table 9).

4. Discussion

4.1. Geophagic soil materials

The properties of the geophagic soils were largely consistent with the effects reported or desired by local geophagists. For example, interviewed geophagists were women and thus subject to blood loss via pregnancy and menstruation (Campbell and Morrison, 1963). Consuming soil may have been a physiologic response to iron deficiency. Although variable, the reddish colours (Table 1) indicative of iron oxides in the geophagic materials (Tables 3 and 5) may support the micronutrient supplementation hypothesis. The preference for yellowish/reddish or brown colours in geophagic materials has been reported in other studies in South Africa (Ngole et al., 2010; Olowoyo and Macheka, 2013; Ekosse and Obi, 2015) and Cameroon (Diko and Ekosse, 2014; Ekosse and Obi, 2015). This may be attributed to the general association of geophagy with low levels of haemoglobin which suggests iron supplementation by ingested material (Abrahams and Parsons, 1997). Similar to Lakudzala and Khonje (2011) the studied geophagic materials had a high (up to 9%) Fe_2O_3 content (Table 5) and thus may provide sufficient iron supplementation. The maximum of 246 g of soil ingested by interviewed geophagists will provide more that the daily requirement of 27 mg Fe day^{-1} during pregnancy.

Most samples had a high silt content which was consistent with the preference for smooth materials by all interviewed geophagists. Samples with excess of coarse quartz (>50%) have an undesirable gritty feel and may negatively affect the dental enamel of geophagic individuals (Ekosse et al., 2017). The preference of soft and smooth soils suggests that geophagists were aware of, or irritated by the effect of coarser soil particles. Similar results have been reported from other parts of South Africa (Sumbele et al.,2014; Ekosse et al., 2017) and Ghana (Badu et al., 2020). In addition to the high silt content, the smooth feel of geophagic samples could also be explained by the prominent occurrence of mica or illite in the samples.

Contrary to the commonly reported dominance of quartz with kaolinite (Ekosse and Obi, 2015; Okunlola and Owoyemi, 2015; Badu et al., 2020), all the geophagic samples contained mica or illite, while samples G1 and G2 did not contain kaolinite. Similarly, Sumbele et al. (2014) and Ekosse et al. (2017) reported quartz, feldspars and mica with only minor amounts of kaolinite in their samples. The differences in mineralogy of the geophagic materials may be attributed to differences in provenance as well as extent of weathering. The prominence of these non-expanding clay minerals together with a low content of plagioclase feldspars corresponds to the low concentrations of CaO and Na_2O found in all the geophagic soils. Traces of kaolinite in the samples may help explain the earthy smell indicated by some geophagists as a reason for ingesting soils. Kaolinite mineral is known to give an earthy smell when dampened with water (Raymond and Johnson, 2017). The presence of muscovite in studied geophagic soil samples suggests incomplete weathering of mica. This may be supported by the occurrence of K-feldspar associated with high silt and sand fractions (Spark and Huang, 1985) in G1 and G2 samples, respectively.

The geophagic materials had low pH which explains the low exchangeable base concentration. Low pH in geophagic materials has been reported in some parts of South Africa (Ngole et al., 2010), Cameroon (Diko and Ekosse, 2014) and Ghana (Badu et al., 2020). The acidity of the geophagic samples is responsible for a sour taste which improved desirability for most of the geophagists (7/8). The low pH can also explain the possible solubility and absorption of iron by geophagic individuals. Lower soil pH may, however, resulted in higher solubility of potentially toxic heavy metals such as Ni, Cu, Zn and Pb (Table 6) released upon ingestion (Olowoyo and Macheka, 2013). Low Ca/Mg ratios (Table 1) could have resulted from accumulation of preferentially leached Mg as geophagic materials were collected at depth below felsic solums (Shaw et al., 2001).

High amounts of essential elements such as Cu, Zn and Co could provide nutritional benefits for geophagists as their release from the soils is likely to occur at low pH similar to that of the stomach. However, individuals who ingested soil daily were likely to be at risk of accumulating toxic levels of heavy metals,

Table 9
Sun protection characteristics of the healing and non-healing soils from Potshini (H1 and C1) and Khokhwane (H2 and C2).

Parameter	Healing soils		Non-healing soils	
	H1	H2	C1	C2
Sun protection factor	2.5	1.8	1.9	2.0
UVA/UVB* ratio	1.1	0.9	1.0	0.9
Critical wavelength (nm)	390.0	389.2	389.6	388.3

* UVA – long-wave ultraviolet A (320–400 nm);
UVB – medium-wave ultraviolet B (280–320 nm)

particularly Pb, in geophagic samples G2, G3, G4 and G7. The risk of exposure to heavy metals is dependent on the amount of soil ingested per day and the bioavailability of the metal. The Ba concentrations may be explained by Ba^{2+} for K^+ substitution in mica interlayer (Speer, 1984). When ingested, these concentrations are potentially toxic to human. The WHO (1999) reported toxic effects in adults for doses as low as 0.2–0.5 mg Ba kg^{-1} of body weight. However, the accompanying high content of iron oxides in the soil materials can facilitate low solubility through adsorption thus counteracting the adverse effects on geophagic individuals.

