Swelling clayey soils promote slope instability in the Muhunguzi watershed, western Burundi

Clairia Kankurize, Gervais Rufyikiri, Bruno Delvaux

clairia.kankurize@uclouvain.be

Introduction

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In Burundi, Mumirwa escarpments forming the western slope of the eastern Congo-Nile ridge are subject to landslides during the rainy season. Studies carried out on this subject and data published in the literature are rare.

Recent studies on landslide susceptibility mapping have shown that landslides occur in clay-rich soils (Nibigira, 2015, Kubwimana, 2018) . However, no studies have yet been carried out on these soils to highlight which of their properties are involved in landslides in this region, particularly, the origin of these properties.

Landslides are triggered by heavy rainfall in Muhunguzi watershed, as it occurs in the neighbouring Mumirwa watersheds upstream of the city of Bujumbura (Nibigira, 2018). This highlights the role of changes in soil moisture content on the triggering of landslides.

In this study, we focus on the soil properties involved in the landslides in the Muhunguza watershed. In particular, we characterize soil texture, weatherring stage, Atterberg limits, shear parameters and identify clay minerals.

Materials and methods

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Soil samples → **air-dried and sieved at 2 mm** → **Analysis and parameters investigated in surface (A, B) and deep (C) horizons**

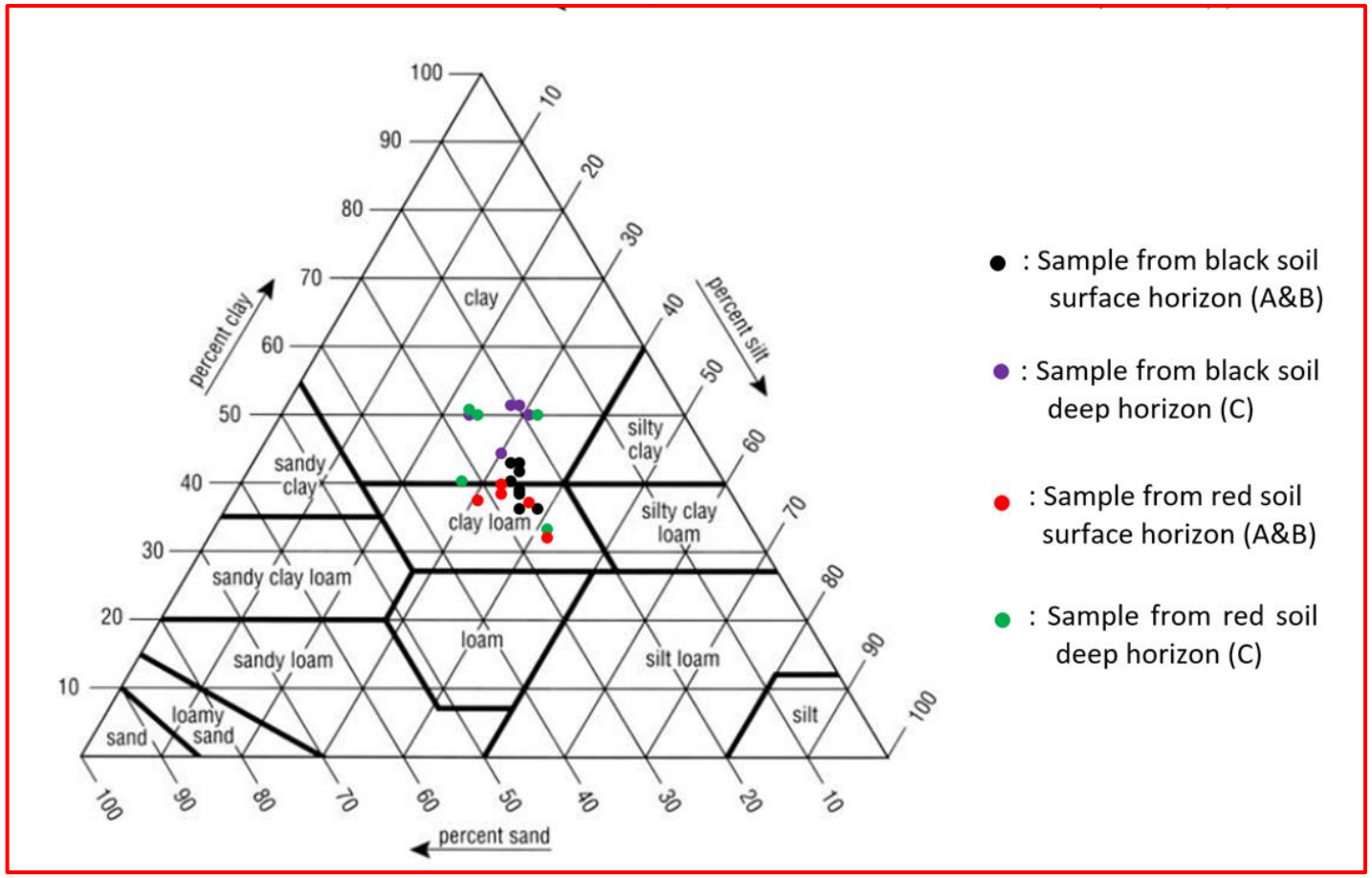
- ✓ As the landslides occurred in both red and black soils, sampling was carried out in two landslide areas located in black soil (1) and (2) and in red soil (3) and (4), respectively.
- ✓ For each site, sampling was carried out at soil 5 profiles on the rupture surface.

