# SOILS OF THE SKELETON COAST NATIONAL PARK AND SCIONA PROJECT AREA IN NAMIBIA

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SCIONA
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# Preface

This document was prepared for SCIONA (*Co-designing conservation technologies for Iona - Skeleton Coast Transfrontier Conservation Area, Angola - Namibia*), a project funded by the European Union (EuropeAid/156423/ DD/ACT/Multi; grant agreement FED/2017/394-802) and led by the Namibian University of Science and Technology (NUST), in association with the Instituto Superior de Ciências de Educação da Huíla (ISCED, the Higher Institute of Education Sciences of Huíla, Angola). The overall goal of the SCIONA project was to strengthen cross-border ecosystem management and wildlife protection in the Iona – Skeleton Coast Transfrontier Conservation Area (TFCA) through co-designing and implementing conservation monitoring technology with the park authorities and surrounding communities.

The document provides descriptions of the soil types of the SCIONA project area in northern Kunene Region and the Skeleton Coast National Park (SCNP), both in Namibia. The information is provided as soil maps, descriptions of the Reference Soil Groups that represent the highest level of classification, the Qualifiers that form a second level of classification, an overview of the chemical and physical soil properties most important for crop production (though that is not a major land use in the area), and it highlights the main soil degradation threats.

The document is not meant as a textbook or to replace the official World Reference Base (WRB) soil classification documentation, but to help lay users to interpret the subject-specific terminology of the WRB and get an overview of the soils of the area. For classification purposes, the user is always referred to the official WRB document, namely *The World Reference Base for Soil Resources 2014. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. Update 2015*, compiled by the World Reference Base Working Group of the International Union of Soil Sciences, and published as World Soil Resources Report No 106 by the United Nations' Food and Agriculture Organization in Rome.

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# TABLE OF CONTENTS


Preface ........ 2

Role and Functions of Soil ........ 6

Simplified Soil Map of Namibia (2021) ........ 8

Soil Map of SCIONA Project Area (Namibia) and Skeleton Coast National Park ........ 9

Soil Map of SCIONA Project Area (Namibia) and Skeleton Coast National Park north of the Khumib River ........ 10

Soil Map of Skeleton Coast National Park south of the Khumib River ........ 11

Classification ........ 12

Distribution ........ 15

Description of Soil Types and their Properties ........ 16

- Leptosols [LP] ........ 16
- Solonetz [SN] ........ 19
- Solonchaks [SC] ........ 22
- Gypsisols [GY] ........ 26
- Calcisols [CL] ........ 32
- Cambisols [CM] ........ 36
- Arenosols [AR] ........ 38
- Fluvisols [FL] ........ 42
- Regosols [RG] ........ 45

Description of Soil Qualifiers ........ 47

- Aeolic (ay) ........ 47
- Albic (ab) ........ 47
- Arenic (ar) ........ 48
- Aridic (ad) ........ 48
- Brunic (br) ........ 48
- Calcaric (ca) ........ 48
- Calcic (cc) ........ 49
  - Hypercalcic (jc) ........ 49
  - Protocalcic (qc) ........ 49
- Cambic (cm) ........ 50
- Chromic (cr) ........ 50
- Clayic (ce) ........ 50
- Colluvic (co) ........ 51
- Dolomitic (do) ........ 51
- Duric (du) ........ 51

Dystric (dy) ....... 52
Eutric (eu) ....... 52
Evapocrustic (ev) ....... 52
Fluvic (fl) ....... 53
Fractic (fc) ....... 53
Calcifractic (cf) ....... 53
Gleyic (gl) ....... 54
Gypsic (gy) ....... 55
Gypsiric (gp) ....... 55
Haplic (ha) ....... 55
Lapiadic (ld) ....... 55
Leptic (le) ....... 56
Lithic (li) ....... 56
Nudilithic (nt) ....... 57
Loamic (lo) ....... 57
Luvic (lv) ....... 57
Natric (na) ....... 58
Ochric (oh) ....... 58
Petric (pt) ....... 58
Nudipetric (np) ....... 58
Petrocalcic (pc) ....... 59
Petroduric (pd) ....... 59
Petrogypsic (pg) ....... 59
Petrosalic (ps) ....... 60
Protic (pr) ....... 60
Puffic (pu) ....... 60
Salic (sz) ....... 61
Endosalic (szn) ....... 61
Hypersalic (jz) ....... 61
Protosalic (qz) ....... 62
Sideralic (se) ....... 62
Siltic (sl) ....... 62
Skeletic (sk) ....... 62
Hyperskeletic (jk) ....... 62
Sodic (so) ....... 63
Protosodic (qs) ....... 63

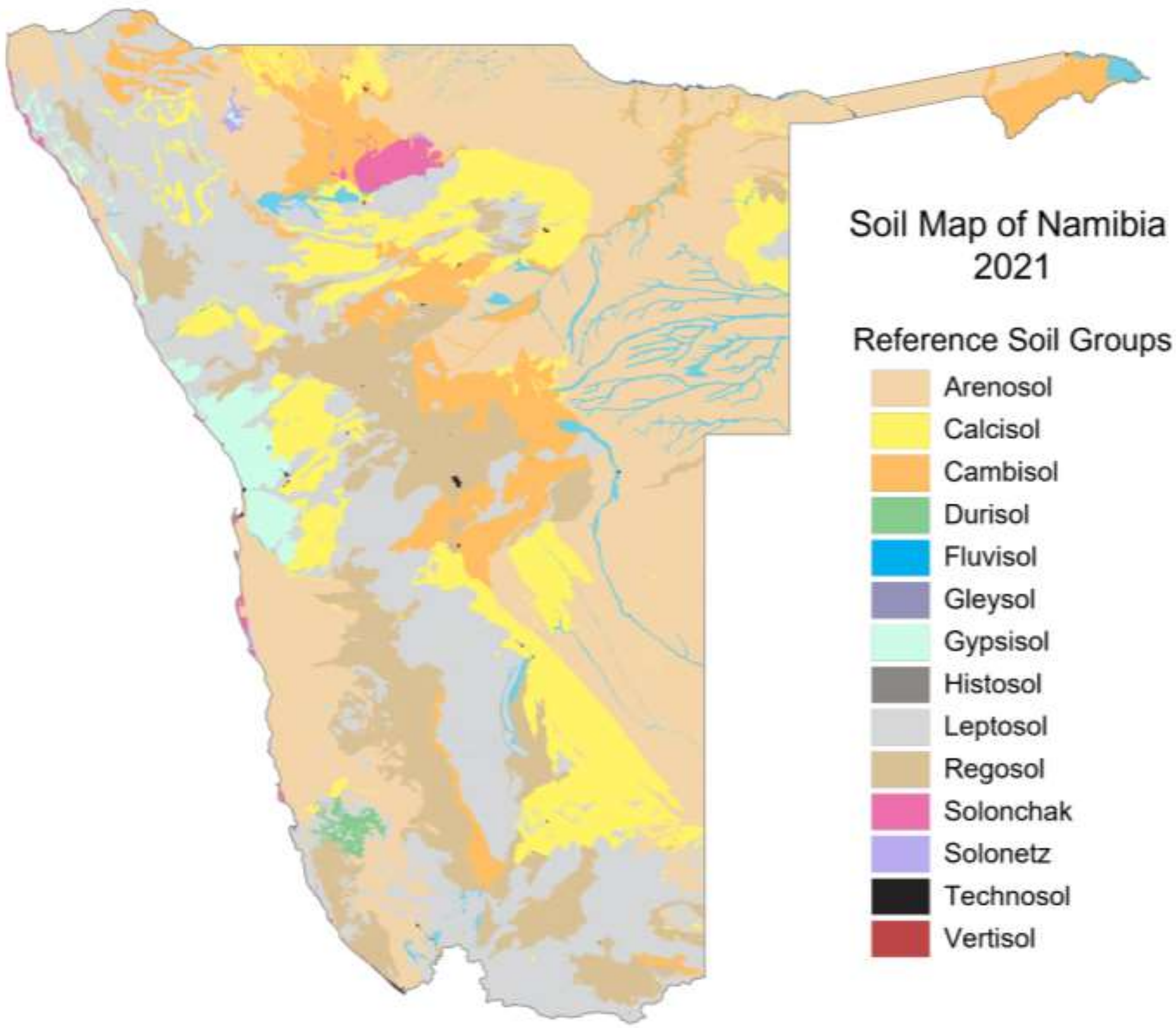
Stagnic (st) ....63
Takyric (ty) ....63
Tidalic (td) ....64
Yermic (ye) ....64
Key Soil Properties ....66
Soil Depth ....66
Clay Fraction ....67
Silt Fraction ....68
Sand Fraction ....69
Soil Texture ....70
Stoniness ....72
Bulk Density ....73
Available Water Capacity ....74
pH ....75
Cation Exchange Capacity ....76
Base Saturation ....77
Soil Organic Carbon ....78
Soil Salinity & Sodicity ....79
Main Threats to Namibian Soils ....80
Desertification and Soil Degradation ....80
Loss of Soil Nutrients, Organic Matter and Biodiversity ....80
Erosion ....80
Aridification ....81
Salinisation and Sodification ....81
Deterioration of Soil Structure, Compaction and Capping ....82
Acidification ....82
Soil Pollution ....82
References ....84
Photos ....84
Cited Sources ....84
Bibliography ....85

# Role and Functions of Soil

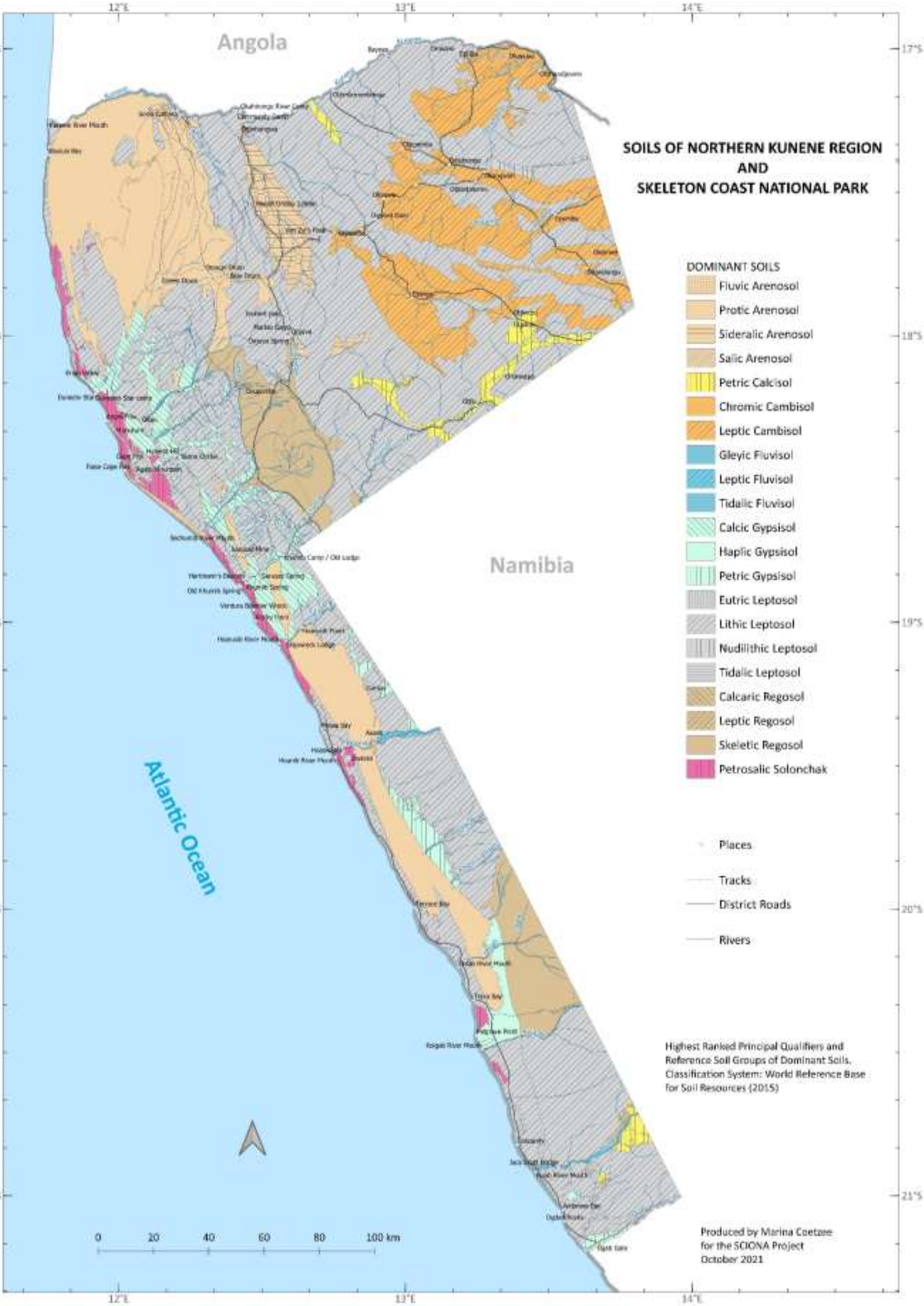
Soil is a natural body of unconsolidated material which constitutes a thin layer on Earth's surface. It is derived from weathered rock materials and decaying organic matter, with water and gases occupying the pores between the mineral and organic particles. Soil, water, landforms, the atmosphere and life have all evolved together. Soil connects, responds to and shapes the land, the atmosphere, climate, surface water, groundwater and ecosystems. It is the living skin of Earth. It is depended upon by all terrestrial life. Yet we take it for granted – treat it as a limitless resource to be used or exploited, without due regard for its health and quality.

Soil formation takes place through weathering of primary minerals, the release of nutrients, accumulation and transformation of organic matter, creation of internal structure – such as aggregates and soil horizons – and creation of charged surfaces for ion retention and exchange. Soil supports primary production, and thus human and animal food, fibre and fuel supply, by providing the medium for seed germination and root growth and the nutrients and water required by plants. More than 95 % of our food comes from the soil. Soil provides the ecosystem service of nutrient cycling through the transformation of organic materials by soil organisms and retention and release of nutrients. It regulates the supply and quality of water by controlling water infiltration and percolation, drainage of excess soil water to groundwater, filtering, buffering and transformation of substances and contaminants in water. It regulates climate through absorption, storage and emission of carbon dioxide, nitrous oxide and methane, and regulates erosion through the retention of soil on the land surface. Soils contain more carbon than the atmosphere and all of Earth's forests combined. Soil provides habitats for countless numbers of living organisms, from the smallest bacteria to mammals, reptiles, amphibians and birds. A tablespoonful of healthy soil contains more living organisms than the entire human population of Earth. It is a source of raw materials, such as used in construction, and unique biological materials and genetic resources. In addition to providing the stable surface for human habitation and infrastructure, soil contributes to our aesthetic experiences, cultural landscape diversity and cultural identity, spiritual enrichment and it preserves our archaeological heritage.

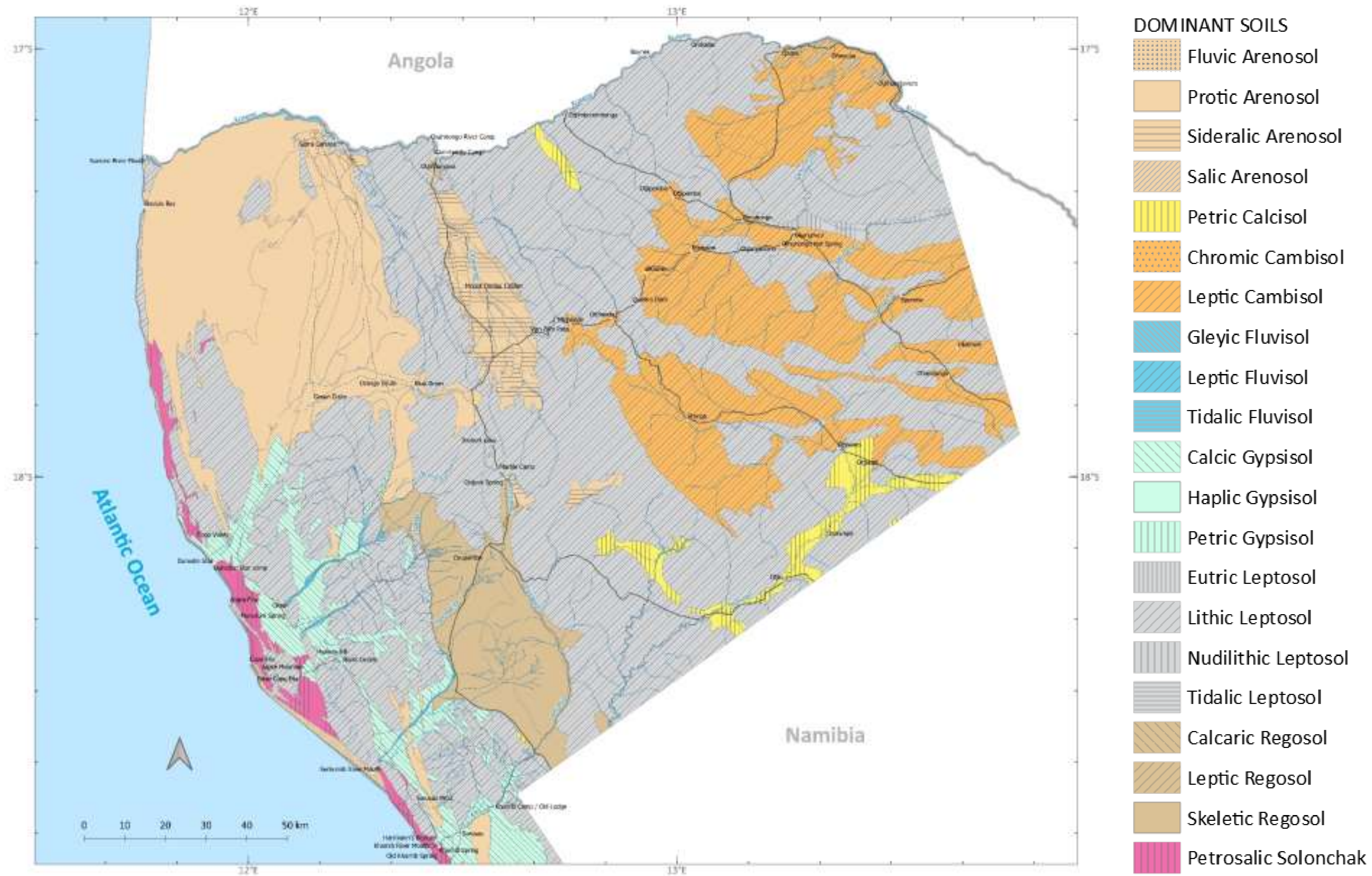
## Simplified Soil Map of Namibia (2021)



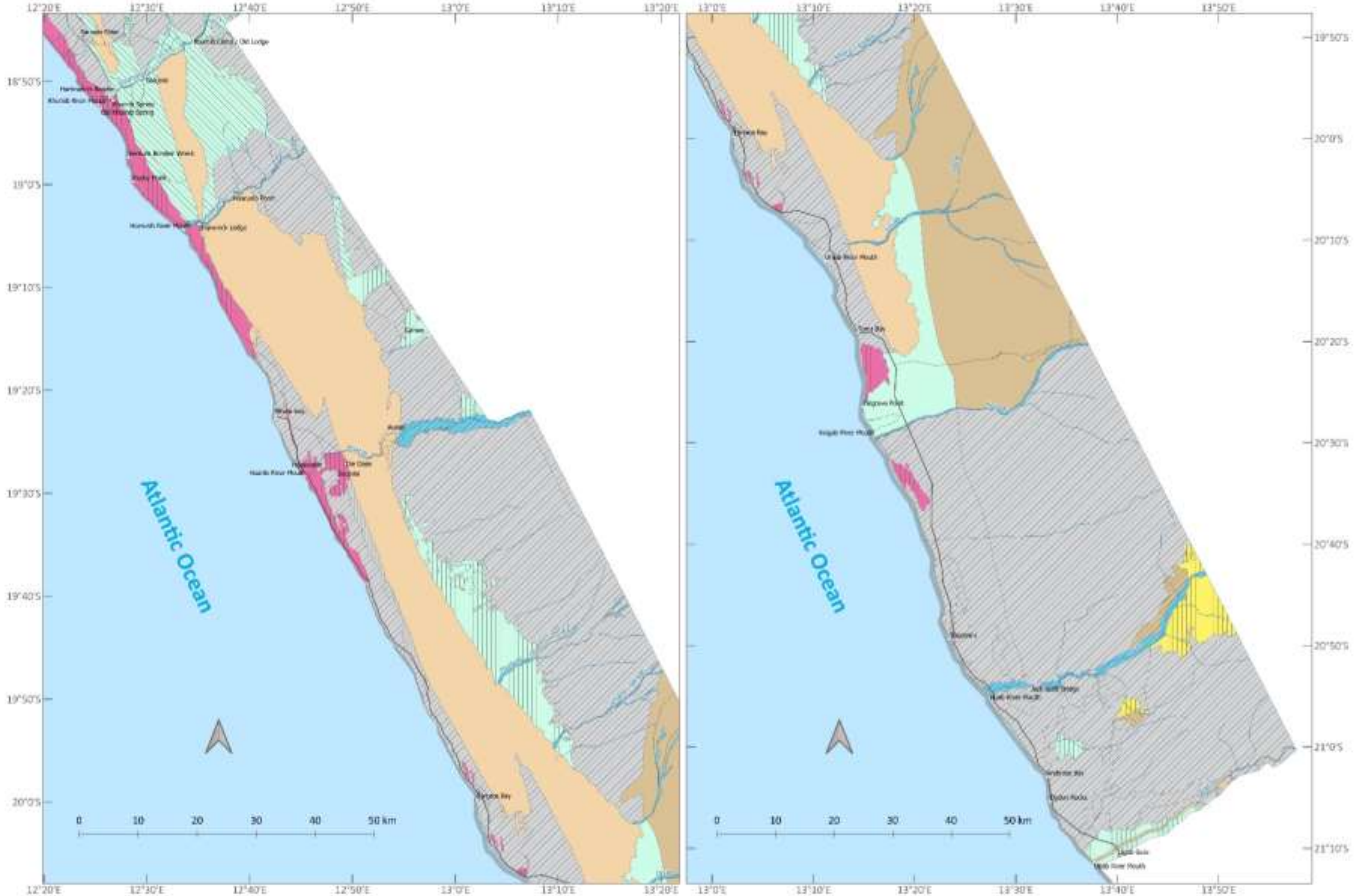
## Soil Map of SCIONA Project Area (Namibia) and Skeleton Coast National Park



## Soil Map of SCIONA Project Area (Namibia) and Skeleton Coast National Park north of the Khumib River



## Soil Map of Skeleton Coast National Park south of the Khumib River



# Classification

The World Reference Base (2014, updated 2015) is an international soil classification system for naming soils and creating soil map legends. Classification is based on 'diagnostic criteria' of soil horizons, soil properties and materials (summary pp. 6-8; full definitions pp. 22-84, IUSS Working Group WRB 2015). The diagnostic criteria are visible or measurable properties with relevance to primary soil-forming processes, soil parent materials or soil use. Diagnostic materials are materials that significantly influence soil-forming processes, while diagnostic properties and horizons have a combination of attributes that mostly reflect the results of soil-forming processes.