As expected for these soil materials, the highest of the major elements in all samples was SiO_2 followed by Al_2O_3 and Fe_2O_3 (Table 5). All geophagic samples had higher K_2O and MgO concentrations, due to the mica and feldspar components (Table 3), compared to the other alkaline earth oxides. Despite the high concentration of K, its availability to the geophagists may be limited as shown by very low extractable K^+ (<0.6 $cmol_c$ kg^{-1}; Table 1) and very low pH of the stomach. The high content of K_2O recorded could suggest that illite is the likely form in which mica occurs in the geophagic samples implying more cumulative K release over time (Li et al., 2015). This would subsequently reduce the risk of hypokalemic myopathy (a muscle weakness disorder) caused by gastrointestional potassium depletion (Ukaonu et al., 2003). Cases of geophagists suffering from this disorder have been reported in South Africa (Chaushev et al., 2003; Dreyer et al., 2004).

4.2. Healing and cosmetic soil materials

The use *ibomvu* has evolved beyond symbolism (rituals) to include functional roles such as healing and cosmetics. Specific selection of *ibomvu* suggests that respondents were aware of the healing and cosmetic functions of this soil, despite not being able to provide explanations. The high acidity of the *ibomvu* due to intense leaching and weathering enables it to provide defence mechanisms against bacteria which flourish in neutral and slightly acidic reaction (Nagoba and Pichare, 2016). Low pH has been recorded for other South African healing and cosmetic materials (Matike et al., 2011; Madikizela et al., 2017). The reddish colours of the soils reflect the presence of iron oxides as confirmed by XRD analysis (Table 6). This natural colour of the soils (particulary ferralsols) makes them more attractive to users as they facilitate painting of bright and colourful decorative patterns on the body (Matike et al., 2011) explaining the common use of *ibomvu* for casual cosmetic and sun protection.

The fine particle size and presence of kaolinite allow for absorption of secretions, toxins and contaminants by soils used for topical application on wounds. This supports the claim of users that when *ibomvu* (Ferralsol) is applied to a wound it dries and heals faster. Moreover, this particle size distribution is consistent with cosmetic mixtures that should be smooth, non-gritty and non-abrasive (Veniale et al., 2007). The effectiveness of iron-rich clays in healing severe skin infections has been documented (Haydel et al., 2008). Moreover, Londono et al. (2017) recently showed that Al toxicity plays an integral role in the antibacterial action of kaolin-rich clays further suggesting that *ibomvu* (Ferralsol) may have antibacterial properties. The high TiO_2 content (mean content of 1.73%; Table 7) may contribute significantly to the dual role (i.e. healing and cosmetic) of *ibomvu*. The healing role could be associated with the nanometre particle size of rutile that may be important for antibacterial activity (Yamamoto, 2001).

One of the active ingredients used in commercial physical sunblock is TiO_2 due to its high refractive index (Judin, 1993). The occurrence of this oxide in the *ibomvu* may explain its efficacy in UV-protection despite the low SPF (Cosmetic, Toiletry and Fragrance Association, 2004) (Table 9) and this is consistent with other studies in South Africa (Dlova et al., 2013; Rifkin et al., 2015; Madikizela et al., 2017) and Kenya (Ng'etich et al., 2014). According to Dlova et al. (2013) the higher proportion of smaller particles in red clays improves their light scattering and absorption abilities that are fundamental for sun protection. The recorded critical wavelength for the soils (>370 nm) supports this claim and qualifies *ibomvu* as a broad-spectrum protectant (Moyal and Fourtanier, 2008).

Moreover, H1 and H2 samples had higher content of Fe_2O_3 and consequently higher potential for UV-protection than the comparison samples. High Fe content (particularly in the form of hematite) has been shown to significantly increase the UV-protection value of clays by reducing UV-transmission levels (Hoang-Minh et al., 2010). Topical application of H1, H3 and H4 samples may present risk of dermatitis due to high concentrations of one or both of Co and Ni (Agency for Toxic Substances and Disease Registry, 2004). However, lack of local evidence of such effects on the interviewed local users suggests only occasional and/or seasonal use of *ibomvu* and such effects may only be experienced with constant continual application.

5. Conclusions

Geophagic materials used in KwaZulu-Natal are C horizon of leptosols and are dominated by silt and clay particles. Colours of geophagic soil samples predominantly are reddish Munsell hues suggesting the presence of iron-bearing minerals. Mineral composition of the geophagic soils is mainly muscovite and kaolinite, with quartz. While studied geophagic soils contain essential elements, they also have some potentially toxic heavy metals including Pb and Ni.

Only one soil type (i.e., *ibomvu*- Ferralsol) is used for healing, cosmetic and sunscreen purposes. The critical wavelength (>370 nm), presence of TiO_2 and high Fe_2O_3 explains the claimed UV-protection ability. Physical, chemical and mineralogical analyses reveals an acidic pH, low exchangeable bases, dominant fine-grained particles (clay and silt) and dominance of kaolinitic clay fraction which could attribute to the healing function of studied soils.

The different mineral and chemical composition of the healing/cosmetic and geophagic materials are important in ascertaining possible explanations for their functional uses. Despite only relying on macromorphology, as well as trial and error, these findings suggest that local users appreciate the differences in the soils and thus have, over time, learnt their functional uses. For example, the use of *ibomvu* was initially in rituals and so mostly symbolic, while now it's observed benefits in terms of healing, cosmetics or sunscreen has broadened its application to casual use. This study has highlighted the importance and role of non-agricultural soils in rural communities of KwaZulu-Natal. Further studies of these soils are necessary to encourage their use and inclusion in land suitability classification.

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