1. particle size → % clay
2. CEC → exchangeable Ca, Mg, Na,K
3. TRB → total Ca, Mg, Na, K
4. Atterberg Limits → plasticity, swelling
5. XRD on the <2µm fraction → clay minerals

Résultats

- **Soil texture**

Both black and red soils exhibit clay to clay loam textures. Clay content tends to increase from surface to deep horizons.



Soil texture ranges involve:

- **sand: 18–32%**
- **silt: 22–43%**
- **clay: 31–52 %**

Such textural classes are in accord with the nature of parent rock.

They denote a moderate weathering, likely more advanced in the red soil.

Résultats

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- **Soil Cation Exchange Capacity (CEC) and contents of total exchangeable bases**

✓ **Black soils**: the mean CEC value is 27.5 $cmol_c\ kg^{-1}$ in A and B horizons, 31.7 $cmol_c\ kg^{-1}$ in C.

✓ **Red soils**: the mean CEC value is 25.0 $cmol_c\ kg^{-1}$ in A horizons and 26.4 $cmol_c\ kg^{-1}$ in C.

✓ Mean CEC slightly differs between the two soil types.

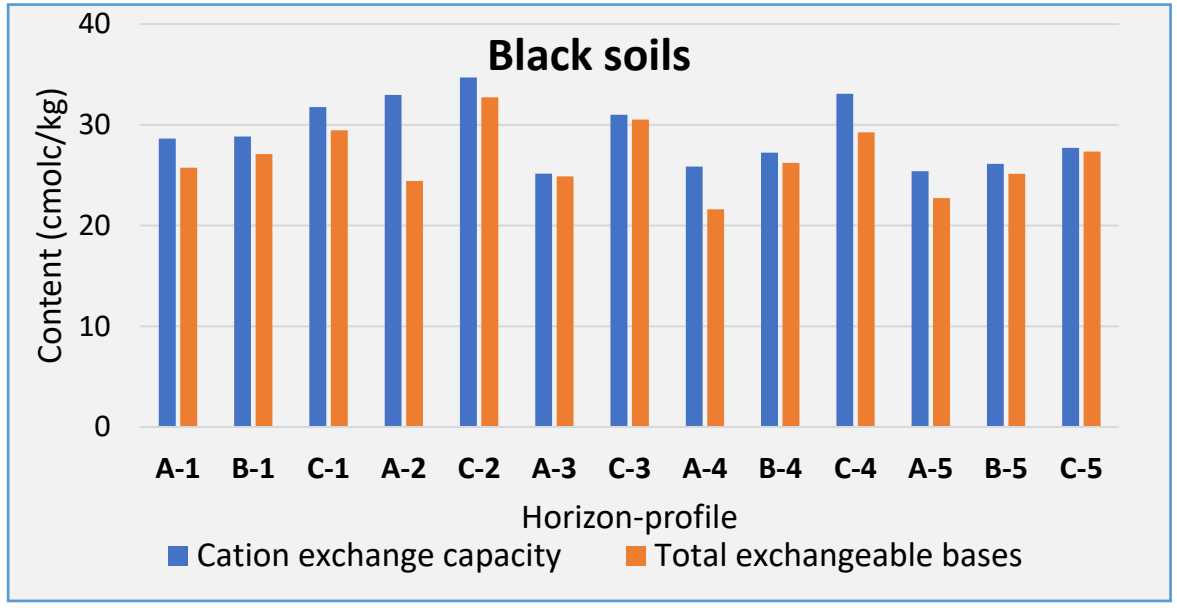
✓ CEC tends to increase in depth in both soil types.

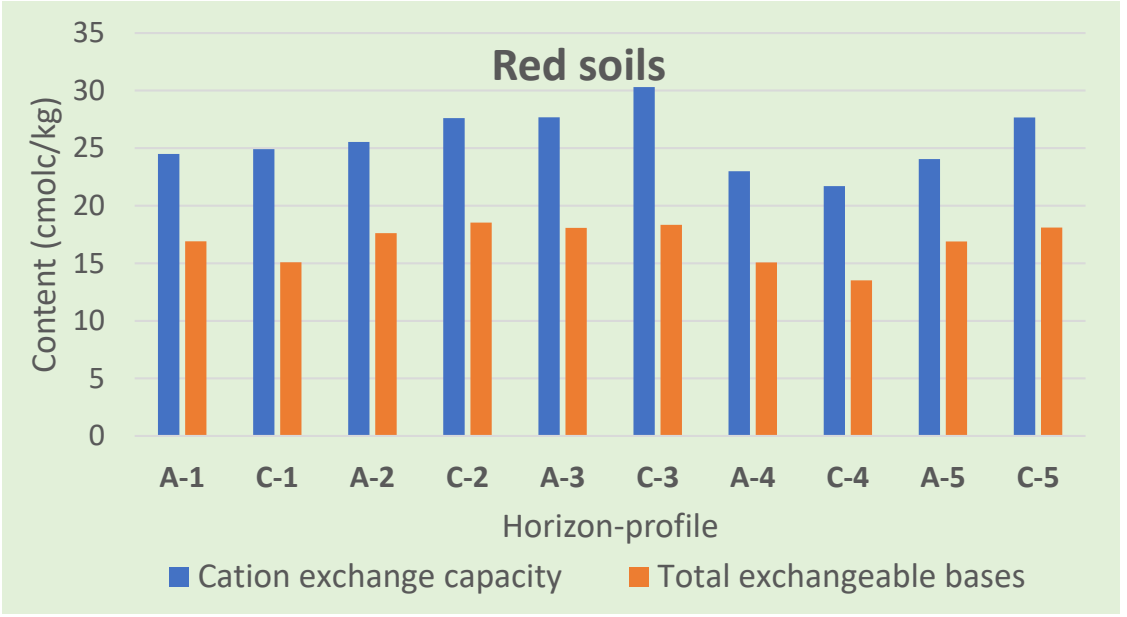
Black soil: Base saturation ranges from 74 to 99%.

Red soil: Base saturation ranges from 61 to 70%.

Base saturation is significantly larger in the black soil

Exchangeable cations are largely dominated by Ca^{2+} and Mg^{2+}.