Soil classification follows 3 steps:

1. Detecting diagnostic horizons, properties and materials;
2. Allocating the soil to a Reference Soil Group;
3. Allocating the qualifiers.

At the highest level of classification, 32 **Reference Soil Groups** (**RSG**s) are identified using a **Key**. The RSGs that have been identified in the Namibian portion of the SCIONA project area and Skeleton Coast National Park are, *in the order that they key out* in the World Reference Base:

Leptosols, Solonetz, Solonchaks, Gypsisols, Calcisols, Cambisols, Arenosols, Fluvisols and Regosols.

A second level of classification uses *qualifiers* that are listed in the Key for every RSG. **Principal qualifiers** provide further subdivision of soils within an RSG and are *ranked in order of importance*. In the full name of a soil, they are written *ahead* of the RSG, with the *highest ranked qualifier closest to the RSG* name. **Supplementary qualifiers** provide information on the expression of soil characteristics and are listed in the Key in *alphabetical order*. In the full name of a soil, they are written *in brackets after the RSG* name, in *alphabetical order*, separated by *commas*. Both RSG and qualifiers are written in title case (starting with a capital letter). Some qualifiers apply to many RSGs, while others apply to only a few or even just one RSG.

For example, Durisols appear as follows in the WRB Key:

| Key to the Reference Soil Groups | Principal qualifiers | Supplementary qualifiers |
|---|---|---|
| Other soils having a *petroduric* or *duric* horizon starting ≤ 100 cm from the soil surface.<br><br>**DURISOLS** | Petric<br>Petrogypsic/ Gypsic<br>Petrocalcic/ Calcic<br>Leptic<br>Acric/ Lixic/ Alic/ Luvic<br>Hyperskeletic/ Skeletic<br>Dystric/ Eutric | Albic<br>Arenic/ Clayic/ Loamic/ Siltic<br>Aric<br>Chromic<br>Fractic<br>Gleyic<br>Novic<br>Ochric<br>Raptic<br>Endosalic<br>Sodic<br>Stagnic<br>Takyric/ Yermic/ Aridic<br>Technic<br>Toxic<br>Transportic<br>Vertic |

A Durisol that has a petroduric horizon ('Petric'), some calcic material ('Calcic'), is very stony ('Skeletic'), has sandy texture ('Arenic') and strong red colour ('Chromic') and has a stone pavement on the surface ('Yermic'), would be classified as:

Skeletic Calcic Petric Durisol (Arenic, Chromic, Yermic)

The list of soils identified in the area, including dominant soils (representing ≥ 50 % of the soil cover), co-dominant soils (25-50 % of the soils cover), and associated soils (5-25 % of the soil cover, or of high relevance in the landscape ecology), are:

| **RSG** | **First Principal Qualifier** | **Full Name** | **Code** |
|---|---|---|---|
| Leptosols | Eutric Leptosols | Eutric Leptosols | euLP |
| | | Eutric Leptosols (Yermic) | euLPye |
| | Lithic Leptosols | Lithic Leptosols | liLP |
| | | Lithic Leptosols (Yermic) | liLPye |
| | | Skeletic Lithic Leptosols | skliLP |
| | | Skeletic Lithic Leptosols (Yermic) | skliLPye |
| | Nudilithic Leptosols | Nudilithic Leptosols | ntLP |
| | | Tidalic Nudilithic Leptosols | tdntLP |
| | Skeletic Leptosols | Tidalic Hyperskeletic Leptosols | tdjkLP |
| Solonetz | Gleyic Solonetz | Calcic Salic Gleyic Solonetz | ccszglSN |
| Solonchaks | Petrosalic Solonchaks | Sodic Gleyic Petrosalic Solonchaks | soglpsSC |
| Gypsisols | Calcic Gypsisols | Calcic Gypsisols | ccGY |
| | | Calcic Gypsisols (Yermic) | ccGYye |
| | | Calcic Gypsisols (Fluvic, Yermic) | ccGYflye |
| | Haplic Gypsisols | Haplic Gypsisols | haGY |
| | | Haplic Gypsisols (Yermic) | haGYye |
| | Petric Gypsisols | Petric Gypsisols (Yermic) | ptGYye |
| | | Calcic Petric Gypsisols | ccptGY |
| | | Calcic Petric Gypsisols (Fluvic) | ccptGYfl |
| | | Calcic Petric Gypsisols (Yermic) | ccptGYye |
| | | Calcic Petric Gypsisols (Fluvic, Yermic) | ccptGYflye |
| Calcisols | Cambic Calcisols | Cambic Calcisols | cmCL |
| | Haplic Calcisols | Haplic Calcisols | haCL |
| | | Haplic Calcisols (Yermic) | haCLye |
| | | Haplic Calcisols (Hypercalcic, Yermic) | haCLjcye |
| | Petric Calcisols | Petric Calcisols | ptCL |
| | | Petric Calcisols (Fluvic) | ptCLfl |
| | | Petric Calcisols (Yermic) | ptCLye |
| | | Petric Calcisols (Fluvic, Yermic) | ptCLflye |
| | | Gypsic Petric Calcisols (Yermic) | gyptCLye |
| | | Gypsic Petric Calcisols (Fluvic, Yermic) | gyptCLflye |

| | | | |
|---|---|---|---|
| Cambisols | Cambisols | Cambisols (Arenic, Yermic) | CMarye |
| | Chromic Cambisols | Chromic Cambisols | crCM |
| | Gypsiric Cambisols | Gypsiric Cambisols (Arenic, Yermic) | gpCMarye |
| | Leptic Cambisols | Leptic Cambisols | leCM |
| | | Chromic Leptic Cambisols | crleCM |
| Arenosols | Fluvic Arenosols | Fluvic Arenosols | flAR |
| | Protic Arenosols | Protic Arenosols (Aeolic) | prARay |
| | Salic Arenosols | Fluvic Endosalic Arenosols | flsznAR |
| | | Fluvic Protosalic Arenosols | flqzAR |
| | Sideralic Arenosols | Sideralic Arenosols | seAR |
| | | Chromic Sideralic Arenosols | crseAR |
| Fluvisols | Fluvisols | Fluvisols (Arenic) | FLar |
| | Calcaric Fluvisols | Calcaric Fluvisols (Arenic) | caFLar |
| | Gleyic Fluvisols | Gleyic Fluvisols (Arenic) | glFLar |
| | Leptic Fluvisols | Calcaric Leptic Fluvisols (Arenic) | caleFLar |
| | Tidalic Fluvisols | Tidalic Fluvisols (Loamic, Sulfidic) | tdFLlosf |
| Regosols | Calcaric Regosols | Calcaric Regosols (Yermic) | caRGye |
| | Eutric Regosols | Eutric Regosols | euRG |
| | Leptic Regosols | Leptic Regosols | leRG |
| | | Leptic Regosols (Arenic, Yermic) | leRGarye |
| | | Calcaric Gypsiric Leptic Regosols (Yermic) | cagpleRGye |
| | | Skeletic Leptic Regosols | skleRG |
| | | Skeletic Leptic Regosols (Yermic) | skleRGye |
| | | Colluvic Skeletic Leptic Regosols | coskleRG |
| | | Colluvic Skeletic Leptic Regosols (Yermic) | coskleRGye |
| | Skeletic Regosols | Skeletic Regosols | skRG |
| | | Colluvic Skeletic Regosols | coskRG |
| | | Eutric Skeletic Regosols (Yermic) | euskRGye |

Other soil types (such as Durisols, Vertisols, Stagnosols) may cover only small, included areas and are not included in the current maps.

Soil mapping is an iterative process, with maps growing more accurate and detailed as more information becomes available.

## Distribution

Leptosols are the dominant soils of the study area as they include all shallow and very stony soils. This is to some extent an artefact of the classification system, where Leptsols key out very early. Many soils of the Kaokoveld are clearly highly calcareous, but because they are also shallow and/or stony, they key out as Leptosols rather than Calcisols. The same is true for sandy soils: if the bedrock is shallow, a sandy plain will key out as a Leptosol rather than an Arenosol. Leptosols are widespread in the SCNP, not only on inselbergs, dykes and exposed bedrock, but also where only a thin layer of soil covers bedrock and there is not enough gypsum or calcium carbonate to key out as Gypsisols or Calcisols.

Gypsisols are widespread along the entire coastline from the Ugab River to Terrace Bay and more sporadic further north, from just beyond the beaches. Their strongest expression, with thick petrogypsic horizons, is close to the coast. Calcium carbonate gains dominance over calcium sulphate as one moves further inland. From 30 to 50 km inland, Calcisols – often with well-developed petrocalcic horizons (calcretes) – gradually take over from Gypsisols, though signs of gypsum have been observed up to 70 km from the coast. In the transition zone, calcic/petrocalcic horizons appear above gypsic/petrogypsic horizons, which points to downward leaching as the main mechanism of accumulation, as calcium sulphate (gypsum) is more soluble than calcium carbonate. This supports the generally accepted theory that marine sulphur is the source of the Namib's gypsum. The situation is reversed in the case of pans or depressions with a shallow water table: upward accumulation results in formation of the gypsic horizon above the calcic horizon. Gypsisols are of particular interest for management of the SCNP, as they host biological crusts and are highly sensitive to off-road driving.

Salt pans are generally classified as Solonchaks, though some pockets of Solonetz, where sodium dominates on the exchange complex, exist.

Sandy beaches are classified as Fluvic Endosalic Arenosols. The dunes are classified as Protic Arenosols (Aeolic), as are some sandy plains on the eastern edge of the Namib. In many cases, however, the sand is only a relatively thin wind-deposited cover over shallow bedrock (classified as Leptosols) or pediments of stabilised Calcisols, Gypsisols or Regosols. The Marienfluss is dominated by Arenosols, though some areas may key out as Calcisols which appears first in the WRB Key.

Riverbeds are a combination of Fluvisols (Arenic), Leptosols, Fluvic Arenosols and Regosols

Regosols are found wherever colluvial material accumulated over time, as at the foot of mountain- or hill slopes.

Vegetated hummock dunes are mainly composed of fine sandy Arenosols or silty Regosols with no or just incipient horizon development.

Cambisols are found in the eastern half of the study area, especially in intermontane valleys. Though genetically young soils, they show the early stages of horizon development, such as translocation of secondary clays, carbonates and oxides, formation of structure, and colour differentiation.

Most of the Skeleton Coast National Park gravel plains and pediments can be assigned the 'Yermic' qualifier, which refers to low organic matter content, light soil colours, the presence of a desert pavement, evidence of aeolian activity such as ventifacts (wind-shaped gravel, stones, rocks), a loamy, vesicular layer, and/or the presence of needle-shaped clay minerals.

# Description of Soil Types and their Properties

(in order of the WRB 2015 Key)

## Leptosols [LP]

(from Greek *leptos*, thin)

Leptosols are either very shallow soils over continuous rock or soils that are extremely stony, with less than 20 % fine earth (soil particles < 2 mm in diameter).

Leptosols are azonal (not limited as to climatic zone). They are prevalent in mountainous regions, in areas with highly dissected topography and where the erosion rate exceeds that of soil formation or sediment accumulation. Lithic Leptosols are less than 10 cm deep and Nudilithic Leptosols have continuous rock at the surface, while Skeletic and Hyperskeletic Leptosols contain up to 40 % and 80 % stones respectively.

Heavy rainfall events cause sheet flooding that removes topsoil, even on gentle slopes, which exposes the underlying unweathered parent material. The chemical and some physical properties of Leptosols are defined by the underlying parent rock. Differential weathering, illuviation and biotic disturbance cause large spatial heterogeneity in these soils.

The stoniness and shallowness of Leptosols decrease their water-holding capacity and mean that they have poor agronomic properties. However, shallow-rooted grasses and forbs effectively utilise these soils, and plants with deeper roots usually find joints and bedding planes in the parent rock that provide pathways for water movement. If the underlying rock is fractured, large trees – even fruit trees – may grow successfully in such soils, but generally they are best left under natural vegetation for extensive grazing or use by wildlife.

Leptosols and Regosols often appear complementary: Leptosols tend to occupy convex crests and steep slopes, where natural erosion keeps pace with soil formation, while Regosols occupy concave landforms, such as footslopes and valley basins, where deposition keeps pace with soil formation.

Leptosols are particularly common along the escarpment, in mountainous areas and highly dissected terrain where natural erosion exceeds the rate of weathering. Along the Skeleton Coast, Leptosols occur on inselbergs, rocky hills and ridges (including dykes and yardangs), valleys scoured down to bedrock by wind (deflation hollows) and many pediments that have only a thin veneer of soil.

A soil keys out as a **Leptosol** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

Other soils having:

1. one of the following:
   a. *continuous rock* or *technic hard* material starting ≤ 25 cm from the soil surface; *or*
   b. < 20 % (by volume) fine earth, averaged over a depth of 75 cm from the soil surface or to *continuous rock* or *technic hard* material, whichever is shallower; *and*
2. no *calcic*, *chernic*, *duric*, *gypsic*, *petrocalcic*, *petroduric*, *petrogypsic*, *petroplinthic* or *spodic* horizon.

In other soil classification systems, *Leptosols* are known as *Leptic Rudosols* or *Tenosols* (Australia), the *Lithic* subgroups of the *Entisol* Order (US Soil Taxonomy), *Petrozems* and *Litozems* (Russia) or *Lithosols* (FAO–UNESCO Soil

Map of the World, 1981). In places, Leptosols on calcareous rock belong to *Rendzinas* and those on acid rocks to *Rankers*. Many classification systems do not recognize continuous rock at the surface as soil.

Nudilithic Leptosol (MC)

Lithic and Nudilithic Leptosol (MC)

Hyperskeletic Leptosol (VdC)

Hyperskeletic Leptosol (MC)

The Leptosols identified in the area, including dominant soils (representing ≥ 50 % of the soil cover), co-dominant soils (25-50 % of the soils cover), and associated soils (5-25 % of the soil cover, or of high relevance in the landscape ecology), are:

| **RSG** | **First Principal Qualifier** | **Full Name** | **Code** |
|---|---|---|---|
| Leptosols | Eutric Leptosols | Eutric Leptosols | euLP |
| | | Eutric Leptosols (Yermic) | euLPye |
| | Lithic Leptosols | Lithic Leptosols | liLP |
| | | Lithic Leptosols (Yermic) | liLPye |
| | | Skeletic Lithic Leptosols | skliLP |
| | | Skeletic Lithic Leptosols (Yermic) | skliLPye |

| | | | |
|---|---|---|---|
| | Nudilithic Leptosols | Nudilithic Leptosols | ntLP |
| | | Tidalic Nudilithic Leptosols | tdntLP |
| | Skeletic Leptosols | Tidalic Hyperskeletic Leptosols | tdjkLP |

Leptosols occurring as dominant, co-dominant or associated soil type in mapping units (Coetzee)

## Solonetz [SN]

(from R. *sol*, salt, and *etz*, strongly expressed)

Solonetz develop in finely textured, sodium-rich clayey or loamy soil of former coastal deposits and flat or gently sloping grasslands with poor drainage. They can be found in semi-arid, temperate and subtropical climates, particularly those with hot, dry summers.

Solonetz typically have a brown to black dense, strongly structured clayey subsurface *natric* horizon with a high amount of exchangeable (adsorbed) sodium ions [$Na^+$] and, in some cases, also magnesium ions [$Mg^{2+}$] on the clay complex. The clay-rich natric (Arabic *natroon* = salt) horizon usually has high bulk density and strong, coarse columnar or prismatic structure with characteristic rounded tops that are often covered by bleached, powdery fine sand or silt. Clay and organic material are easily dispersed by sodium in the topsoil, washed into the subsoil and there form thick, dark coatings ('cutans' or skins) on the outside of the structural elements.


Solonetz with characteristic columnar structure overlain by albic material. (EM)

Solonetz do not support plant growth well. Their physical properties are not conducive to crop farming: high water retention (waterlogging), low hydraulic conductivity, strong swelling-shrinking and high plasticity. Natric horizons exhibit very poor drainage under wet conditions, due to break-down of soil aggregates and subsequent dispersion of the soil. They tend to be hard to extremely hard when dry. The topsoil of Solonetz is highly erodible. Solonetz that contain free sodium carbonate [$Na_2CO_3$] are strongly alkaline, with $pH_{H2O}$ > 8.5. High sodium concentration in soil can be directly toxic to plants, can cause imbalances in uptake of other nutrients and can inhibit root growth and downward percolation of water.

Surface of Solonetz (LL)

Nudinatric Solonetz, with the topsoil removed by erosion (MC)

A soil keys out as a **Solonetz** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

| |
|---|
| Other soils having a *natric* horizon starting ≤ 100 cm from the soil surface. |

A **natric horizon** is a dense subsurface horizon with a distinct increase in clay content, high exchangeable sodium [Na] and sometimes relatively high exchangeable magnesium [Mg]. The diagnostic criteria are highly technical (see IUSS Working Group WRB, 2015, pp. 41-43) and thus not explained here in detail. For field identification, the coarse columnar or prismatic subsoil structure with rounded tops, sometimes covered by a whitish powder ('albic material', is characteristic.

In other soil classification systems, *Solonetz* correlate with *Sodosols* (Australia), the *Solonetzic Order* (Canada), *Solonetz* (Russia, FAO–UNESCO Soil Map of the World, 1981), *Sols sodiques horizon B et Solonetz solodis* (France), and *Natric Great Groups* (e.g. *Natrustalfs*, *Natrustolls*, *Natrixeralfs*, *Natrargids* or *Nadurargids*) of several Soil Taxonomy Orders (USA). They are commonly known as *alkali soils* and *sodic soils*.

In the study area, Calcic Salic Gleyic Solonetz occur in clayey and loamy coastal pan sediments with a high level of sodium, in association with Solonchaks, as well as with calcic and gypsic horizons.

Solonetz occurring as associated soil type in mapping units (Coetzee)

## Solonchaks [SC]

(from R. *sol*, salt)

Solonchaks have soluble salts accumulating on or below the surface. A soil is regarded as saline if the salt concentration exceeds about 2,500 parts per million. Salt-affected soils primarily occur in coastal zones that are affected by sea spray, seawater seepage or occasional inundation, and in arid and semi-arid regions, notably in seasonally or permanently waterlogged conditions. This may happen where the evapotranspiration rate is much higher than precipitation and rising groundwater reaches the upper soil – such as the case with seawater seepage into coastal salt pans – or where surface water collects in closed depressions such as the terminal pans at the end of present or paleo endorheic rivers or washes, and in poorly managed irrigation schemes. Salts come from saline groundwater, saline surface water flowing from higher ground into depressions and parent materials that contain high salt levels, such as old marine sediments or evaporation deposits. Ultimately, soluble salts derive from the weathering of rocks. The main ions responsible for salinization are sodium [$Na^+$], potassium [$K^+$], calcium [$Ca^{2+}$], magnesium [$Mg^{2+}$], sulphate [$SO_4^{2-}$] and chloride [$Cl^-$].

In low-lying areas with a shallow water table, salt accumulation is strongest at the soil surface (external Solonchaks), while the greatest accumulation of salts occurs at some depth below the soil surface in cases where ascending groundwater does not reach the topsoil (internal Solonchaks). The waterlogged, reducing soil conditions in which Solonchaks form, mean that most have gleyic properties at some depth. Sometimes a hard, white salt crust appear on the surface, but in very wet Solonchaks the salt may not be visible as salts only precipitate once most of the soil moisture has evaporated.

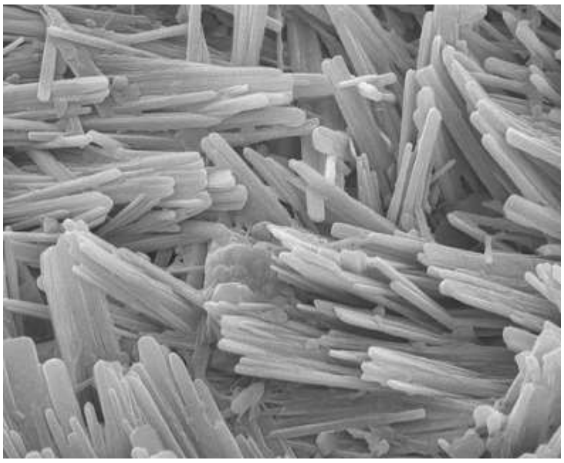
Petrosalic (Gr.*petros* = rock; Latin *sal* = salt) Solonchaks are strongly cemented by salts and extremely hard, with large polygonal patterns often visible on the soil surface.

Solonchak (MC)

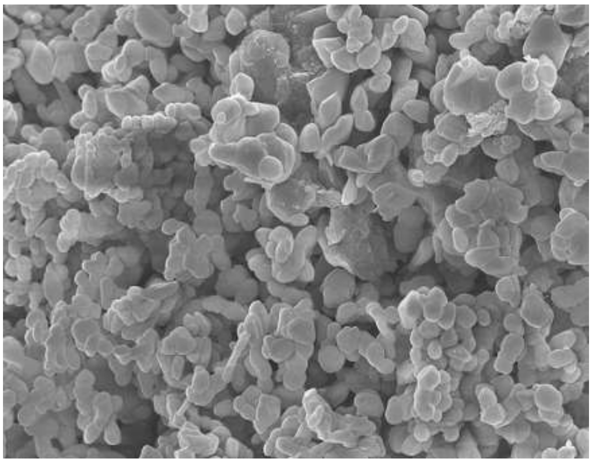
Petrosalic Solonchak (MC)

Polygonal features on surface of halite (NaCl dominated salt mineral) deposits (MC)

**Puffed Solonchacks** form where sodium sulphate is the dominant salt and large diurnal temperature and humidity fluctuations occur. Under cool conditions with high air humidity, as the Namibian coast experiences at night and under fog, sodium sulphate occurs as the hydrated mineral mirabilite ($Na_2SO_4$. $10H_2O$), which has needle-shaped crystals that push soil aggregates apart. As the day heats up and air humidity drops, mirabilite loses its water and transforms to the non-hydrated form, thenardite ($Na_2SO_4$), which has fine, rounded crystals that occupy less space between the soil aggregates. Repeated mirabilite-thenardite cycles produce the characteristic soft, fluffy, puffy surface.



Mirabilite $Na_2SO_4$. $10H_2O$ (Internet)



Thenardite $Na_2SO_4$ (Internet)

Puffed Solonchak (qualifier: puffic) in a desert salt pan (MC)

Another noticeable transition is found in external Solonchaks that are dominated by hygroscopic salts ($CaCl_2$, $MgCl_2$ and to a lesser extent NaCl). They are dark coloured and slippery in the morning and during thick fogs, on account of absorbed moisture, and become lighter in colour and less slippery as the temperature rises and air humidity declines during the day.

Solonchaks pose a challenge to vegetation growth and thus to farming, as dissolved electrolytes create an osmotic potential that affects water uptake. Plants have to overcome both the matrix potential of the soil (the force with which the soil matrix retains water) and the osmotic potential before they can absorb water. In addition, salts are responsible for antagonistic effects (for example between Na and K, Na and Ca, and Mg and K) that disturb nutrient uptake and salts may be directly toxic to plants at high concentrations. Sodium and chloride ions disturb nitrogen metabolism.

Most desert, arid and semi-arid zone vegetation has some degree of tolerance towards salinity. Faunal activity is severely restricted in Solonchaks and mostly absent where salt concentrations exceed 3 %. Halophytic plants such as *Salicornia*, *Tamarix* and *Salsola* tolerate high soil salinity while *Mopane* can endure moderate salinity.

Almost all irrigation water contains some dissolved salts which are left behind in the soil once plants have used the water and they accumulate over time. Salinity of irrigation schemes can be managed by installing underground drainage systems and drainage ditches and flushing the salts out of the soil by applying an excess of good quality water from time to time.

Coastal salt pans are mostly dominated by Sodic Gleyic Petrosalic Solonchaks, sometimes in association with Solonetz and with Gypsisols found at pan margins. Many soils have raised salinity, but do not quite fulfil the criteria to be classified as Solonchaks, thus ‘salic’ and ‘endosalic’ qualifiers are applied.

A soil keys out as a **Solonchak** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

Other soils having:

1. a *salic* horizon starting ≤ 50 cm from the soil surface; *and*
2. no *thionic* horizon starting ≤ 50 cm from the soil surface; *and*
3. not permanently submerged by water and not located below the line affected by tidal water (i.e. not located below the line of mean high water springs).

A **salic horizon** (Latin *sal* = salt) is a surface or subsurface horizon at a shallow depth that contains high amounts of readily soluble salts (more soluble than gypsum). It may include a salt crust and may consist of either mineral or organic material. The diagnostic criteria for a **salic horizon**, according to the World Reference Base (IUSS Working Group WRB, 2015), are as follows:

A *salic* horizon has:

1. at some time of the year an electrical conductivity of the saturation extract ($EC_e$) at 25 °C of
    a. ≥ 15 dS $m^{-1}$; *or*
    b. ≥ 8 dS $m^{-1}$ if the pHwater of the saturation extract is ≥ 8.5; *and*
2. at some time of the year a product of thickness (in centimetres) and $EC_e$ at 25 °C (in dS $m^{-1}$) of ≥ 450; *and*
3. a thickness of ≥ 15 cm.

In other soil classification systems, *Solonchaks* are known as *Halosols* (China), *Halomorphic soils* (Russia) and *Salids* (US Soil Taxonomy). They are commonly called *saline soils* and *salt-affected soils*.

Solonchaks occurring as dominant, soil type in mapping units (Coetzee)

## Gypsisols [GY]

(from Greek *gypsos*, gypsum)

Gypsisols have substantial subsurface accumulation of secondary gypsum and occur in the driest parts of arid climate zones where evapotranspiration greatly exceeds precipitation, natural vegetation is sparse and there is a source of sulphate to form gypsum [$CaSO_4.2H_2O$].

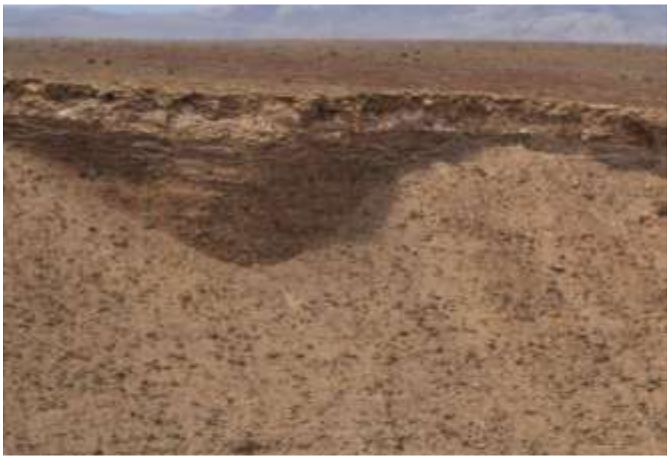
Gypsisols have off-white to light brown surface horizons. Calcium [$Ca^{2+}$] and sulphate [$SO_4^{2-}$] ions are dissolved and leached by soil water from gypsiferous parent material (or by fog; see below for explanation of the process taking place in the Namib Desert) in the upper part of the soil and precipitated as various forms of gypsum further down where the percolation stops and water evaporates. Alternative wetting (by rain or fog) and drying (by evaporation) of the soil tend to concentrate the gypsum in a *gypsic* horizon. In time, *gypsic* horizons can become indurated (cemented, petrified) by gypsum into hard, light-coloured platy or massive *petrogypsic* horizons.

Gypsisol (MC)

Gypsisol with small desert roses (MC)

Calcic and gypsic horizons may be found together in one soil, but they usually occupy distinct positions, as gypsum is more soluble than calcium carbonate.

Gypsisol with incipient petrogypsic horizon (EM)



Petric Gypsisol (MC)

Biological crust formed in Gypsisol (MC)

Top (L) and bottom (R) of a biological crust (MC)

Gypsisols that are subject to high soil temperatures (>40 °C) and repeated cycles of partial dehydration of gypsum [$CaSO_4.2H_20$] to hemihydrate / bassanite ($CaSO_4.½H_20$) or complete desiccation to anhydrite [$CaSO_4$], and rehydration as from coastal fog, develop a characteristic puffy structure and feels spongy underfoot (Loeppert & Suarez, 1996). Any weight causes collapse of the puffy structure, thus off-road driving across Gypsisol gravel plains leaves highly visible vehicle tracks on the desert floor.

Puffy structure of Gypsisols collapsed by a vehicle (MC)

Gypsisols are widespread in stable, long exposed surface gravels and sands of the coastal plain pediments along the Namib coast, especially north of the Kuiseb River. Highly porous gypsic ('gypsiferous') soils are present intermittently from the Ugab River up to Agate Mountain and Cape Fria. They manifest as alterations to Tertiary and Pleistocene age calcretes and crusts, up to 50 km from the coast, but mainly concentrated in the first 5-10 km from the coast. Older deposits tend to be denser with compact surface and subsurface horizons. The surface may be covered by a thin layer of relatively gypsum-free sand. Generally, the surface layer of 0.5-1 m thick contains well-formed crystals ('mesocrystalline'), while the subsurface layer, up to 5 m thick and up to 10 m deep, consists of massive crusts of impure gypsum cementing poorly sorted sediments. Horizontally bedded crusts, containing 50-80 % gypsum, can be found on edges of coastal salt pans, where they exhibit well-develop crystals and sometime *desert roses*. These gypsum rosettes are aggregates of interlocking, double-convex lenticular (disk-shaped) selenite (gypsum) crystals with sand inclusions that grow from gypsum rich soil or the rise and fall of the water table in brine-rich salt pans, where evaporation exceeds precipitation. Large polygonal patterns are on occasion observed on the soil surface (up to 20 m ∅). Curved, columnar, fibrous satin spar crystals are fairly common. Predominantly, one finds fibrous and dispersed mesocrystalline gypsum in puffy soils, with insipient crust development. At Agate Mountain, rocks that had been coated by a thin layer of dune sand for some time have coatings of fibrous satin spar. Inland of Toscanini, single transparent crystal sheets of gypsum were observed in fractures of red Gai-as Formation shales and siltstones (Miller, 2008, pp 25-46…51).

Fragment of a petrogypsic horizon (MC)

Desert roses (EM)

Desert roses (Internet; MC)

Ram's horn satin spar (MC)

The main theories to explain Namib Desert Gypsisol formation are summarised by Goudie and Viles (2015, pp.103-105) and Miller (2008, pp. 25-50 – 25-51). The leading theory is deposition of atmospheric sulphates of marine biogenic origin. Dimethyl sulphide is produced by phytoplankton during photosynthesis, oxidised to sulphate, carried as an aerosol by onshore winds and deposited on stable pediments and bedrock surfaces. Fog provides the necessary moisture to carry surface deposits down into the soil, thus Gypsisols are found in the mist belt. The best developed Gypsisols are downwind of the largest upwelling cells, where phosphorite brought to the surface stimulates primary production. This is one reason why gypsum accumulation in subsurface soil horizons of the Skeleton Coast National Park is less well developed than in the central Namib. Secondly, stronger winds of the northern Namib mobilise pediments to a greater extent, while Gypsisol formation requires more stable conditions.

Thirdly, lower fog incidence in the northern Namib limits the available moisture for vertical transport of surface sulphate deposits deeper into the soil (Miller, 2008, p. 25-51).

Gypsisols prevail over Calcisols up to 30-50 km from the coast, due to the input of marine sulphur and greater aridity. In the transition zone, (petro)calcic horizons appear above (petro)gypsic horizons. This is an indication that downward leaching is the main mechanism of accumulation in the Namib, as calcium sulphate (gypsum) is more soluble than calcium carbonate. The situation is reversed in the case of saline pans or depressions with a shallow water table: upward accumulation results in formation of the gypsic horizon above the calcic horizon.

Gypsisols often have a surface crust that impedes water infiltration and germination. Large pores and cavities form inside the soil as gypsum is dissolved and washed out by rainwater, thus the soil is well aerated but does not hold water well and dries out quickly.

Gypsum stabilises the soil surface, allowing lichens, mosses, green algae, microfungi and cyanobacteria to colonise alluvial fans and desert pediments to form biological crusts.

A soil keys out as a **Gypsisol** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

> Other soils having a *petrogypsic* horizon starting ≤ 100 cm from the soil surface;
>
> *or* both of the following:
>
> a. a *gypsic* horizon starting ≤ 100 cm from the soil surface; *and*
>
> b. no *argic* horizon above the *gypsic* horizon unless the *argic* horizon is permeated with secondary gypsum or secondary carbonate, throughout.

A **gypsic horizon** (Gr. *gypsos* = gypsum) is a non-cemented surface or subsurface horizon containing accumulations of secondary gypsum (CaSO4.2H2O) in various forms: light brown 'desert roses', crystals of selenite and satin spar, 'vermiform' (coarse pseudomycelia), 'nests', 'beards, elongated groupings of fibrous crystals, coatings or powdery ('microcrystalline') accumulations. The fine-grained powdery gypsum, occurring as lenses or filling the interstices of the soil matrix, gives gypsic horizons their massive structure. Gypsum crystals tend to be yellowish white, needle-shaped and usually visible to the naked eye (sugar grain size), whereas pedogenic calcium carbonate crystals are white, much finer in size and usually not visible to the naked eye. Gypsum crystals can be distinguished from quartz crystals, which they resemble, by their relative softness (2 on Mohs hardness scale). They can easily be broken between thumbnail and forefinger.

The diagnostic criteria for a **gypsic horizon,** according to the World Reference Base (IUSS Working Group WRB, 2015), are as follows:

> A *gypsic* horizon consists of mineral material and:
>
> 1. has ≥ 5 % (by mass) gypsum in the fine earth fraction; *and*
> 2. has one or both of the following:
>    a. ≥ 1 % (by volume) of visible secondary gypsum; *or*
>    b. a gypsum content in the fine earth fraction of ≥ 5 % higher (absolute, by mass) than that of an underlying layer and no lithic discontinuity between the two layers; *and*
> 3. has a product of thickness (in centimetres) times gypsum content (percentage, by mass) of ≥ 150; *and*
> 4. does not form part of a *petrogypsic* horizon; *and*

| | |
|---|---|
| 5. | has a thickness of ≥ 15 cm. |

When a gypsic horizon becomes indurated, it transitions to a **petrogypsic horizon** (Gr. *petros* = rock; *gypsos* = gypsum). The latter has a hard, whitish, platy or massive cemented structure, that may be capped by a thin laminar of layer of newly precipitated gypsum. Air-dry fragments of the petrogypsic horizon do not slake in water. Petrogypsic horizons (also known as gypcrete duricrusts) develop from the top down in a typical sequence: massive, laminar, newly precipitated gypsum of up to 3 cm thickness; massive, dense alabastrine; mesocrystalline honeycomb structure; a network of sinuous, vertical, horizontal and inclined veinlets of fibrous gypsum, fading out with depth or grading into calcrete, calcareous sand and gravel. The petrogypsic horizon often displays large vertical cracks caused by contraction during desiccation, that gives it a columnar structure.

The diagnostic criteria for a **petrogypsic horizon,** according to the World Reference Base (IUSS Working Group WRB, 2015), are as follows:

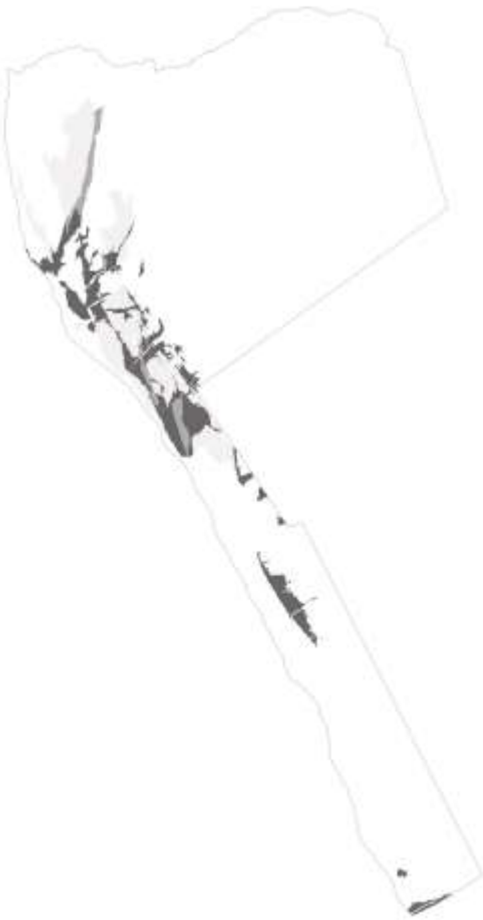
A *petrogypsic* horizon consists of mineral material and:

1. has ≥ 5 % (by mass) gypsum; *and*
2. has ≥ 1 % (by volume) visible secondary gypsum; *and*
3. shows induration or cementation, at least partially by secondary gypsum, to the extent that air-dry fragments do not slake in water; *and*
4. is continuous to the extent that vertical fractures, if present, have an average horizontal spacing of ≥ 10 cm and occupy < 20 % (by volume); *and*
5. cannot be penetrated by roots except, if present, along the vertical fractures; *and*
6. has a thickness of ≥ 10 cm.

In other classification systems, *Gypsisols* are known as *Desert grey-brown soils* (Russian, French classifications), *gipsgronde* (Afrikaans), *Gypsids* (US Soil Taxonomy) or fall under *Yermosols* or *Xerosols* (old FAO classification). *Petric Gypsisols* are also called *gypcretes* or *gypsic duricrusts*.

The following Gypsisols appear in the Soil Map of the SCIONA Project Area and Skeleton Coast National Park, generally as dominant or co-dominant soils:

| RSG | First Principal Qualifier | Full Name | Code |
|---|---|---|---|
| Gypsisols | Calcic Gypsisols | Calcic Gypsisols | ccGY |
| | | Calcic Gypsisols (Yermic) | ccGYye |
| | | Calcic Gypsisols (Fluvic, Yermic) | ccGYflye |
| | Haplic Gypsisols | Haplic Gypsisols | haGY |
| | | Haplic Gypsisols (Yermic) | haGYye |
| | Petric Gypsisols | Petric Gypsisols (Yermic) | ptGYye |
| | | Calcic Petric Gypsisols | ccptGY |
| | | Calcic Petric Gypsisols (Fluvic) | ccptGYfl |
| | | Calcic Petric Gypsisols (Yermic) | ccptGYye |
| | | Calcic Petric Gypsisols (Fluvic, Yermic) | ccptGYflye |



Gypsisols occurring as dominant, co-dominant or associated soil type in mapping units (Coetzee)

## Calcisols [CL]

(from Latin *calcarius*, lime-rich)

Calcisols have a significant accumulation of secondary calcium carbonate [lime, $CaCO_3$] within one metre of the soil surface. They are commonly found in arid and semi-arid environments with distinct dry seasons. They occur in level to hilly landscapes under sparse natural vegetation of shrubs, trees, ephemeral grasses and forbs that are adapted to arid conditions. Calcisols form in alluvial, colluvial and aeolian parent materials that are rich in bases, notably calcium and magnesium.

Movement of calcium carbonate [$CaCO_3$] from surface horizons to an accumulation layer at some depth is one of the most widespread soil-forming processes in arid climates. The surface horizon is often completely or partially de-calcified, as calcium carbonate is dissolved by rainwater, the calcium [$Ca^{2+}$] and bicarbonate [$HCO_3^-$] ions are leached from the upper part of the soil and precipitated as calcite (a form of calcium carbonate) further down where the percolation stops and water evaporates, or where the partial pressure of carbon dioxide in soil air drops. These 'secondary' calcium carbonate accumulations appear as dispersed, fine calcite particles within pores of the soil matrix, or as discontinuous concentrations in the form of veins, pseudomycelia, coatings, soft and hard nodules. Alternative wetting (by rain) and drying (by evaporation) of the soil tend to concentrate the calcium carbonate in a calcic horizon. In time, calcic horizons can become indurated (cemented, petrified) by calcium carbonate and/or magnesium carbonate into nodular, lamellar or massive, extremely hard petrocalcic horizons (calcrete, *caliche*).

Calcisols typically have a thin, pale brown surface horizon, often with well-developed crumb or granular structure, or vesicular or biological crusts, bleaching and desert pavement. The calcic horizon is usually white, pinkish to reddish or grey and has low porosity, as soil pores are filled with lime. The sparse vegetation and high temperatures result in low organic matter content. Soil faunal activity is high in these soils.

Calcisols (JK/HM, MC)

Calcisols have neutral to high pH (≥7) that may reach 8-8.5 in the subsoil if free carbonates are present. They usually contain high amounts of bases [Ca, Mg, to a lesser extent K], but these are not necessarily accessible to plants, as excess calcium impedes the uptake of other bases. Uptake of phosphate and many trace elements are suppressed by the high pH and the predominance of calcium and magnesium on the exchange complex. Stone fruits, such as peaches, are very sensitive to iron [Fe] deficiencies on calcic soils. Boron [B] is highly mobile at high pH and may reach plant-toxic levels. Some Calcisols are also saline.

Most Calcisols have fine to medium texture and good water retention. Internal drainage and root development are impeded if the petrocalcic horizon is strongly and continuously cemented. However, a petrocalcic horizon beneath a thick B horizon can be an asset in an arid climate with very sandy soils, as it allows water to be retained in the root zone for longer. Most Calcisols are susceptible to erosion. The surface is prone to slaking and crusting, thus hampering water infiltration.

Calcisols support good grazing with nutritious grasses. They can be used successfully for grapevines (grafted on rootstock tolerant of high soil pH) and fruit trees, if the petrocalcic horizon is broken up by deep ripping. They can be productive under irrigation with good management practices for fertilization and to prevent salinisation and erosion. Calcisols provide good, stable road surfacing material.

A soil keys out as a **Calcisol** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

Other soils having:

1. a *petrocalcic* horizon starting ≤ 100 cm from the soil surface; *or*
2. both of the following:
   a. a *calcic* horizon starting ≤ 100 cm from the soil surface; *and*
   b. no *argic* horizon above the *calcic* horizon unless the *argic* horizon is permeated throughout with secondary carbonate.