Résultats

- **Total Reserve in Bases (TRB)**

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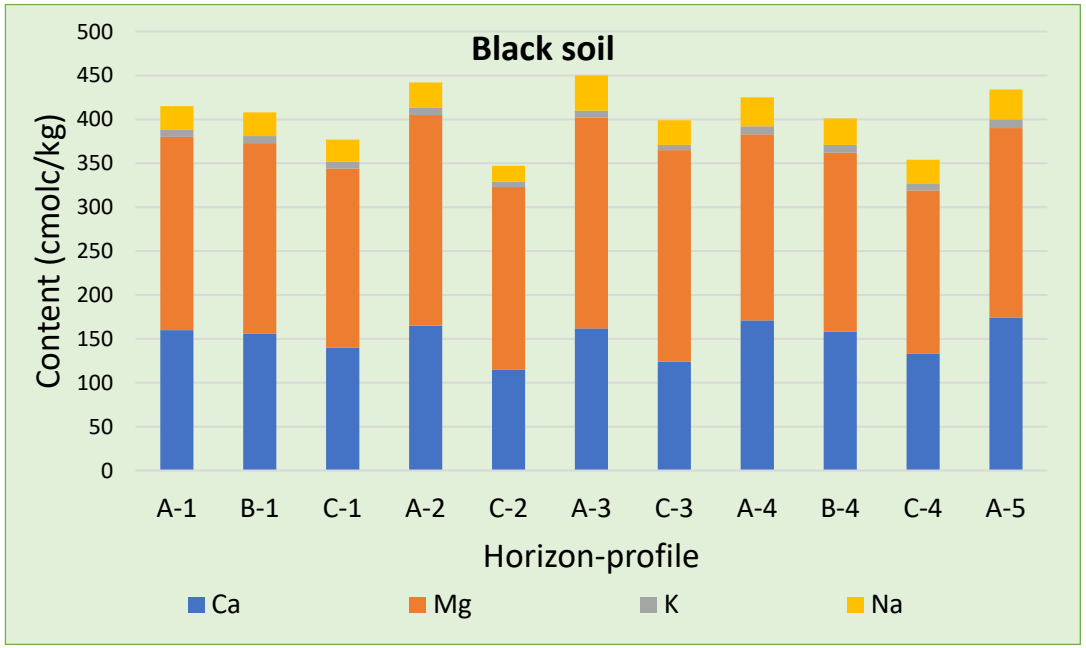
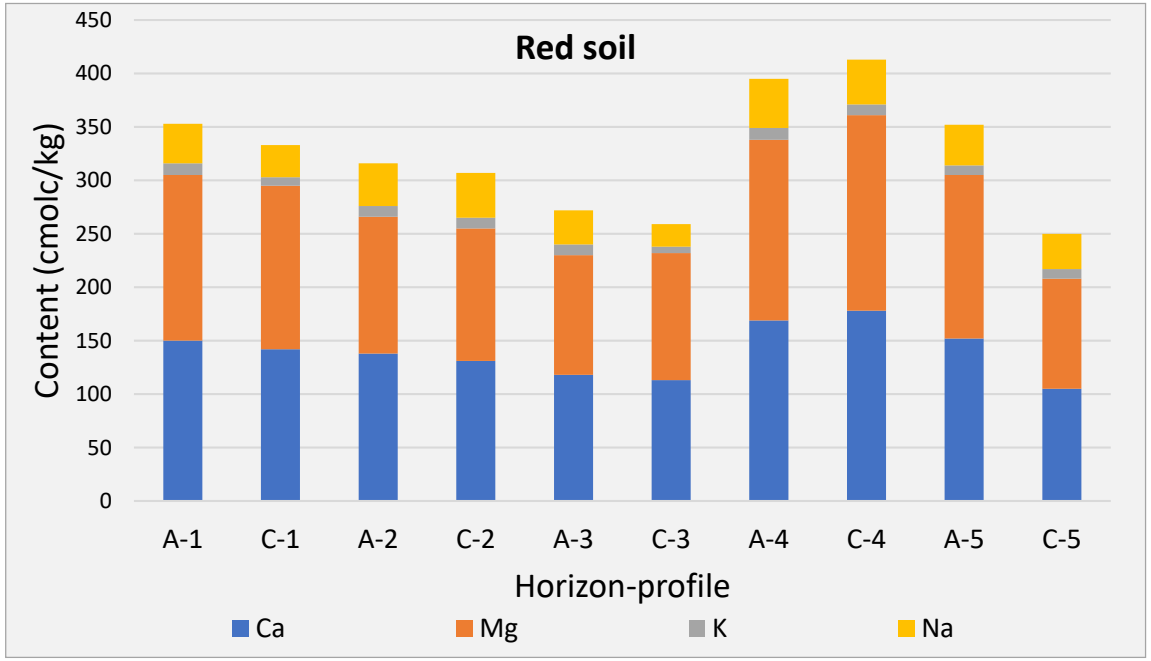
✓ **Black soil**: the mean TRB value ($cmol_c\ kg^{-1}$ soil) is 433 in A horizon, 403 in B and 396 in C.