A **calcic horizon** (Latin *calx* = lime) is a non-cemented surface or, more commonly, subsurface horizon within the top 100 cm of soil, in which secondary calcium carbonate ($CaCO_3$), also known as lime, has accumulated either as dispersed, fine calcite particles within the matrix, or as discontinuous concentrations in the form of veins, pseudomycelia, coatings, soft and/or hard nodules. Some primary carbonates may be present in a calcic horizon. In the field, the presence of calcium carbonate in soil is confirmed by applying a few drops of 1 M hydrochloric acid [HCl] solution. The degree of effervescence (audible only, visible as individual bubbles, or foam-like) is an indication of the amount of lime present. $pH_{water}$ can be used to differentiate between soils dominated by the carbonates of calcium (pH 8.0-8.7) and sodium and/or magnesium (pH > 8.7). The diagnostic criteria for a **calcic horizon,** according to the World Reference Base (IUSS Working Group WRB, 2015), are as follows:

A *calcic* horizon:

1. has a calcium carbonate equivalent in the fine earth fraction of ≥ 15 %; and
2. has one or both of the following:
   a. ≥ 5 % (by volume) secondary carbonates; or
   b. a calcium carbonate equivalent in the fine earth fraction of ≥ 5 % higher (absolute, by mass) than that of an underlying layer and no lithic discontinuity between the two layers; and
3. does not form part of a *petrocalcic* horizon; and

4. has a thickness of ≥ 15 cm.

When a calcic horizon becomes indurated by either calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$), it transitions to an extremely hard **petrocalcic horizon** (Gr. *petros* = rock; Latin *calx* = lime). The petrocalcic horizon may occur as nodular, massive, lamellar or petrified lamellar *calcrete* (also known as *caliche*).

A calcic horizon and a petrocalcic horizon may overlie each other. A petrocalcic horizon may grade into a gypsic, petrogypsic or petroduric horizon.

A *petrocalcic* horizon consists of mineral material *and*:

1. has very strong effervescence after adding a 1 M HCl solution; *and*
2. shows induration or cementation, at least partially by secondary carbonates, to the extent that air-dry fragments do not slake in water; *and*
3. is continuous to the extent that vertical fractures, if present, have an average horizontal spacing of ≥ 10 cm and occupy < 20 % (by volume); *and*
4. cannot be penetrated by roots except, if present, along the vertical fractures; *and*
5. has an extremely hard consistence when dry, so that it cannot be penetrated by spade or auger; *and*
6. has a thickness of ≥ 10 cm or ≥ 1 cm if it is laminar and rests directly on *continuous rock*.

Petrocalcic horizon at the surface (JK/HM)

(MC)

In other classification systems, *Calcisols* are known as *Calcarosols* (Australia), *calcids* (US Soil Taxonomy) or fall under *Xerosols* or, to a lesser extent, *Yermosols* (FAO Soil Map of the World).

The following Calcisols appear in the Soil Map of the SCIONA Project Area and Skeleton Coast National Park, generally as dominant or co-dominant soils:

| RSG | First Principal Qualifier | Full Name | Code |
|---|---|---|---|
| Calcisols | Cambic Calcisols | Cambic Calcisols | cmCL |
| | Haplic Calcisols | Haplic Calcisols | haCL |
| | | Haplic Calcisols (Yermic) | haCLye |
| | | Haplic Calcisols (Hypercalcic, Yermic) | haCLjcye |
| | Petric Calcisols | Petric Calcisols | ptCL |
| | | Petric Calcisols (Fluvic) | ptCLfl |
| | | Petric Calcisols (Yermic) | ptCLye |
| | | Petric Calcisols (Fluvic, Yermic) | ptCLflye |
| | | Gypsic Petric Calcisols (Yermic) | gyptCLye |
| | | Gypsic Petric Calcisols (Fluvic, Yermic) | gyptCLflye |

Calcisols occurring as dominant, co-dominant or associated soil type in mapping units (Coetzee)

## Cambisols [CM]

(from Latin *cambiare*, to change)

Cambisols are poorly developed soils formed where the parent material is recently deposited or exposed, or where aridity or low temperatures slow down the processes of soil formation. They form in a wide variety of medium- to fine-textured parent materials, mostly in young colluvial, alluvial and aeolian deposits. Cambisols are found in level to mountainous terrain, in all climates – being particularly prevalent in arid climates – and under a wide range of vegetation types.

They show early signs of parent material weathering and horizon development, such as the beginning of clay and/or carbonate movement, structure formation and colour differentiation. If the underlying layer has the same parent material, the cambic horizon usually shows slightly higher clay and/or oxide contents than this underlying layer and/or evidence of removal of carbonates and/or gypsum.

Cambisols are generally some of the better soils for agriculture in Namibia as the chemical weathering of parent material and accumulation of clay minerals increase the cation exchange capacity and thus the soil's ability to store nutrients, while the formation of soil structure (even if still poorly developed) improves the soil's physical properties and the rooting environment. They have good structural stability, porosity, internal drainage, water holding capacity and are not highly erodible.

A soil keys out as a **Cambisol** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

Other soils having:

1. a *cambic* horizon
   a. starting ≤ 50 cm from the soil surface; *and*
   b. having its lower limit ≥ 25 cm from the soil surface; *or*
2. an *anthraquic*, *hydragric*, *irragric*, *plaggic*, *pretic* or *terric* horizon; *or*
3. a *fragic*, *petroplinthic*, *pisoplinthic*, *plinthic*, *salic*, *thionic* or *vertic* horizon starting ≤ 100 cm from the soil surface; *or*
4. one or more layers with *andic* or *vitric* properties with a combined thickness of ≥ 15 cm within ≤ 100 cm of the soil surface.

A cambic horizon is a weak to relatively strong, pedogenetically altered subsurface horizon that has lost at least half of its original rock structure. If the underlying layer has the same parent material, the cambic horizon usually shows higher oxide and/or clay contents than this underlying layer and/or evidence of removal of carbonates and/or gypsum. The pedogenetic alteration of a cambic horizon can also be established by contrast with one of the overlying mineral horizons that are generally richer in organic matter and therefore have a darker and/or less intense colour. In this case, some soil structure development is needed to prove pedogenetic alteration.

The diagnostic criteria for a **cambic horizon,** according to the World Reference Base (IUSS Working Group WRB, 2015, pp. 27-28), is highly technical and not repeated here.

In other soil classification systems, *Cambisols* are as known as *Braunerden* and *Terrae fuscae* (Germany), *Sols bruns* (France), *Brunizems* or B*urozems* (Russia), *Tenosols* (Australia), *Cambisols* (FAO–UNESCO Soil Map of the World, 1971–1981), *Cambissolosfoot* (Brazil), *Inceptisols* (US Soil Taxonomy), while their old names in the US Soil Taxonomy were *Brown soils* and *Brown forest soils*.

The following Cambisols appear in the Soil Map of the SCIONA Project Area and Skeleton Coast National Park, generally as dominant or co-dominant soils:

| RSG | First Principal Qualifier | Full Name | Code |
|---|---|---|---|
| Cambisols | Cambisols | Cambisols (Arenic, Yermic) | CMarye |
| | Chromic Cambisols | Chromic Cambisols | crCM |
| | Gypsiric Cambisols | Gypsiric Cambisols (Arenic, Yermic) | gpCMarye |
| | Leptic Cambisols | Leptic Cambisols | leCM |
| | | Chromic Leptic Cambisols | crleCM |

Cambisols occurring as dominant, co-dominant or associated soil type in mapping units (Coetzee)

## Arenosols [AR]

(from Latin *arena*, sand)

Arenosols are deep loamy sand and sandy soils found in aeolian, lacustrine, marine and littoral landscapes, where they form in recently deposited sands such as dunes, sandy plains and beaches, and in residual sands formed by *in situ* weathering of quartz (silica, $SiO_2$)-rich sediments or rocks such as sandstone, granite and quartzite.

Fluvic Endosalic Arenosol – beach sand (MC)

Protic Arenosol (Aeolic) (MC)

Arenosols: reddish – quartz grains coated with haematite [$Fe_2O_3$], indicating, good internal aeration and drainage; yellowish – quartz grains coated with goethite [$FeO(OH)$], indicating somewhat longer periods of moisture in the soil; pale gray – uncoated quartz grains, indicating advanced leaching. The soil on the right exhibits clay lamellae. (MC)

Arenosols are often unconsolidated, with weak single grain structure. Water-scarcity and wind-driven mobility in arid environments lead to very little horizon development in these soils. Bulk density varies between 1.5 and 1.7

g/cm$^3$. Although total porosity (36-46 % per volume) may be lower than that of many finer-textured soils, the high proportion of macropores account for the good aeration, rapid drainage and low moisture and nutrient holding capacity. Water quickly drains downwards beyond the roots zone. The combination of coarse textures, high permeability and low organic carbon content (typically <0.5 % and <0.2 % in topsoil and subsoil, respectively) allows soluble substances to be leached from the topsoil and beyond the reach of shallow-rooted plants.

Decalcification of the surface layer is common. As the parent material, quartz, is chemically inert and the soil contains low quantities of clay minerals and organic carbon, Arenosols have low cation exchange capacity and thus low inherent fertility and poor buffering capacity. Arid zone Arenosols usually have somewhat larger quantities of smectite and/or vermiculite and chlorite clay minerals than those of more humid areas. Reddish and yellowish colours are imparted by coatings of hematite and goethite, respectively, on sand grains. Fine to medium-grained sands are highly susceptible to wind erosion if they are not stabilised by vegetation. Fine sand is easily compacted by heavy agricultural machinery, trampling by livestock and use of ploughs.

Extensive grazing is the predominant land use on Arenosols in arid and semi-arid lands with less than 300 mm annual rainfall. Care must be taken to prevent overgrazing and loss of the natural vegetation, as these soils can easily be destabilised and revert to shifting dunes. Dryland farming is possible where rainfall exceeds 300 mm/a, provided water harvesting (e.g. the ridge and furrow system) and conservation agriculture is practiced – addition of organic material (manure, compost, crop residues), cover crops (especially legumes to incorporate nitrogen into the soil), crop rotation, mulches, etc. Cultivation, rooting and harvesting of tuber and root crops are easy in Arenosols due to the low coherence. Supplementary irrigation can lead to good yields of small grains, melons, pulses and fodder crops, provided drip or trickle irrigation with small applications of fertilisers spaced out through the growing season. Surface irrigation is wasteful, on account of high percolation losses. Arenosols may exhibit hydrophobic properties that hamper water infiltration, especially after long hot and dry spells. This is caused by water-repellent exudates of soil fungi that coat sand grains. Addition of wetting agents (surfactants) can alleviate this problem.

The beach sands and the dune sands of the Skeleton Coast- and Kunene Dune Fields are Arenosols, composed of up to 70-80 % quartz (Garvanti et al., 2014) in addition to feldspars and, to a lesser extent, micas, ferromagnesian minerals (pyroxenes, amphiboles, olivines) and heavy minerals such as zircon, garnet, tourmaline, ilmenite, magnetite and rutile.

A soil keys out as an **Arenosol** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

Other soils having:

1. a weighted average texture class of loamy sand or coarser, if layers of finer texture have a combined thickness of < 15 cm, to a depth of 100 cm from the mineral soil surface; *and*
2. < 40 % (by volume) of coarse fragments in all layers within ≤ 100 cm of the mineral soil surface.

In other soil classification systems, *Arenosols* may be known as *Psamments* (US Soil Taxonomy), *Sols minéraux brut*s and *Sols peu évolués* (France), *Arenic Rudosols/Tenosols* (Australia), *Psammozems* (Russia) and *Neossolos* (Brazil).

Arenosols key out quite late among the WRB Reference Soil Groups, as other diagnostic horizons, properties and materials have priority over the sandy character. In such a case, it is important to add the *arenic* qualifier to the assigned RSG. For example, a soil would be classified as Calcisols (Arenic) if a calcic or petrocalcic horizon occur within the first 100 cm from the surface, even though coarse, reddish sand may cover the surface as in the photos below:

Petric Calcisol (Arenic). Shallow calcrete (petrocalcic horizon), broken up and brought to the surface during preparation for cultivation (JB)

The following Arenosols appear in the Soil Map of the SCIONA Project Area and Skeleton Coast National Park, as dominant or co-dominant soils:

| RSG | First Principal Qualifier | Full Name | Code |
|---|---|---|---|
| Arenosols | Fluvic Arenosols | Fluvic Arenosols | flAR |
| | Protic Arenosols | Protic Arenosols (Aeolic) | prARay |
| | Salic Arenosols | Fluvic Endosalic Arenosols | flsznAR |
| | | Fluvic Protosalic Arenosols | flqzAR |
| | Sideralic Arenosols | Sideralic Arenosols | seAR |
| | | Chromic Sideralic Arenosols | crseAR |

Arenosols occurring as dominant, co-dominant or associated soil type in mapping units (Coetzee)

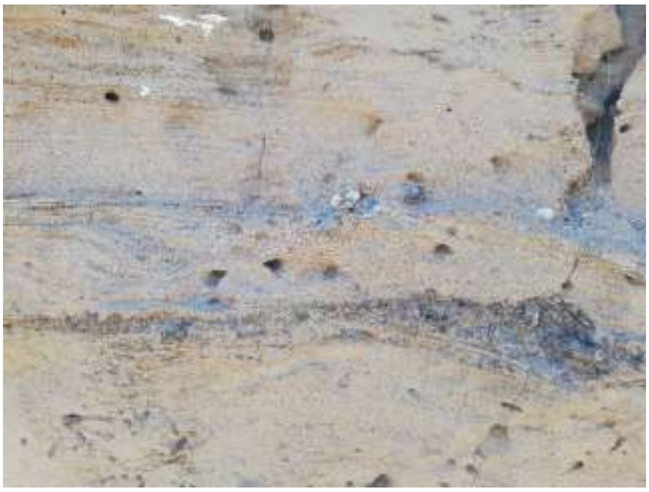
## Fluvisols [FL]

(from Latin *fluvius*, river)

Fluvisols are genetically young soils developed in unconsolidated fluvial, lacustrine or marine sediments such as riverbeds, river valleys, alluvial fans, deltas, tidal marches and recent marine deposits.

Periodic inundation deposits layers of sediment in which soil formation ensues between successive flood events. They show stratification in texture, colour, organic matter content and the nature of coarse fragments. Gravelly or sandy deposits indicate fast-flowing water and turbulence while standing or slow-moving water deposits fine-textured sediment. Some Fluvisols display takyric properties such as compact, fine-textured crusts with prominent polygonal cracks developed over underlying material that has a platy or massive structure.

Silty and loamy Fluvisols are fertile and easy to work. Fluvisols are not influenced by shallow groundwater and do not have high salt concentrations in the topsoil.



Fluvisol (MC)

Fluvisol of a palaeodelta (MC)

Fluvisols (MC)

A soil keys out as a **Fluvisol** in the World Reference Base (IUSS Working Group WRB, 2015) once it meets the following criteria:

Other soils having *fluvic* material:

1. ≥ 25 cm thick and starting ≤ 25 cm from the mineral soil surface; *or*
2. from the lower limit of a plough layer that is ≤ 40 cm thick, to a depth of ≥ 50 cm from the mineral soil surface.

**Fluvic material** refers to fluviatile, marine and lacustrine deposits that receive fresh material or have received it in the past and still show stratification. Their associated with water bodies allows them to be distinguished from colluvial material. Stratification is shown by layers exhibiting variations in texture, colour, organic matter content (irregular patterns of lighter and darker layers) and/or content and nature of coarse fragments.

The diagnostic criteria for **fluvic material,** according to the World Reference Base (IUSS Working Group WRB, 2015), are as follows:

*Fluvic* material:

1. is of fluviatile, marine or lacustrine origin; *and*
2. has one or both of the following:
    a. obvious stratification (including stratification tilted by cryoturbation) in ≥ 25 % of the soil volume over a specified depth (including strata thicker than the specified depth); *or*
    b. stratification evidenced by a layer with all of the following:
        i. has ≥ 0.2 % soil organic carbon; *and*
        ii. has a content of soil organic carbon ≥ 25 % (relative) and ≥ 0.2 % (absolute) higher than in the overlying layer; *and*
        iii. does not form part of a *spodic* or *sombric* horizon.

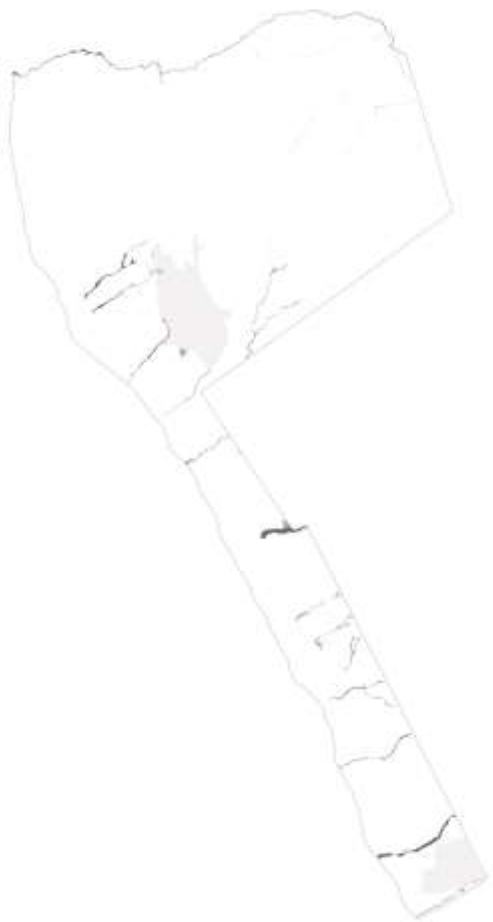
In other soil classification systems, *Fluvisols* are known as *Fluvents* (US Soil Taxonomy), *Sols minéraux bruts d'apport alluvial ou colluvial* or *Sols peu évolués non climatiques d'apport alluvial ou colluvial* (France), *Stratic Rudosols* (Australia), *Alluvial soils* (Russia) and *Neossolos* (Brazil).

Periodically flooded soils (Fluvisols) in arid regions often display **takyric** properties. Where surface waters that are rich in silt and clay but low in salts accumulate in depressions, they leach salt out of the upper soil horizons, causing clay dispersion and formation of compact, fine-textured crusts that contain more than 80 % clay and silt. Prominent polygonal cracks develop when the crust dries out. The underlying material has a platy or massive structure.

The following Fluvisols appear in the Soil Map of the SCIONA Project Area and Skeleton Coast National Park, generally as co-dominant or associated soils of riverbeds, river valleys and palaeo alluvial fans:

| **RSG** | **First Principal Qualifier** | **Full Name** | **Code** |
|---|---|---|---|
| Fluvisols | Fluvisols | Fluvisols (Arenic) | FLar |
| | Calcaric Fluvisols | Calcaric Fluvisols (Arenic) | caFLar |
| | Gleyic Fluvisols | Gleyic Fluvisols (Arenic) | glFLar |

| | | | |
|---|---|---|---|
| | Leptic Fluvisols | Calcaric Leptic Fluvisols (Arenic) | caleFLar |
| | Tidalic Fluvisols | Tidalic Fluvisols (Loamic, Sulfidic) | tdFLlosf |



Fluvisols occurring as dominant, co-dominant or associated soil type in mapping units (Coetzee)

## Regosols [RG]

(from Greek *rhegos*, blanket; referring to the weathered shell of the earth)

Regosols are young, minimally developed soils with no diagnostic horizons and very little evidence of soil-forming processes. They occur in all climates (except frozen lands) and at all elevations. They are usually found in medium to finely textured, unconsolidated materials. They occur where soil formation has been inhibited by adverse conditions, such as an arid, hot climate, or soil formation has been interrupted by recent truncation, exposure (by erosion) or constant rejuvenation (by deposition). They are common in young sediments, eroding and accreting landscapes, particularly in arid and semi-arid areas.

Regosols on slopes are highly erodible, due to the low coherence of the unconsolidated matrix material. High permeability and low water holding capacity make Regosols prone to desiccation, so they have low rainfed crop production potential. They are widely used for extensive grazing.

Leptosols and Regosols often appear complementary: Leptosols tend to occupy convex crests and steep slopes, where natural erosion keeps pace with soil formation, while Regosols occupy concave positions in the landscape, such as footslopes and valley basins, where deposition keeps pace with soil formation.

Regosols on footslopes and intermontane valleys (MC)

Regosols are the ‘leftover soils’, once one has worked through the entire WRB Key. Being a taxonomic rest group, they are defined by the *absence* of strongly expressed diagnostic properties.

The following Regosols appear in the Soil Map of the SCIONA Project Area and Skeleton Coast National Park, generally as dominant or co-dominant soils:

| RSG | First Principal Qualifier | Full Name | Code |
|---|---|---|---|
| Regosols | Calcaric Regosols | Calcaric Regosols (Yermic) | caRGye |
| | Eutric Regosols | Eutric Regosols | euRG |
| | Leptic Regosols | Leptic Regosols | leRG |
| | | Leptic Regosols (Arenic, Yermic) | leRGarye |
| | | Calcaric Gypsiric Leptic Regosols (Yermic) | cagpleRGye |
| | | Skeletic Leptic Regosols | skleRG |
| | | Skeletic Leptic Regosols (Yermic) | skleRGye |
| | | Colluvic Skeletic Leptic Regosols | coskleRG |
| | | Colluvic Skeletic Leptic Regosols (Yermic) | coskleRGye |

| | | | |
|---|---|---|---|
| | Skeletic Regosols | Skeletic Regosols | skRG |
| | | Colluvic Skeletic Regosols | coskRG |
| | | Eutric Skeletic Regosols (Yermic) | euskRGye |

Regosols occurring as dominant, co-dominant or associated soil type in mapping units (Coetzee)

# Description of Soil Qualifiers

Qualifiers are used in association with Reference Soil Groups to provide more information. Some qualifiers are not widespread enough or expressed strongly enough to be included in the current Soil Map of the SCIONA Project Area (Namibia) and Skeleton Coast National Park at the mapping scale used for this project, but they do occur in the area and are included in the list below.

## Aeolic (ay)

(from Greek *aiolos*, wind)

Soils with a wind-deposited surface layer of at least 10 cm thickness and low organic carbon content (less than 0.6 %). The dunes of the Namib are examples of Aeolic Arenosols.

Wind-deposited and -sculpted sand in the Namib (MC)

## Albic (ab)

(from Latin *albus*, white)

Soils with a layer of *albic* material, at least 1 cm thick and starting within 100 cm from the surface. Albic material is light-coloured (low chroma), with most organic material and/or free iron oxides removed so that the actual sand and silt grain colour is visible without any coatings on these particles. They are usually associated with strongly expressed relocation of clay materials and usually overlie horizons with accumulations of clay. They are also frequently associated with *stagnic* properties.

The fine, white, powdery layer on top of rounded columns in Solonetz, is albic material.

(EM; ISRIC)

## Arenic (ar)

(from Latin *arena*, sand)

Soils with a sandy or loamy sand texture and thickness of at least 30 cm, within 100 cm from the soil surface.

## Aridic (ad)

(from Latin *aridus*, dry)

Soils with surface layers typical of arid conditions. Aridic properties refer to a number of characteristics of surface horizons of arid zone soils, such as low soil organic carbon, evidence of aeolian activity, high base saturation (≥ 75 %) and relatively dark and strong colour, especially when moist. Aeolian activity is demonstrated by rounded to subangular sand particles with a matt surface, ventifacts (wind-shaped rocks), aeroturbation (e.g. crossbedding) or other signs of wind erosion or deposition.

Ventifacts, wind-sculpted rocks and stones – signs of wind erosion (MC)

## Brunic (br)

(from Low German *brun*, brown)

Soils with a layer of at least 15 cm thick and starting within 50 cm from the soil surface, that does not consist of albic material and meets the criteria for a cambic horizon, except criterion 1 (having a texture class of sandy loam or finer, or very fine sand or loamy very fine sand).

## Calcaric (ca)

(from Latin *calcarius*, containing lime)

Calcaric soils contain at least 2 % calcium carbonate equivalent inherited from parent materials, i.e. primary carbonates, throughout, between 20 and 100 cm from the soil surface. Calcaric material effervesces with 1 M hydrochloric acid [HCl], does *not* consist of masses, nodules, concretions that are soft and powdery when dry, does *not* appear as soft coatings on ped faces or pore surfaces and does *not* form pseudomycelia (filaments). A layer may consist of calcaric material and additionally show *protocalcic properties* but does *not* have a *calcic* or *petrocalcic* horizon.

## Calcic (cc)

(from Latin *calx*, lime)

Calcic soils meet the diagnostic criteria for a *calcic horizon*, which contains at least 15 % of non-cemented secondary calcium carbonate [$CaCO_3$] equivalent – indicated by development of foam upon adding 1 M hydrochloric acid [HCl] to the soil – and is at least 15 cm thick and starts less than 100 cm from the soil surface. The calcium carbonate accumulations appear as a diffused powder dispersed in the soil matrix or discontinuous concentrations such as veins, pseudomycelia, coatings, soft and/or hard nodules. Secondary carbonates do not belong to the soil parent material or other sources such as dust but are derived from the soil solution and precipitated in the soil. A calcic horizon is often white, pinkish to reddish or grey and have relatively low porosity.

Accumulation of secondary, pedogenic carbonates (EM, MC)

Hypercalcic Calcisol (JK/HM)

### Hypercalcic (jc)

(from Greek *hyper*, over and Latin *calx*, lime)

A hypercalcic soil has a *calcic* horizon where the calcium carbonate equivalent of the fine earth fraction (i.e. excluding gravel and stones) is at least 50 %. Continuous but soft concentrations of calcium carbonate dominate the soil or rock structure.

### Protocalcic (qc)

(from Greek *protou*, before and Latin *calx*, lime)

Soils with less pronounced accumulations of secondary carbonates, that do *not* meet the diagnostic criteria for a *calcic* horizon.

## Cambic (cm)

(from Latin *cambiare*, to change)

Soils that show some signs of subsurface horizon development, starting within 50 cm from the soil surface, in terms of changes in colour, texture, structure and consistency, but not so strongly developed that they meet diagnostic criteria for other types of horizons. Examples of such pedogenic alterations are higher oxide and/or clay content than the underlying layer, evidence of removal of carbonates and/or gypsum, lighter and/or more intense colour than the overlying horizon(s) and/or some soil structure development.

## Chromic (cr)

(from Greek *chroma*, colour)

Soils with bright reddish colours in the subsoil. Chromic soils have a layer, at least 30 cm thick, between 25 and 150 cm from the soil surface, that has, in more than 90 % of its exposed area, a moist Munsell colour hue redder than 7.5YR (i.e. 5YR, 2.5YR, 10R, 7.5R, 5R) and chroma of more than 4.

Chromic soils (JK/HM)

## Clayic (ce)

(from English *clay*)

Soils with a clay, sandy clay or silty clay texture in a layer at least 30 cm thick, within 100 cm from the soil surface.

Clayic soils (MC)

## Colluvic (co)

(from Latin *colluvio*, mixture)

Soils formed in poorly sorted heterogeneous material that has moved down a slope under the influence of gravity, through erosional wash or soil creep. They are found on concave slopes, footslopes, fans, depressions etc., show evidence of downslope movement, are not of fluviatile, lacustrine or marine origin, are usually of Holocene age and have lower bulk density than the underlying buried soil material.

## Dolomitic (do)

(from the mineral *dolomite*, named after French geoscientist Déodat de Dolomieu)

Soils formed in dolomitic parent material that include at least 2 % of a mineral that contains less than 1.5 times as much $CaCO_3$ as $MgCO_3$. It effervesces weakly with 1 M hydrochloric acid [HCl] at room temperature, but strongly with heated HCl.

## Duric (du)

(from Latin *durus*, hard)

Soils with weakly cemented to indurated silica-rich [$SiO_2$] concretions or nodules (‘*durinodes’*) or fragments of a broken-up *petroduric* horizon. Durinodes must be at least 1 cm in diameter and the duric horizon at least 10 cm thick and starting within 100 cm from the soil surface. Dry durinodes do not slake in water, but prolonged soaking can cause some slaking and breaking-off of thin platelets. Air-dry durinodes do not slake much in 1 M hydrochloric acid (HCl) but do in concentrated potassium hydroxide (KOH) or sodium hydroxide (NaOH) or alternating acid and alkali.

Duric soils (JK/HM; MC)

## Dystric (dy)

(from Greek *dys*, bad, and *trophae*, food)

Soils that are relatively infertile, with effective base saturation of less than 50 % in at least half of the soil between 20 and 100 cm from the soil surface.

## Eutric (eu)

(from Greek *eu*, good, and *trophae*, food)

Soils that are relatively fertile, with effective base saturation of at least 50 % in the major part of the soil between 20 and 100 cm from the soil surface.

## Evapocrustic (ev)

(from Latin *e*, out and *vapor*, steam and *crusta*, crust)

Solonchaks having a saline crust less than 2 cm thick on the soil surface.

Evapocrustic Solonchaks (MC)

## Fluvic (fl)

(from Latin *fluvius*, river)

Soils formed in river, coastal or lake deposits that either receive fresh sediments at present or received it in the past, with distinctive stratification in the form of variations in texture and/or content and/or nature of coarse fragments, different colours related to the source materials or alternating lighter and darker coloured layers, indicating an irregular decrease in soil organic carbon content with depth.

Fluvic soil (MC)


Fluvic soils (MC)

## Fractic (fc)

(from Latin *fractus*, broken)

Soils with a broken cemented or indurated horizon, at least 10 cm thick and starting within 100 cm from the soil surface, with the fragments less than 10 cm long and occupying 40-80 % of the soil volume.

Calcifractic (cf) and gypsifractic (gf) refer to broken *petrocalcic* and *petrogypsic* horizons respectively.

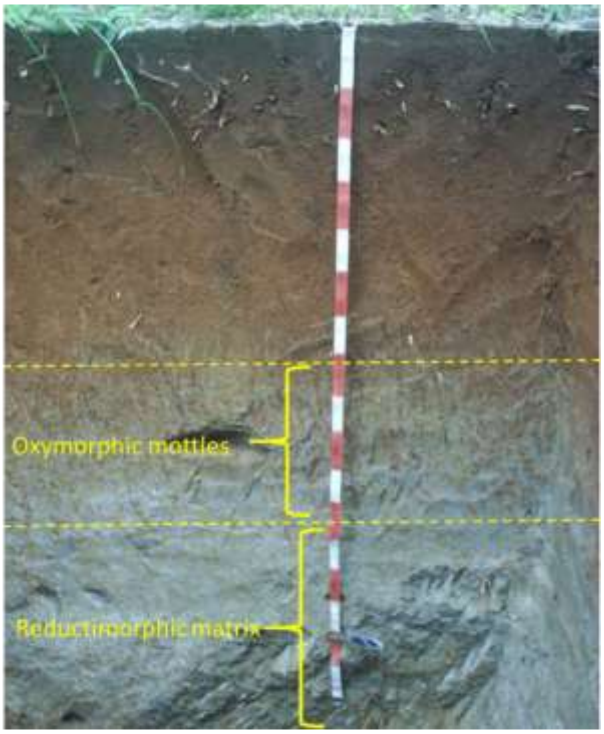
Calcifractic soil (cf) – broken petrocalcic horizon (JK/HM)

## Gleyic (gl)

(from R. *gley*, mucky soil mass)

Soils saturated by groundwater long enough for anaerobic (reducing) conditions to occur in a layer at least 25 cm thick, starting within 75 cm from the soil surface.

The diagnostic criteria are quite technical: (a) more than 95 % of the layer's exposed area must have reductimorphic colours (moist Munsell colour hue of N, 10Y, GY, G, BG, B, PB, *or* moist Munsell colour hue of 2.5 Y or 5Y with a chroma of 2 or less); *or* (b) more than 5 % of the layer's exposed area must have oximorphic mottles, predominantly around root channels or at/near the surfaces of peds (aggregates) *and* moist Munsell colour hue at least 2.5 units redder *and* chroma at least 1 unit higher than the surrounding material; or (c) a layer fulfilling criterion (b) directly underlying a layer fulfilling criterion (a).




Gleyic properties (MC)

Oximorphic mottles within a reductimorphic matrix (MC)

Gleying soil – capillary fringe mottling (EM)

Oximorphic ped surface, reductimorphic ped interior (CvH)

Oximorphic colours around root channels (CvH)

## Gypsic (gy)

(from Greek *gypsos*, gypsum)

Gypsic soils meet the diagnostic criteria for a *gypsic* horizon, which contains at least 5 % of non-cemented accumulations of secondary calcium sulphate [$CaSO_4.2H_2O$], is at least 15 cm thick, starts within 100 cm from the soil surface, has a product of thickness (in cm) times % gypsum of at least 150, has at least 1 % visible secondary gypsum or at least 5 % (absolute, by mass) more visible gypsum than an underlying layer, and does not form part of a *petrogypsic* horizon. A *gypsic* and *petrogypsic* horizon may overlie each other.

## Gypsiric (gp)

(from Greek *gypsos*, gypsum)

*Gypsiric* material contains at least 5 % primary gypsum (by volume), and none or very little secondary gypsum. It does *not* meet the requirements for a *gypsic* or *petrogypsic* horizon.

## Haplic (ha)

(from Greek *haplous*, simple)

Haplic is used when none of the other principal qualifiers applies. It refers to soils that are typical of that RSG, without other prominent characteristics.

## Lapiadic (ld)

(from Latin *lapis*, stone)

Leptosols with continuous rock at the soil surface that has dissolution features (rills, grooves) of at least 20 cm deep and covering between 10 and 50 % of the surface of the rock.

Lapiadic Leptosols (MC)

## Leptic (le)

(from Greek *leptos*, thin)

Shallow soils that have continuous rock or technic hard material starting within 100 cm from the soil surface.


Leptic soils (EM/MC)

## Lithic (li)

(from G *lithos*, stone)

Very shallow Leptosols that have continuous rock or technic hard material starting within 10 cm from the soil surface.


Lithic Leptosols (MC)

### Nudilithic (nt)

(from Latin *nudus*, naked and Greek *lithos*, stone)

Leptosols with continuous rock at the surface.


Nudilithic Leptosols (MC)

## Loamic (lo)

(from English *loam*)

Soils with loam, sandy loam, sandy clay loam, clay loam or silty clay loam texture in a layer at least 30 cm thick and starting within 100 cm from the soil surface.

## Luvic (lv)

(from Latin *eluere*, to wash)

Soils with subsoil clay accumulation (an *argic* horizon) starting within 100 cm from the soil surface, cation exchange capacity of at least 24 $cmol_c$/kg and base saturation of at least 50 % in the major part of the soil between 50 and 100 cm from the surface.

## Natric (na)

(from Arabic *natron*, salt).

A *natric* horizon is a dense subsurface horizon with a distinct increase in clay content, high exchangeable sodium [Na] and sometimes relatively high exchangeable magnesium [Mg]. The diagnostic criteria are highly technical and thus not explained here in detail. For field identification, the coarse columnar or prismatic subsoil structure with rounded tops, sometimes covered by a whitish powder, is characteristic.

Only Cryosols (frozen soils, not found in Namibia) and Solonetz can have a *natric* horizon. Other soils with high sodium content have *sodic* qualifiers.


Natric horizon of Solonetz (EM)

## Ochric (oh)

(from Greek *ochros*, pale)

Soils with ≥ 0.2 % topsoil organic carbon, but not meeting the criteria for *mollic*, *umbric* or *humic* horizons/qualifiers.

## Petric (pt)

(from Greek *petros*, rock)

Soils with a cemented or indurated layer that is a diagnostic horizon of the respective RSG, starting within 100 cm from the soil surface.

### Nudipetric (np)

(from Latin *nudus*, naked and Greek *petros*, rock)

Nudipetric refers to the cemented or indurated diagnostic horizon of the respective RSG, starting at the soil surface.

Nudipetric Calcisols (JK/HM, MC)

## Petrocalcic (pc)

(from Greek *petros*, rock and Latin *calx*, lime)

Soils with a *petrocalcic* horizon, namely relatively continuously cemented or indurated accumulations of secondary carbonates, starting within 100 cm from the soil surface.

## Petroduric (pd)

(from Greek *petros*, rock and Latin *durus*, hard)

Soils with a *petroduric horizon*, namely relatively continuously cemented or indurated accumulations of secondary silica, starting within 100 cm from the soil surface.

Petroduric horizon (MC)

## Petrogypsic (pg)

(from Greek *petros,* rock and *gypsos*, gypsum)

Soils with a *petrogypsic horizon*, namely relatively continuously cemented or indurated accumulations of secondary gypsum, starting within 100 cm from the soil surface.

Top of petrogypsic horizon exposed by grader (MC)

Petrogypsic soil (MC)

## Petrosalic (ps)

(from Greek *petros,* rock and Latin *sal*, salt)

Soils with relatively continuously cemented or indurated accumulations of salts that are more soluble than gypsum, in a layer at least 10 cm thick within 100 cm from the soil surface.

Petrosalic Solonchaks (MC)

## Protic (pr)

(from Greek *protou*, before)

Soils showing no signs of horizon development.

## Puffic (pu)

(from English, *to puff*)

Solonchaks with a crust pushed up by salt crystals.


Puffic Solonchaks (MC; AD)

## Salic (sz)

(from Latin *sal*, salt)

Salic soils are rich in highly soluble salts, having a *salic horizon* within 100 cm of the soil surface. The *salic horizon* must have a thickness of at least 15 cm, electrical conductivity of the saturation extract ($EC_e$) of at least 15 dS/m (or $EC_e$ at least 8 dS/m if the $pH_{water}$ of the saturation extract is 8.5 or higher), and the product of the $EC_e$ (in dS/m) and thickness (in cm) must be at least 450 for some time of the year.


Salic soil (EM)

Salic, puffic, evapocrustic soil (AD)

### Endosalic (szn)

(from Greek *endon*, inside and Latin *sal*, salt)

Soils with a *salic horizon* somewhere between 50 and 100 cm from the soil surface and absent in the upper 50 cm.

### Hypersalic (jz)

(from Greek *hyper*, over and Latin *sal*, salt)

Highly saline soils with an electrical conductivity of the saturation extract ($EC_e$) of at least 30 dS/m within 100 from the soil surface.

### Protosalic (qz)

(from Greek *protou*, before and Latin *sal*, salt)

Soils with some salinity ($EC_e$ of at least 4 dS/m within 100 from the soil surface), but *not* meeting the criteria for a *salic* horizon.

## Sideralic (se)

(from Greek *sideros*, iron, and Latin *alumen*, alum)

Sideralic properties occur in a subsurface horizon with low cation exchange capacity (below 24 $cmol_c$/kg soil), or both very low CEC (below 4 $cmol_c$/kg soil) and intense colour (a moist Munsell colour chroma ≥ 5). These soils are usually rich in iron and/or aluminium oxides and hydroxides.

## Siltic (sl)

(from English *silt*)

Soils with silt or silt loam texture, at least 30 cm thick and starting within 100 cm of the soil surface.

## Skeletic (sk)

(from Greek *skeletos*, dried out)

Soils with > 40 % (by volume) gravel or other coarse fragments over a depth of 100 cm from the surface or to continuous rock or an indurated layer.

### Hyperskeletic (jk)

(from Greek hyper, over and skeletos, dried out)

Soils with > 80 % (by volume) gravel or other coarse fragments over a depth of 100 cm from the surface or to continuous rock or an indurated layer.

Hyperskeletic soils (MC)

## Sodic (so)

(from Spanish *soda*, gaseous water)

Soils with at least 6 % exchangeable sodium [Na], at least 15 % exchangeable sodium plus magnesium [Mg], thickness of at least 20 cm and starting within 100 cm from the soil surface, but not meeting the criteria for a *natric horizon*.

### Protosodic (qs)

(from Greek *protou*, before and Spanish *soda*, gaseous water)

Soils with at least 6 % exchangeable sodium [Na], thickness of at least 20 cm and starting within 100 cm from the soil surface, that do not meet the criteria for a *natric horizon*.

## Stagnic (st)

(from Latin *stagnare*, to stagnate)

Soils subject to saturation by *surface* water long enough for reducing (anaerobic) conditions to occur. This is indicated by a bleached (‘*albic*’) layer appearing above a layer with heavier texture and/or reductimorphic colours around root channels and the surfaces of soil aggregates (peds), and/or dark oximorphic mottles, concretions and/or nodules inside peds.

*Stagnic* properties differ from *gleyic* properties in that they are caused by stagnation of a reducing agent (mostly rainwater) intruding from the *top*, leading to an *overlying reduced layer* and underlying layer with oximorphic colours inside the soil aggregates.

Stagnic soils (CvH, EM; MG; CvH)

## Takyric (ty)

(from Turkic languages *takyr*, barren land)

Takyric properties are a special case of *aridic* properties and refer to heavy-textured surface layers under arid conditions in periodically flooded soils (e.g. clay pans). They have a surface crust and platy or massive structure, clay loam, silty clay loam or clay texture, are very hard when dry, are plastic and sticky when wet, are thick enough not to curl entirely upon drying, show polygonal cracks at least 2 cm deep when dry, and are not saline.

Takyric properties occur in association with *natric*, *salic*, *gypsic*, *calcic* and *cambic* diagnostic horizons.

Takyric soils (MC)

## Tidalic (td)

(from English *tide*)

Soils affected by tidal water, located between the mean high and low springtide lines.

Tidalic soils (MC)

## Yermic (ye)

(from Spanish *yermo*, desert)

Soils with a layer of stone fragments ('desert pavement') embedded in fine material, often with air bubbles and sometimes covered by a thin layer of wind-blown sand. Yermic properties are a subsection of Aridic Properties and are associated with desert pavement in arid regions. Gravel or stone fragments may be embedded in a loamy vesicular ('bubble', 'foamy', 'schaumboden') layer that is frequently found in the upper few centimetres of unvegetated, structurally unstable, silty loam soils (Ellis, 1988; Ellis, 1990, Lambrechts, 2004). Finely textured in-blown material is moistened by low amounts of rainfall or fog. Moisture does not penetrate far into the soil and the fine mud dries out quickly, trapping bubbles of air (from soil macropores) that did not have time to work their way to the surface. There are some theories that cyanobacteria may be involved in producing these bubbles. A common feature is polygonal networks of desiccation cracks that extend into the underlying layers and are filled with in-blown material. Desert varnish, ventifacts, soluble mineral accumulations, layers with weak to moderate platy structure, thin aeolian sand or loess may occur on the surface above the vesicular layer.