✓ **Red soil**: the mean TRB value ($cmol_c\ kg^{-1}$ soil) is 337 in A horizon, 312 in C.

✓ TRB is significantly lower in the red soil
✓ Total Ca, Na and K contents are similar.
✓ Total Mg content is significantly lower in the red soil

The red soil has reached a more advanced weathering stage.



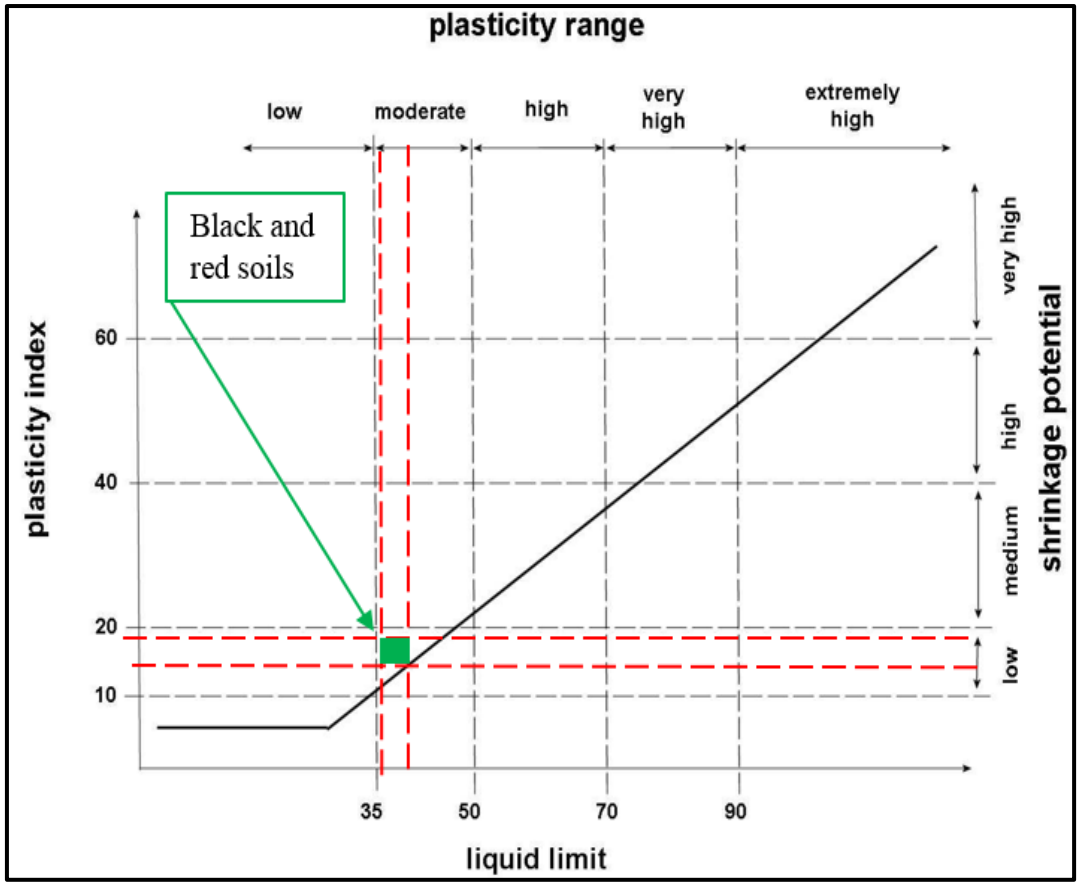


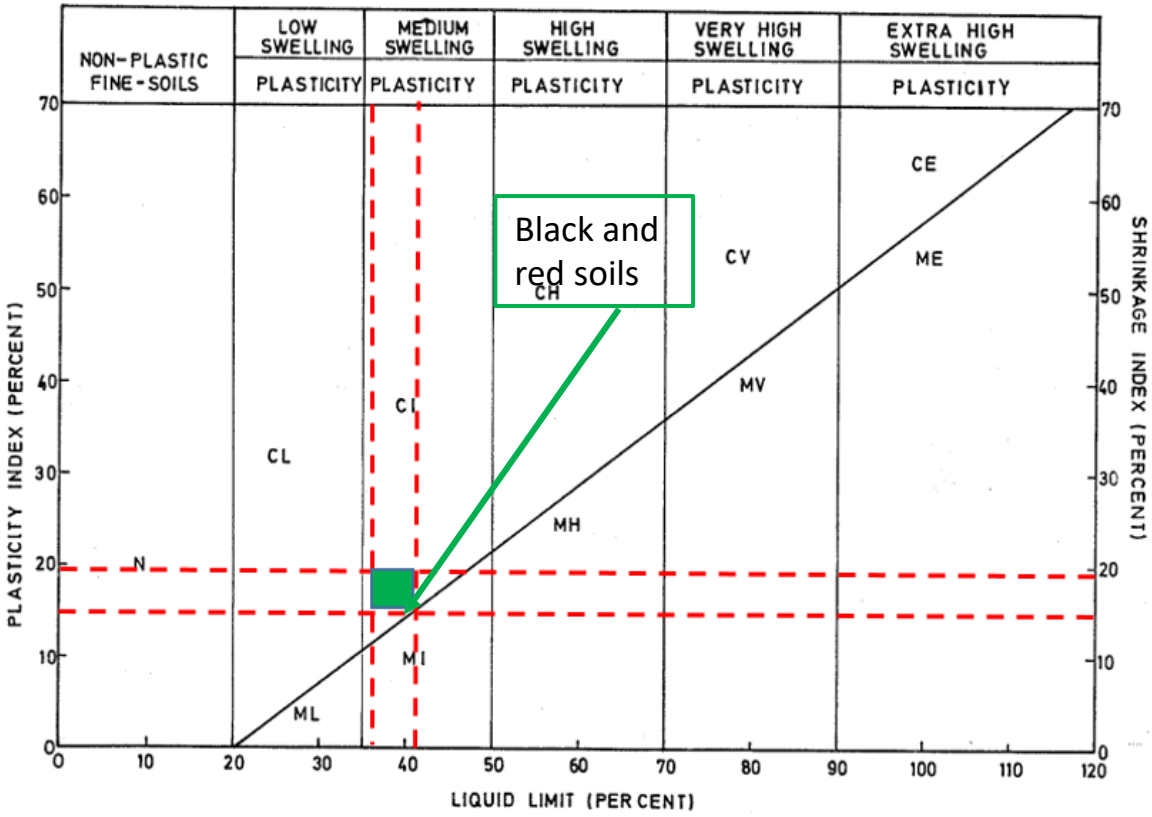
Résultats

- **Atterberg Limits**

In the Casagrande plasticity diagram the red soil and the black soil are classified as medium plasticity soils .