Vesicular crust underlying desert pavement (MC)

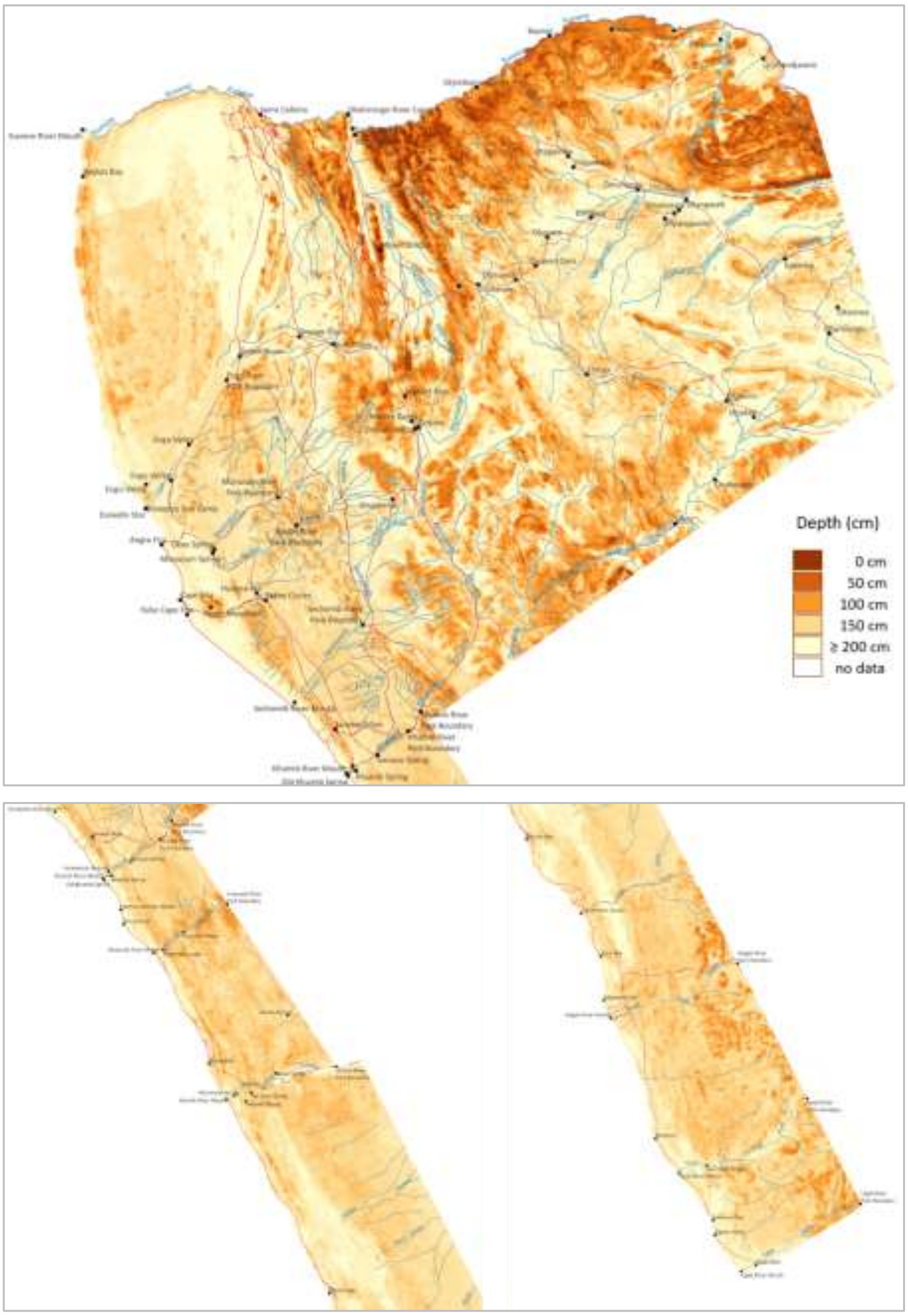
Desert pavement (MC)

'Dreikanter' (type of ventifact) with desert varnish (MC)

# Key Soil Properties

## Soil Depth

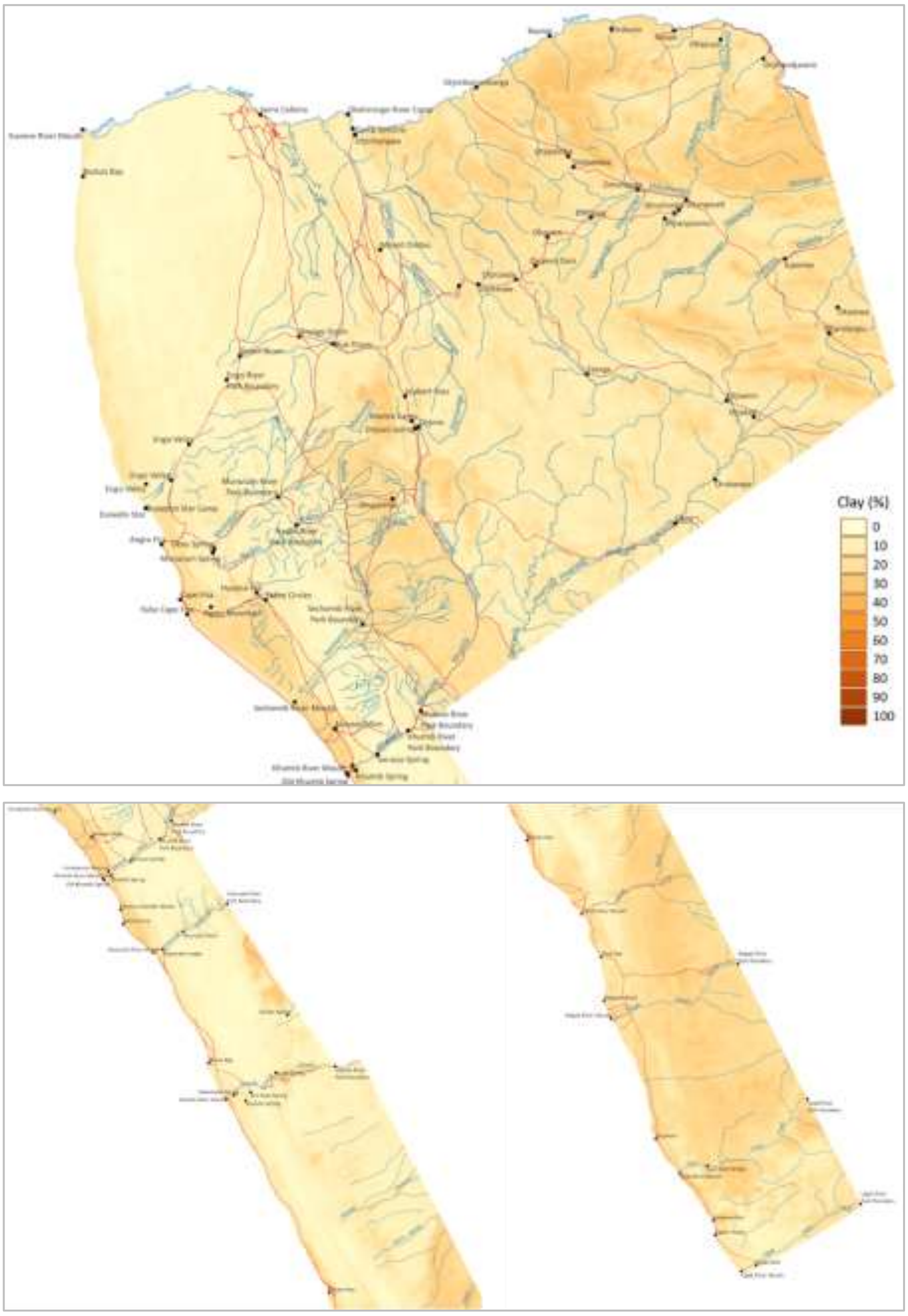
Deeper soils generally provide more water and nutrients and better conditions for root growth than shallow soils. Soil depth is not only limited by the presence of shallow bedrock, but also by indurated horizons within the soil. Natural processes can cement soil with calcium carbonate (lime), calcium sulphate (gypsum), silica, and iron and/or manganese oxides to form hard petrocalcic, petrogypsic, petroduric and petroplinthic horizons, respectively. Agricultural practices such as livestock trampling and the use of heavy machinery on wet soil, and the use of mouldboard ploughs can cause compaction of subsoil. These hardpans hamper root growth and effectively limit the depth of the soil. In sandy soil in an arid climate, a cemented layer at some depth can be an advantage, as it impedes deep drainage, allowing more moisture to be stored in the soil above it, within reach of roots.




Soil Depth (Source: ISRIC SoilGrids250m)

## Clay Fraction

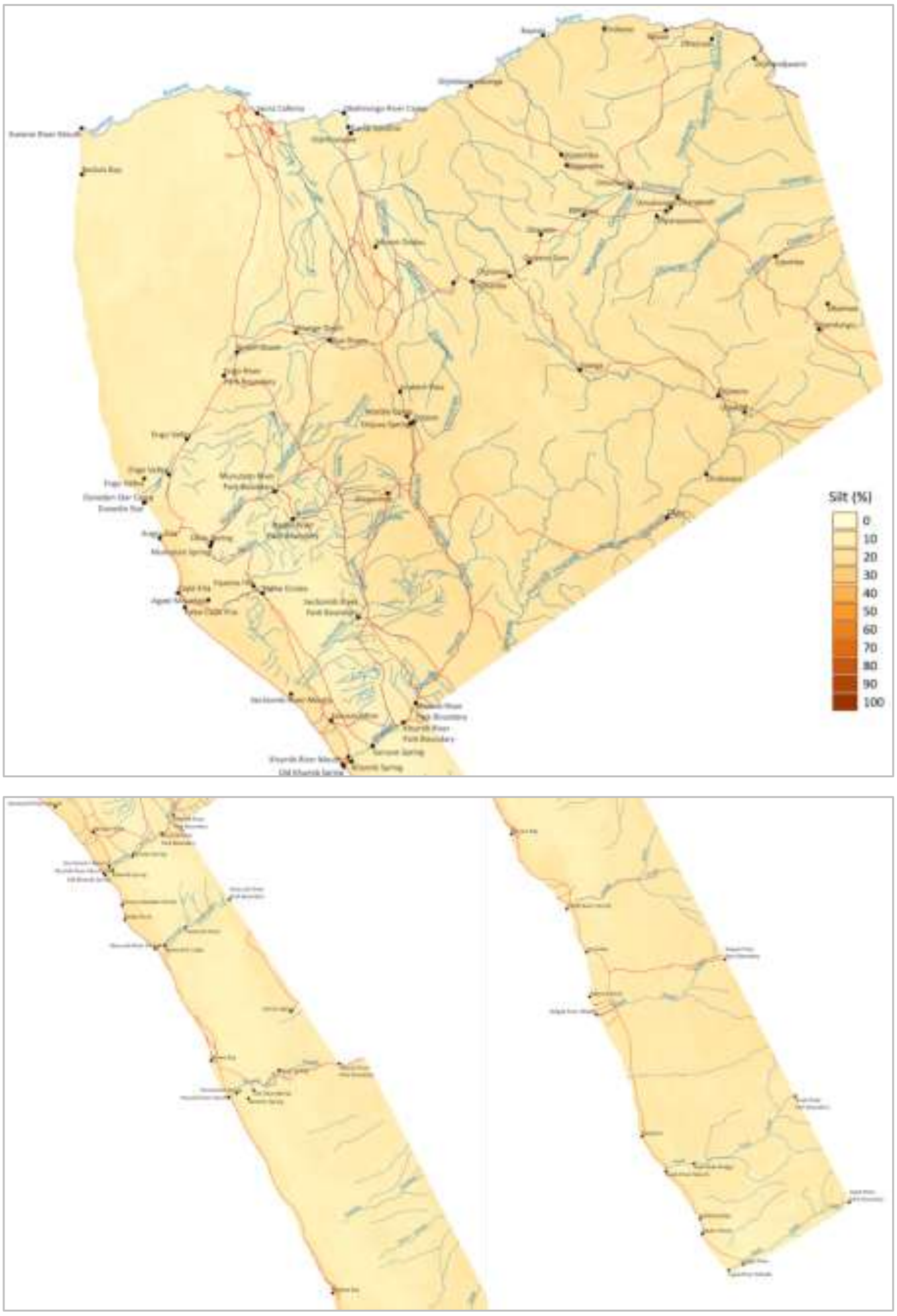
Clay particles are the result of chemical weathering of parent materials. They are, per definition, smaller than 2 nm (0.002 mm), can only be seen with a microscope and can remain suspended in water for hours or even days. Their large surface-to-volume-ratios give them special properties to retain nutrients, thus clayey soils are usually fertile. The have more micropores and few macropores between the clay particles, thus water infiltrates and drains very slowly in clayey soils, they are poorly aerated and tend to become waterlogged. Plants may have difficulty to absorb soil water that is held strongly in the tiny pores. Clayey soils can be extremely hard when dry and sticky when wet, and therefore difficult to cultivate.




Clay Fraction (Source: ISRIC SoilGrids250m)

## Silt Fraction

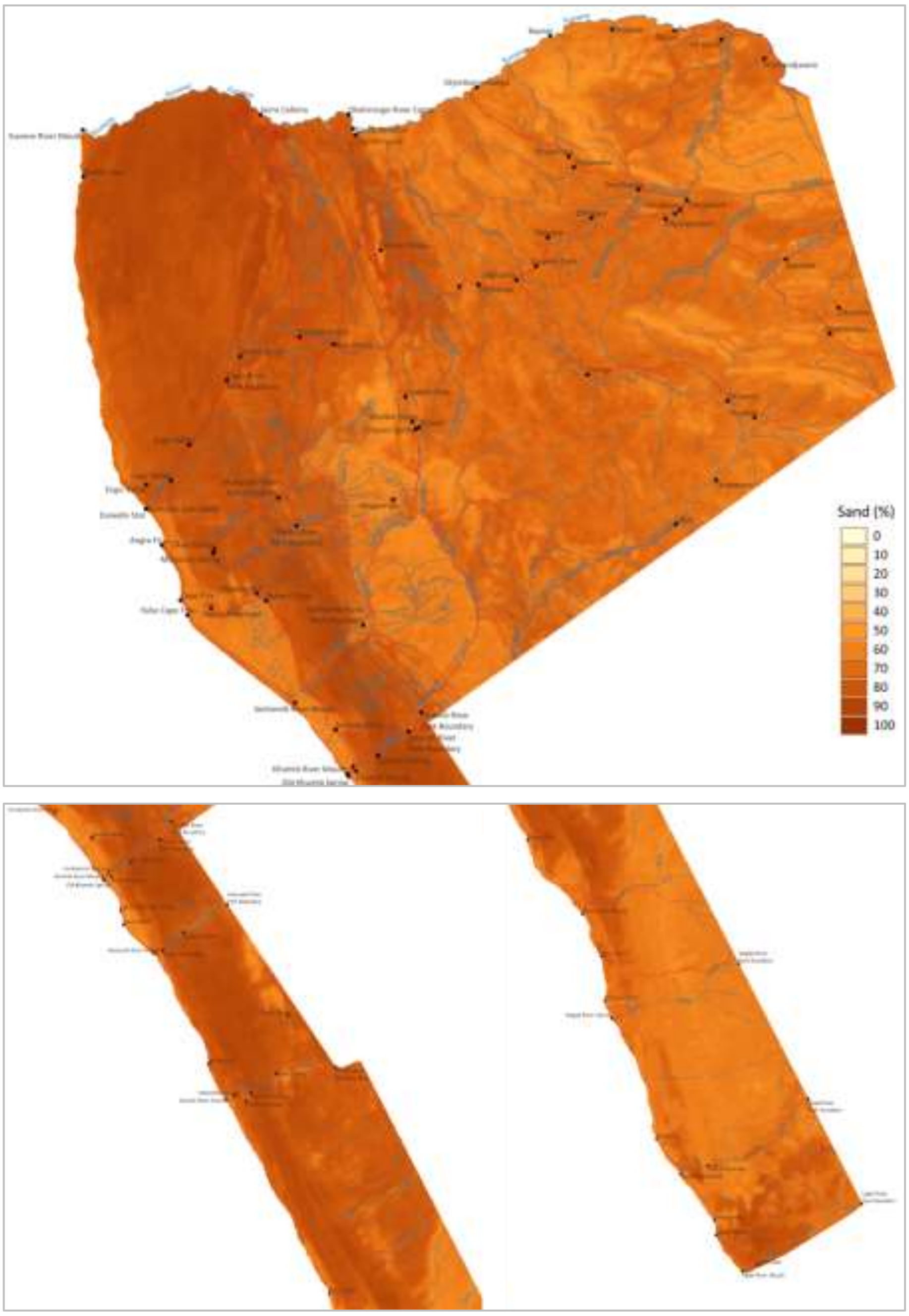
Silt particles are formed by physical weathering of rocks by water, wind and ice. They feel smooth, like talc, when dry and slick and silky when wet. They are too small to see with the naked eye, being between 2 nm (0.002 mm) and 50 nm (0.050 mm) in diameter. Silty soils are among the best agricultural soils of the world – fertile, easily cultivated, with good water storage potential – provided their high susceptibility to erosion is managed well.




Silt Fraction (Source: ISRIC SoilGrids250m)

## Sand Fraction

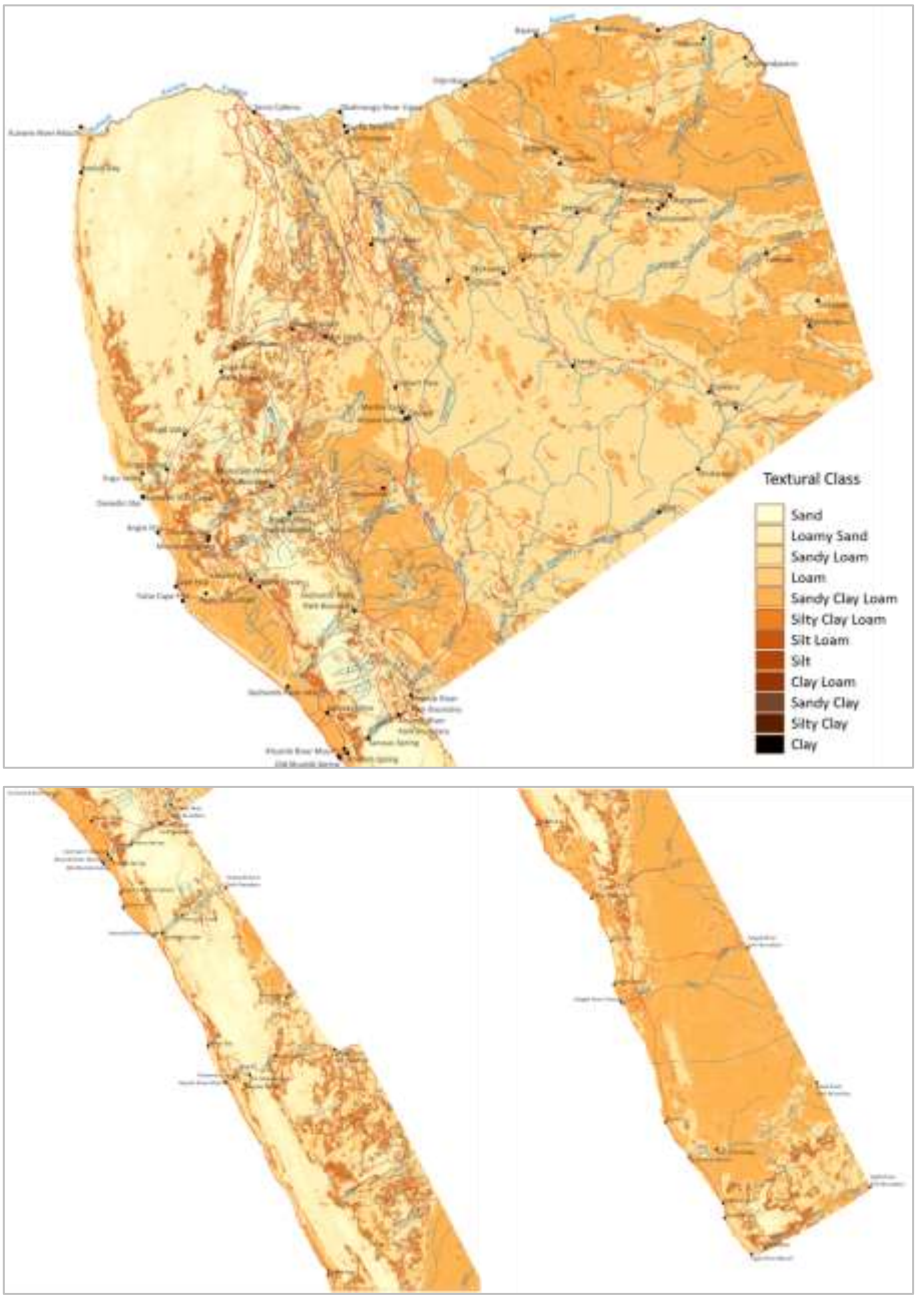
Sand particles are large enough – 50–2,000 nm (0.050-2 mm) in diameter – to be distinguished by the naked eye. They feel and sound gritty when rubbed between the fingers. Sand particles are formed of minerals that are highly resistant to both physical and chemical weathering, such as quartz. Sandy soils have large pores that allow fast infiltration of water, good internal drainage and aeration, but they dry out quickly and do not store nutrients well. They are easy to till. Fine sand is quite erodible and easily compacts (even at the surface, under the impact of raindrops). Large parts of Namibia are under sandy soils, the Arenosols, and arenic phases of other soil types.



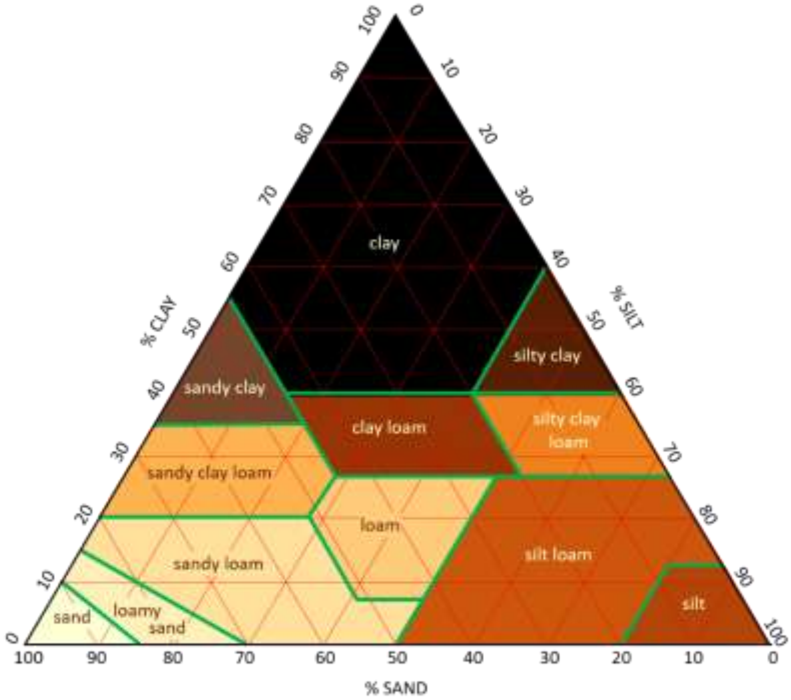

Sand Fraction (Source: ISRIC SoilGrids250m)

## Soil Texture

A soil textural class reflects the relative proportions of differently sized particles that constitute a soil. Once the percentages of sand, silt and clay particles are known, the combined soil texture can be read from a texture triangle. For example, a soil with 20 % clay, 45 % silt and 35 % sand has a loamy texture. Soil texture governs soil-forming processes, soil structure, water- and nutrient holding capacity, drainage characteristics and workability. Medium-textured soils – such as loam, clay loam, sandy clay loam, silty clay loam, sandy loam, silt loam and silt – are best for most crops. Lightly-textured soils – such as sand and loamy sand – typically have poor water holding capacity and low cation exchange capacity, thus they are poor in nutrients. The heavily-textured soils – such as clay, sandy clay and silty clay – may cause waterlogging and poor root development, though they usually are rich in nutrients. Soil texture cannot be changed, but the negative effects of unfavourable texture can be ameliorated to some extent by adding high amounts of organic matter such as compost, manure and crop residues.

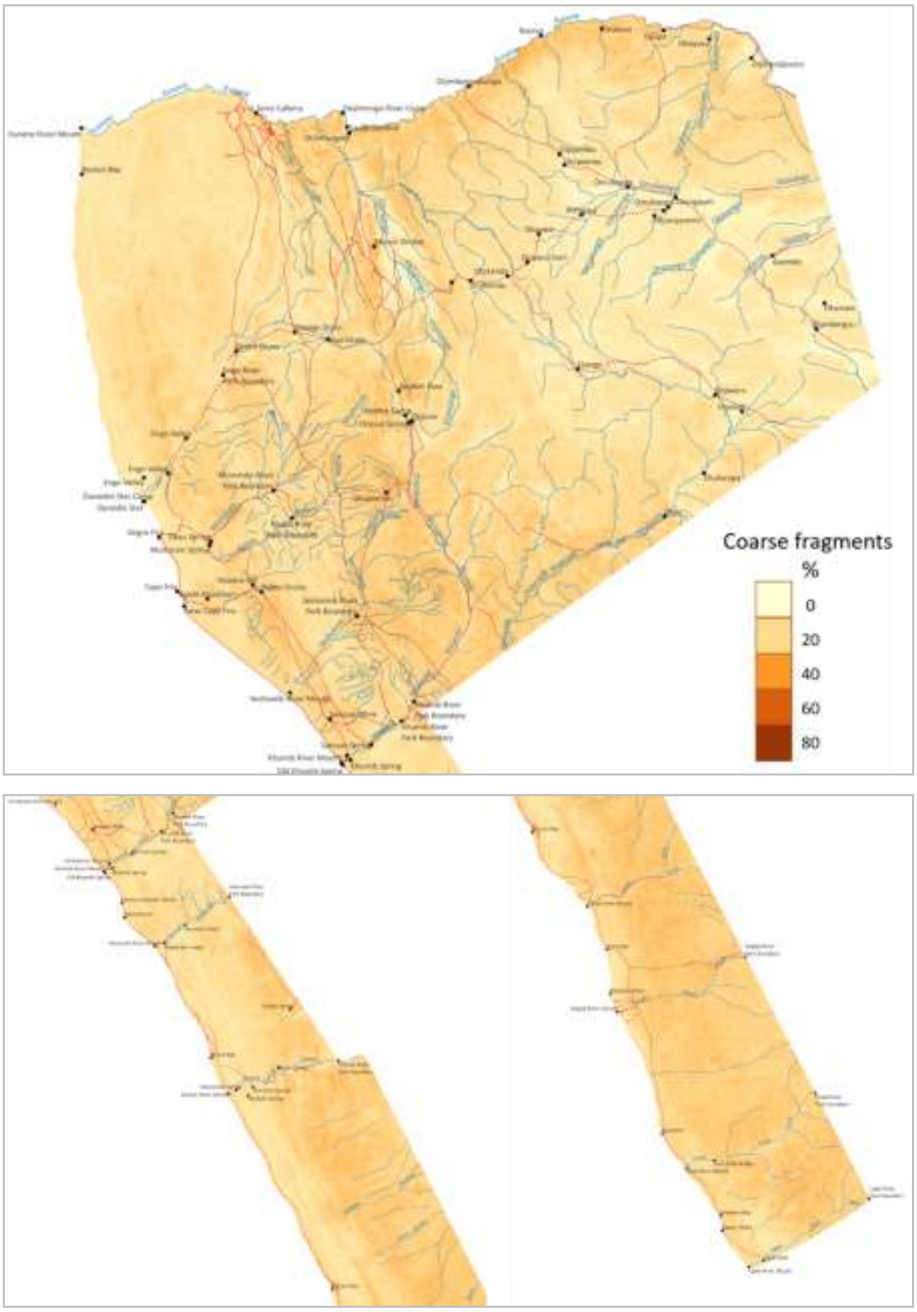



Textural Class (Source: ISRIC SoilGrids250m)


clay
silty clay
sandy clay
clay loam
silty clay loam
sandy clay loam
loam
silt loam
sandy loam
silt
sand
loamy sand
% CLAY
% SILT
% SAND
0
10
20
30
40
50
60
70
80
90
100

## Stoniness

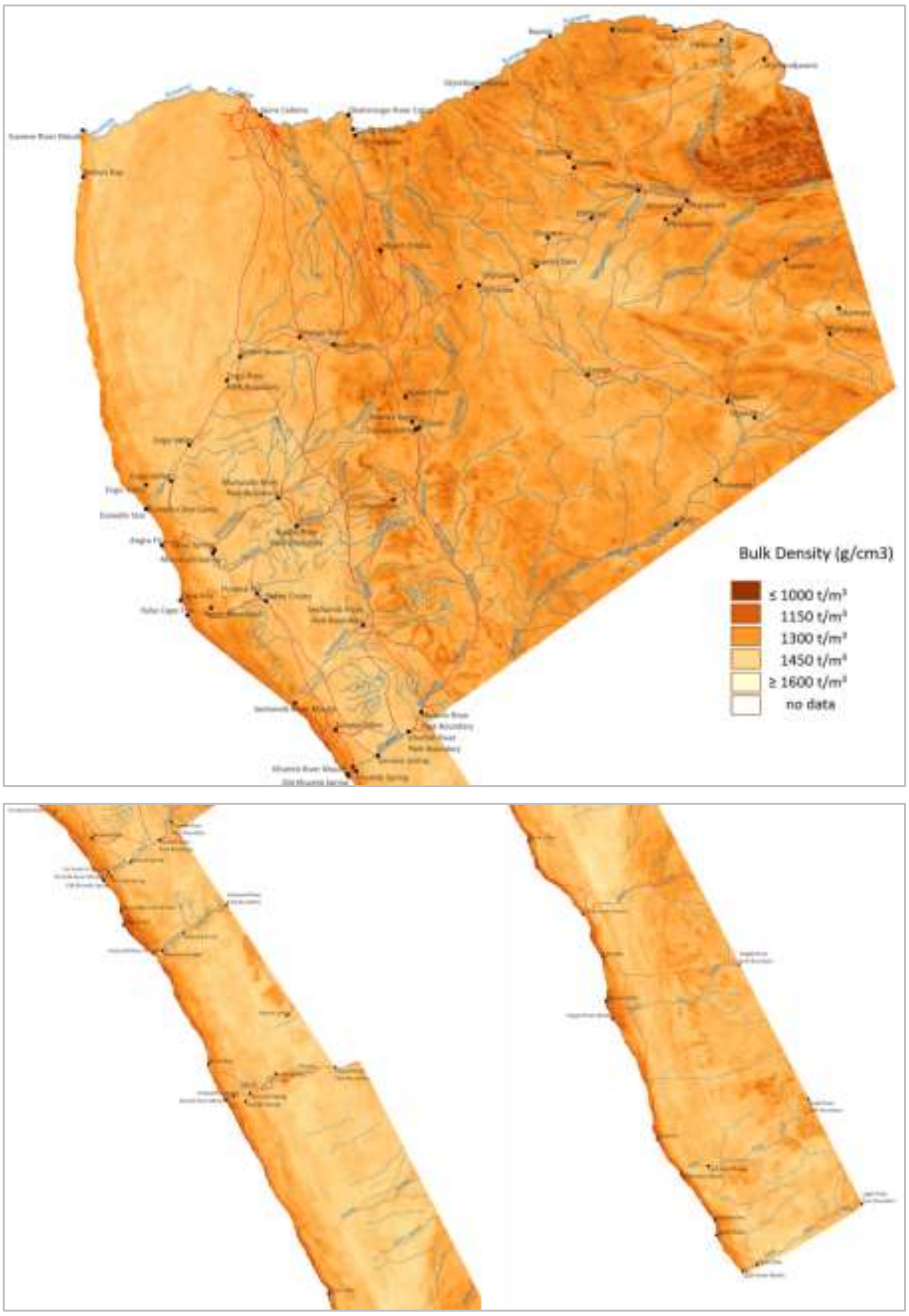
Stones and gravel influence the rate of infiltration and percolation of water, decrease the volume of soil available for roots, storage of water and nutrients and they pose problems for tillage of field crops, especially by hand and animal-drawn implements. However, stony soils can be suitable for vineyards, orchards and plantations. In nature, stony soils are often associated with very distinctive, specialised ecosystems, such as those found on inselbergs. Surface gravel reduces susceptibility to wind and water erosion.




Stoniness (Source: ISRIC SoilGrids250m)

## Bulk Density

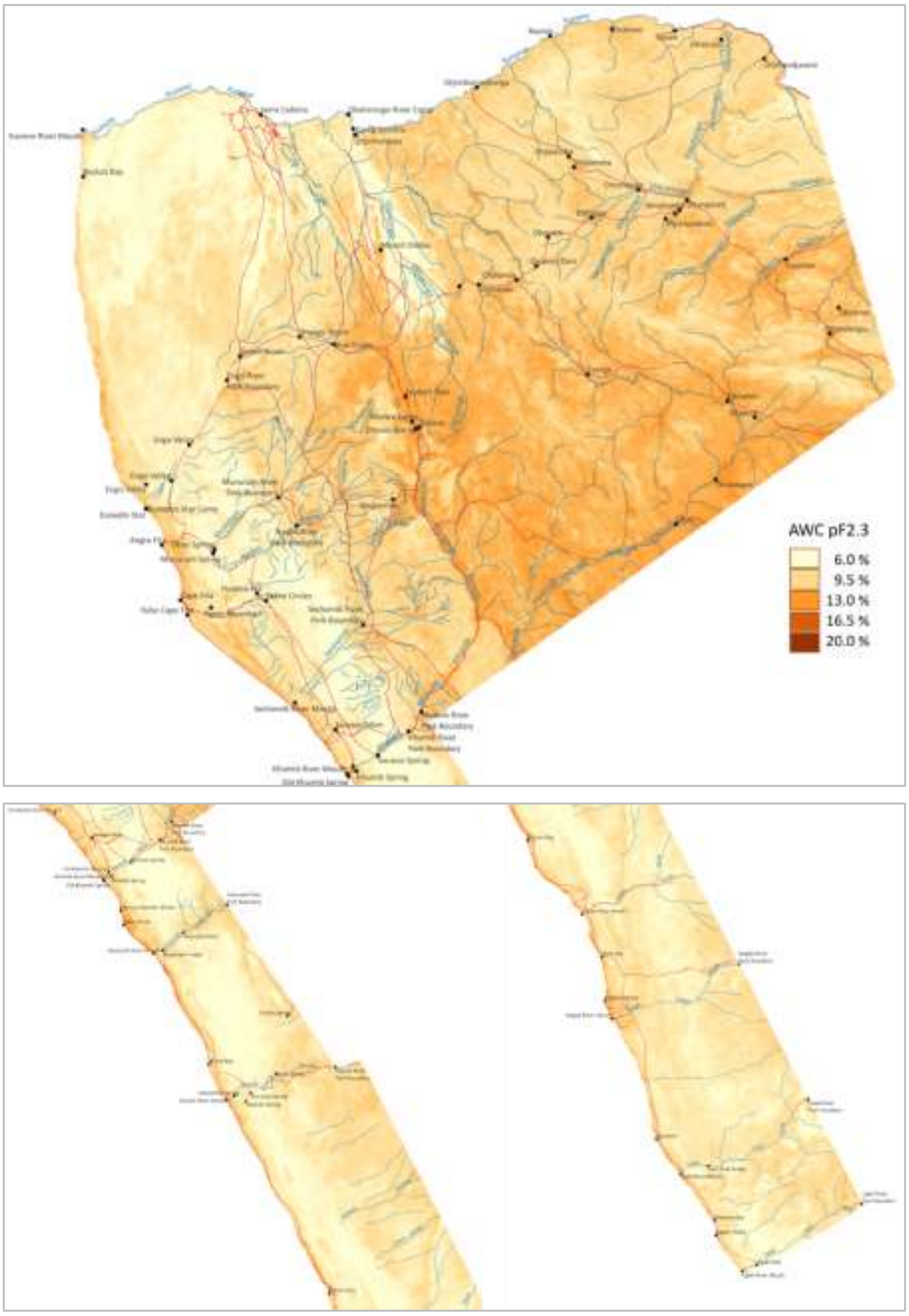
Bulk density of a soil refers to its dry weight in relation to its volume. It is an indicator of soil compaction, reflects the soil's ability to provide structural support and habitats for soil organisms, and the extent to which it enables movement of air, water and dissolved substances. Bulk density is determined by soil texture, soil porosity and the type and degree of development of soil structure. In good, humus-rich topsoil with a well-developed crumb structure, the bulk density is around 1.2 kg/m$^3$ and about half of the soil volume consists of macro-pores (that are visible to the naked eye and allows good aeration and free drainage of water under the influence of gravity) and micro-pores (that are microscopic and retains capillary water). The pore volume in a soil compacted by livestock trampling or use of heavy machinery is about 36 % and the bulk density above 1.7 kg/m$^3$, which would impede root growth considerably.




Bulk Density (Source: ISRIC SoilGrids250m)

## Available Water Capacity

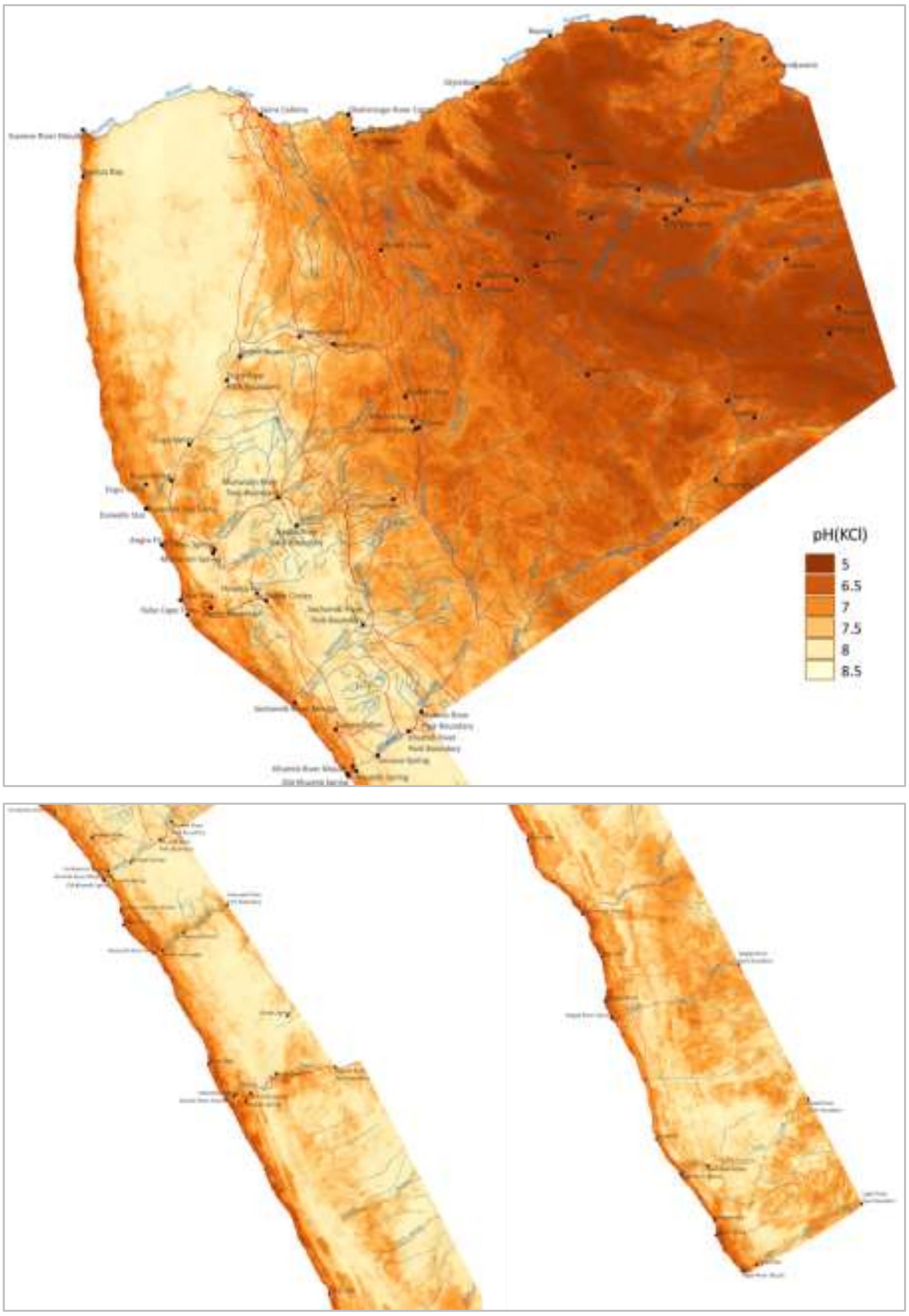
AWC refers to the amount of water held in soil pores between the extreme situations of a soil saturated with water (at 'field capacity') and a soil so dry that plants growing in it cannot recover rigidity even when they are watered again (at 'wilting point'), and can be expressed as a volume fraction, percentage or depth (mm water per m of soil). This map does not take soil depth into account, just the ability of the soil to hold water in its pores.




Available Water Capacity (Source: ISRIC SoilGrids250m)

## pH

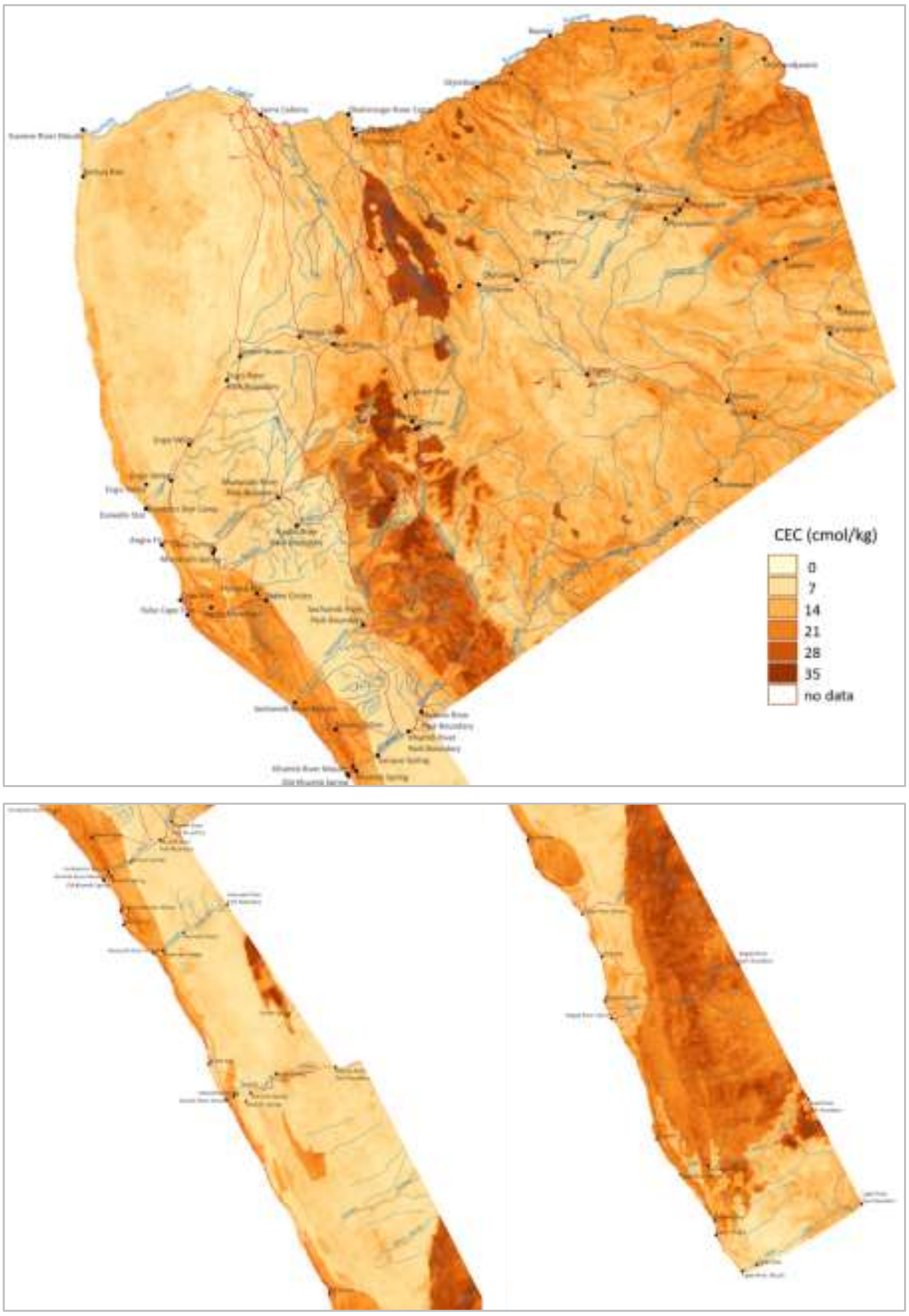
pH expresses the concentration of hydrogen ions in the soil solution, on a scale from 1 (extremely acidic) to 14 (extremely alkaline), with most soils falling in the range 3-8. Most plants prefer neutral conditions (pH 6-7). In highly alkaline soils, plants have difficulty absorbing nitrogen, phosphorus, iron, copper, zinc, cobalt, manganese and boron. On the other side of the scale, plants' uptake of calcium, magnesium, nitrate-nitrogen, phosphorus, boron and molybdenum is suppressed in acid soils, whereas aluminium and manganese are readily accessible, even to levels that are toxic to most plants. Low pH slows down organic matter mineralisation, nitrification and nitrogen fixation. Soil acidity can restrict microbial activity, reduce the availability of essential nutrients and cause subsurface aluminium toxicity. Sandy soils are naturally susceptible to acidification, with high rainfall, removal of crop residues and use of acidifying nitrogen fertilisers speeding up the process. Soil acidity can be reduced by application of agricultural lime.