Based on the WL and PI and on PI and clay contents, both soils are classified as soil with medium swelling potential.

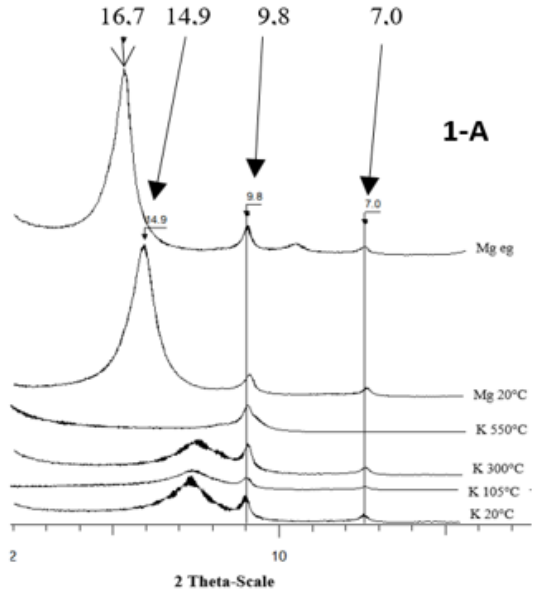


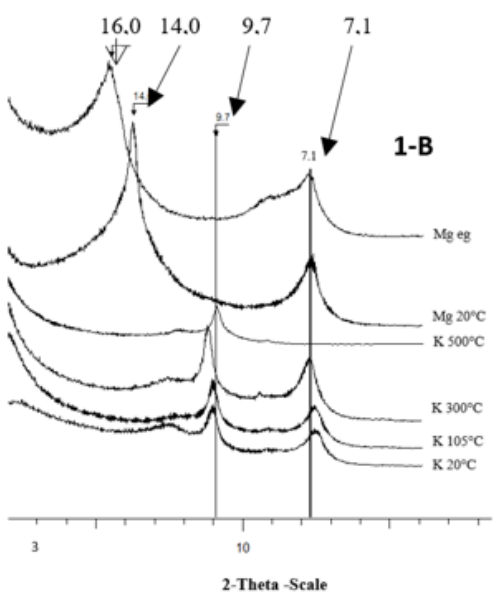


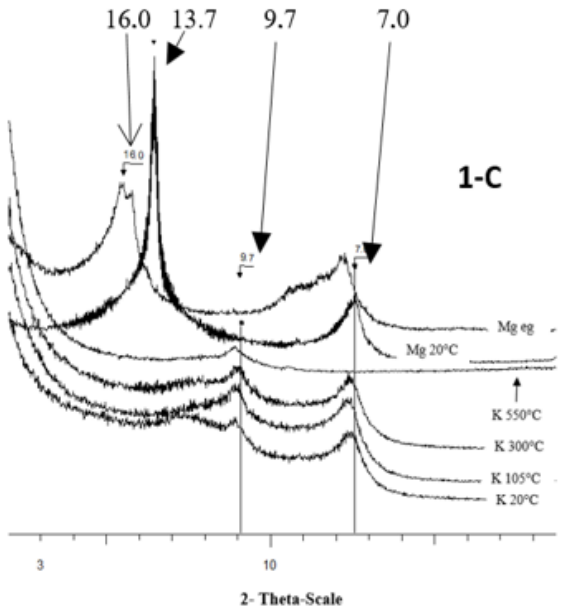
Résultats

- **Clay mineralogy**

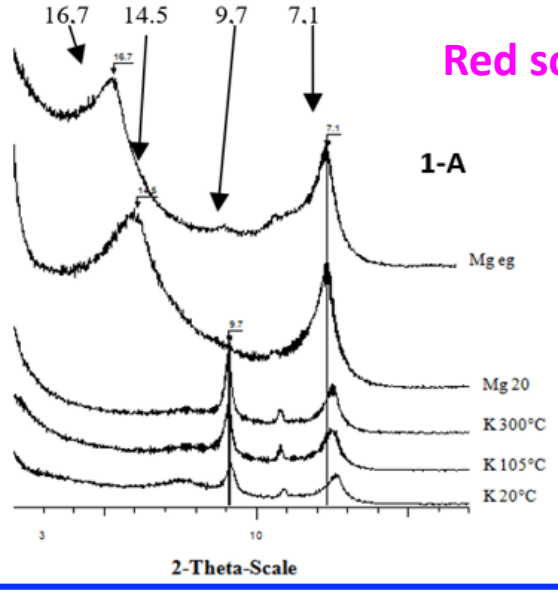
Black soil

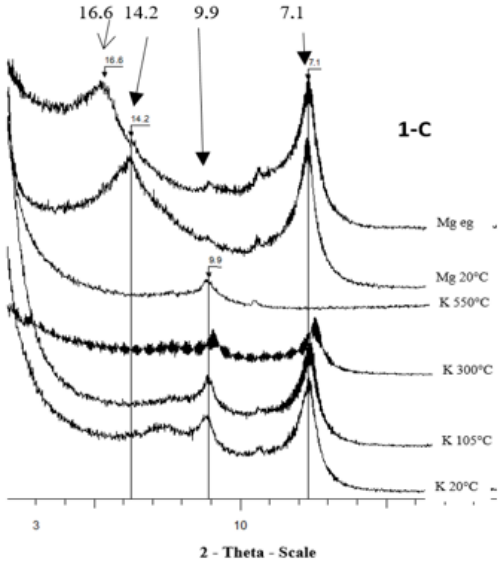






Red soil





XRD shows a similar mineralogical composition of the clay fractions of red and black soils:

- Kaolinite (7 Å)
- Illite (10 Å)
- Smectite: 13-14.5 Å at 25°C; 16-16.7 Å after glycolation (EG treatment); collapse at 17 Å upon heating.
- Interstratified minerals are highlighted by asymmetry of XRD reflections. They are linked to the weathering and transformation of micaceous clay minerals.

Discussion

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TRB is 6 to 11 times higher than 40 $cmol_c\ kg^{-1}$ (upper limit of ferrallitic domain) → Soils are moderately weathered → The soil environment is favourable to smectite formation

Soils are fine textured and clayey → Active weathering produces swelling clay minerals → The shear strength decreases at depth because of SOM decrease

XRD data point to smectite occurrence in soil clay fractions → Smectite swells on water saturation → Soils exhibit medium plasticity and swelling

Intense rainfalls during the rainy season abruptly saturate soils → The soil moisture increase induces swelling that decreases macro-porosity, reducing infiltration → Swelling promotes soil movement on steep slopes, hence slope instability

Intense rainfall in the rainy season is a factor triggering landslide.
Soil clay content and clay swelling are factors that promote slope instability.

Conclusions

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In the Muhunguzi watershed, the red and black soils are moderately weathered.

Weathering is one of the main processes forming clay-sized secondary minerals. This process induces a reduction in shear strength, which increases slope instability and exposure to landslides.

A high clay content does not only affect the shear strength of the soil; in the presence of water, clays can disperse and clog pores, reducing permeability.

The weathering conditions favour the formation of 2:1 clay minerals of smectite type, as observed in both red and black soils.
Swelling of clay particles increases pore volume, reduces pore size and soil permeability, hence decreasing the shear strength of the soil, leading to failure.

Landslides in the Muhunguzi watershed are triggered by intense rainfall during the rainy season. They are promoted by soil swelling properties as linked to the nature of clay minerals.