pH (Source: ISRIC SoilGrids250m)

## Cation Exchange Capacity

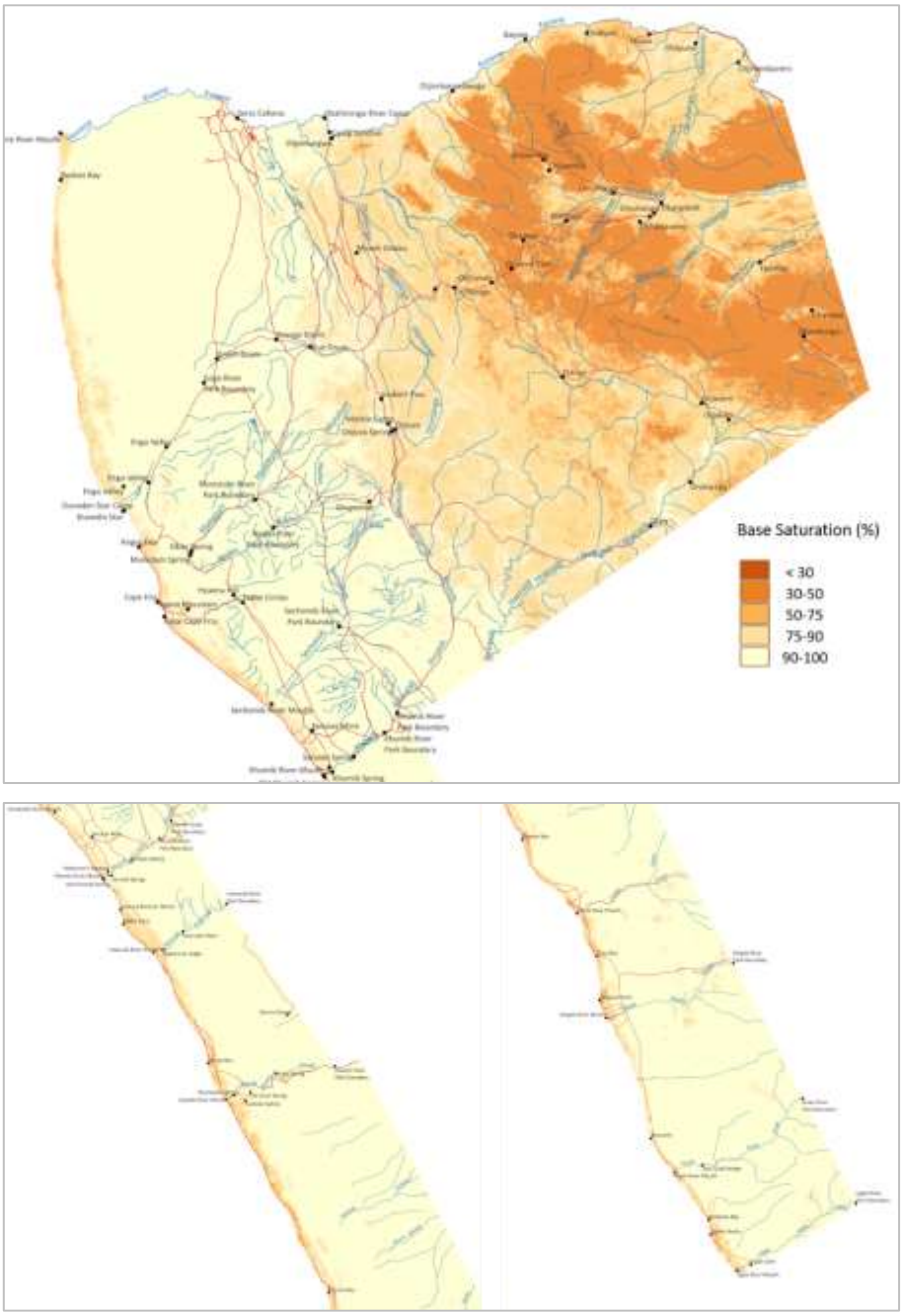
Cation exchange capacity (CEC) is an inherent characteristic of soil's ability to retain and supply essential nutrients and to provide a buffer against acidification. Miniscule clay and organic matter particles (collectively known as 'soil colloids') impart high CEC to soils. They adsorb (hold onto) positively charged ions ('cations') such as sodium ($Na^+$), potassium ($K^+$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), hydrogen ($H^+$) and aluminium ($Al^{3+}$), and exchange these with hydrogen ($H^+$) from the soil solution, thereby releasing those nutrients to become available to plants. One can think of soils with high CEC as analogous to a supermarket with many shelves on which food can potentially be stored. Soils with low CEC (less than 10 cmol/kg) – comparable to a small kitchen cupboard with little shelve space for food – have low nutrient storage capacity, low buffering capacity and thus low inherent fertility. Sandy soils typically have CEC below 4 cmol/kg. CEC, and thus soil fertility, can be increased by adding organic matter in the form of compost, manure and crop residues.




Cation Exchange Capacity (Source: ISRIC SoilGrids250m)

## Base Saturation

Base saturation is the percentage of exchange sites on colloids that are occupied by basic cations such as sodium ($Na^+$), potassium ($K^+$), calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$) – as opposed to 'acid' cations that lower soil pH, namely hydrogen ($H^+$) and aluminium ($Al^{3+}$). If all the exchange cations are basic and none are acidic, the base saturation is 100 % and the soil pH 7 or higher. A soil pH between 6.5 and 6.8 typically corresponds to base saturation of 80-90 %. In the supermarket vs kitchen cupboard shelving analogy, one can think of high base saturation as well-stocked shelves.

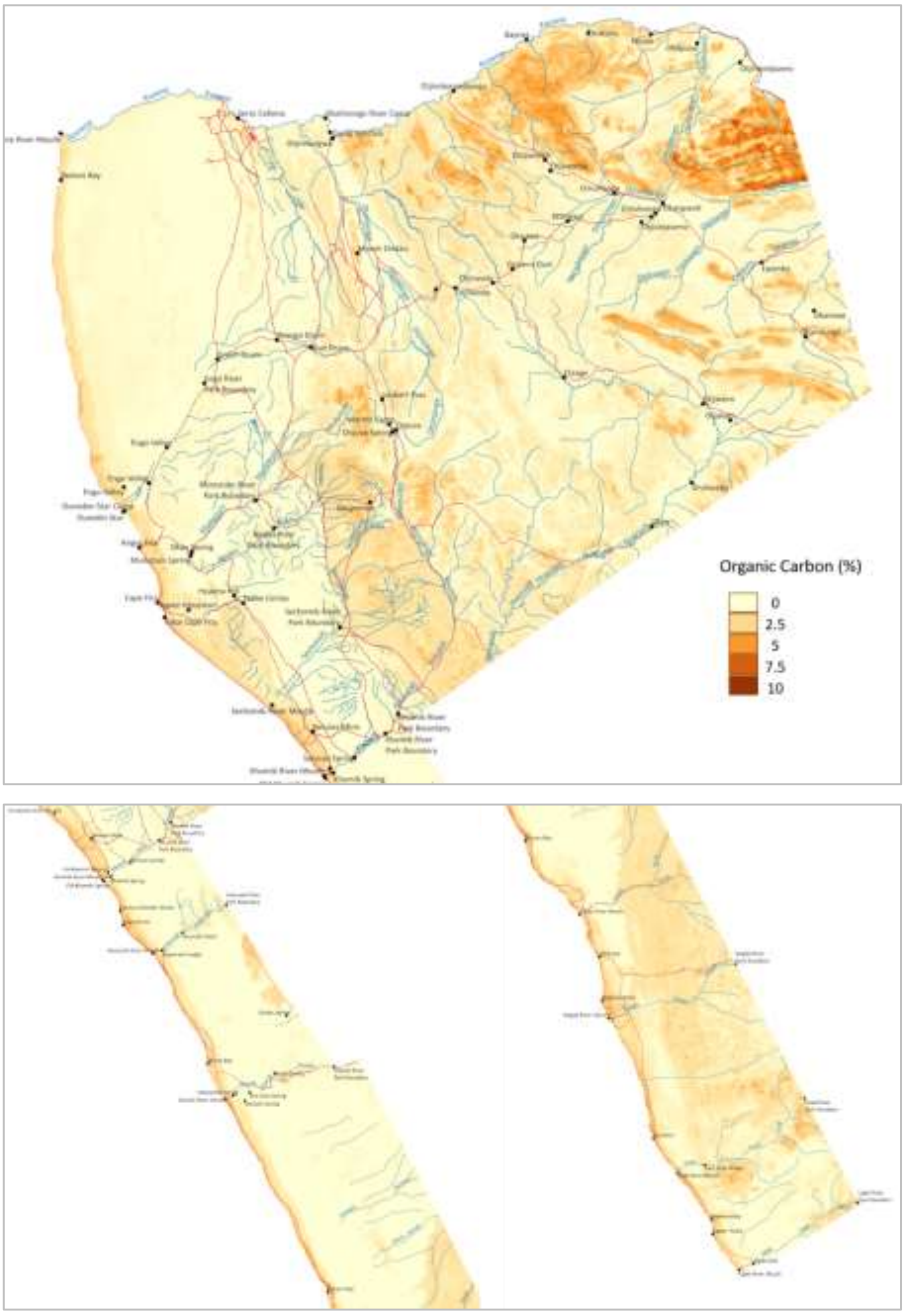



Base Saturation (Source: ISRIC SoilGrids250m)

## Soil Organic Carbon

Soil organic matter (SOM) is an essential component of soils, made up of living organisms (plant roots, fungi, bacteria, micro-, meso- and macrofauna), plant litter, exudates (e.g. faeces, urine, slime) and dead, decaying and decomposed plant and animal material. It contains, among others, cellulose, lignin, lipids, starches, proteins and charcoal – all molecules with carbon backbones. It provides energy for soil organisms, supports and stabilises soil structure, increases water retention, stores and supplies nutrients, builds biological diversity, enhances soils' resistance to disease, stores carbon from the atmosphere and buffers chemical changes. Soil organic carbon (SOC) content gives an indirect measure of soil organic matter, as carbon comprises between 50 % and 58 % of SOM.

The low levels of SOC in Namibia are a consequence of low biomass production (little plant litter that returns to the soil), high soil temperatures (causing rapid mineralisation of SOC molecules back into the component elements), removal of plant material during de-bushing, deforestation, harvesting and burning of both crop residues and natural vegetation. The depletion of SOC is one of the worst forms of soil degradation taking place in Namibia.

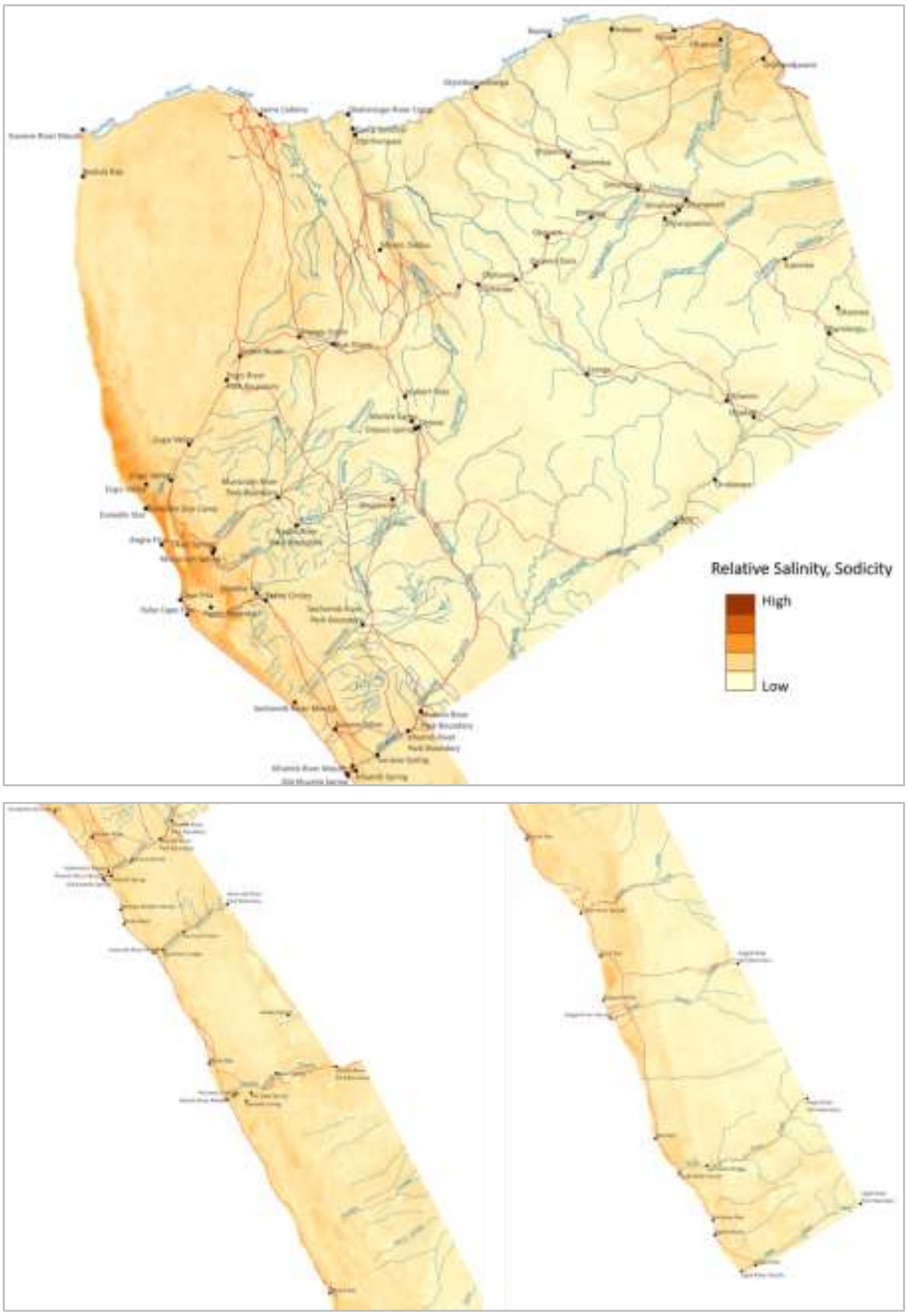



Soil Organic Carbon (Source: ISRIC SoilGrids250m)

## Soil Salinity & Sodicity

Salinity (presence of water-soluble salts), alkalinity (where pH>8.5) and sodicity (presence of high concentrations of sodium) are common in arid and semi-arid regions where rainfall is insufficient to leach salts out beyond the root zone. Soils tend to be naturally saline in closed depressions, such as pans, and where water evaporates from seasonally inundated wetlands. Fluctuating and erratic rainfall, high temperature and evapotranspiration combinedly cause capillary rise of salt to the surface. Historical inundation, current seawater seepage and occasional overtopping during high tides lie behind the existence of coastal salt pans.

High salinity affects soil properties and plant growth adversely through chemical reactions, while sodicity causes poor physical soil conditions.




Relative Salinity and Sodicity (Source: ISRIC SoilGrids250m)

# Main Threats to Namibian Soils

In addition to the low and variable rainfall, the low inherent fertility of Namibian soils adds a further restraint to agriculture. The Arenosols have low water- and nutrient-holding capacity and are slightly acidic. The shallow Leptosols and stony Skeletic Regosols provide limited soil depth in which water and nutrients can be stored. The salty Solonchaks and sodium containing Solonetz cause chemical and physical problems for plant growth. Calcisols may contain sufficient basic plant nutrients, but the imbalance between the bases suppresses uptake of some of these nutrients by plant roots. The natural vegetation has adapted to local soil conditions, but commercial crops perform poorly in these marginal soils, and this is reflected in low crop yields.

## Desertification and Soil Degradation

Desertification is an umbrella term for ecosystem degradation in arid, semi-arid and sub-humid regions that decreases productivity and exceeds the capacity of the land to heal itself. While natural factors – such as droughts, sustained high temperatures, windstorms and irregular, intense rainfall – play an important role, the main drivers are poor management practices – such as overgrazing, deforestation, monoculture, incorrect and over-use of agrochemicals – that denude vegetation cover and damage the soil. High population and livestock pressure on marginal lands accelerate desertification. Degraded land loses productivity and biodiversity, it does not recover well after droughts and eventually cannot support human populations any longer. This leads to a range of socio-economic problems, such as food insecurity, spiralling poverty, conflict over increasingly scarce resources, forced migration and social upheaval. The following are some of the forms of soil degradation prevalent in Namibia:

## Loss of Soil Nutrients, Organic Matter and Biodiversity

Soil organic matter and nutrients are lost through grazing, when vegetation is cleared and removed from land, and when crops are grown on marginal land without sufficient inputs of fertilisers, manure, crop residues or compost. Inability to afford fertilisers to replace the 'mined' nutrients leads to reduced plant growth and crop yields, sinking farmers ever deeper into poverty and food insecurity.

Namibian soils naturally suffer from low organic matter content due to low plant biomass production under the prevailing arid and semi-arid conditions, as well as rapid mineralisation of organic matter at high soil temperatures. This is worsened by overgrazing, removal of crop residues, absence of cover crops and long periods of land lying bare – thus drying out and heating up – between harvest and subsequent planting. Soil biodiversity suffers from the loss of organic matter, which forms the basis of soil food webs. Overuse of agrochemicals further disrupts soil biotic communities, and their breakdown negatively affects the ecosystem services provided by soil.

Very little crop farming takes place in the project area, thus loss of soil nutrients, soil organic matter and soil biodiversity is more strongly linked to livestock management practices.

## Erosion

Erosion is the detachment, transport and deposition of soil particles by water, wind, ice and gravity. It is a natural process, but human activities accelerate it to the extent that fertile soil is lost faster than new soil can form. In addition to on-site loss of productivity, transported and deposited sediments smother plants and aquatic organisms, fill up dams and dust causes respiratory problems.

Sparse vegetation, soils with low coherence, long and steep slopes and infrequent, high-intensity rainfall events predispose drylands to water erosion. This takes the forms of splash erosion (destruction of soil aggregates and detachment of soil particles by the impact of raindrops), sheet erosion (the transport of loose soil particles by shallow, laminar overland flow), rill erosion (sediment carried by fast downslope-flowing water that converges in small rivulets, cutting into topsoil) and gully ('donga') erosion (accumulation and flow of larger volumes of sediment-laden water in large, deep channels cut into the subsoil). Dongas initiate at a nick point, a cut in the landscape such as a wheel rut or cattle track. They extend upslope by undercutting intact soil surfaces at the head of the gully. The greatest ecological impact of dongas is that they siphon surrounding landscapes dry. Sheet erosion is less apparent to the eye, but more insidious and causes greater loss of soil fertility. Bare areas, water puddles that form as soon as it rains, exposed grass and tree roots, stones and grass tufts left on little soil pedestals, small soil mounds under bushes, flow marks and exposed subsoil are signs of sheet erosion. Around 80-90 % of Namibian soils show signs of sheet erosion. Maintaining good vegetation cover and soil organic matter content are essential to protect the soil, slow down overland flow and enhance infiltration of water into the soil. Low tillage, planting along contours, strip- and rotational cropping can be applied to decrease water erosion on croplands.

Wind erosion is common where soils are dry and bare and wind speeds high. Fine particles – those clay and organic matter colloids that give a soil good cation exchange capacity and, hence, fertility – are carried aloft as dust, while larger particles bounce and roll along the surface. Dust clouds, sand ripples and sand drifts against obstacles are indicators of wind erosion. Between 10 % and 20 % of Namibian soils show signs of moderate to severe wind erosion. It can be minimised by avoiding overgrazing, retaining vegetative cover in the form of cover crops, crop residues and mulches to break wind speed at ground level, by planting windbreaks, and by adding organic material and using minimum tillage to maintain good soil structure and increase soil cohesion.

The project area outside the park is heavily eroded in places.

## Aridification

Namibian soils are naturally prone to desiccation, as a result of the prevailing low and erratic rainfall. This is exacerbated by various factors that reduce the capture, infiltration and storage of rainwater, increase soil temperatures and promote excessive evaporation of soil moisture. Deforestation and clear-cutting, overgrazing, inappropriate burning, loss of vegetation cover, loss of deep-rooted shrubs, forbs and perennial grasses, formation of soil crusts and hardpans, loss of soil organic matter, erosion of topsoil and gully formation all rob the soil of moisture.

Aridification is a major problem in the communal lands of the project area.

## Salinisation and Sodification

Salinisation refers to the accumulation of water-soluble salts in soil to a level where agricultural production and ecosystem quality are negatively affected. High levels of salt are toxic to plants and causes water stress in plants by hampering uptake of water, even when the actual volume of water in the soil is sufficient. All irrigation water contains some salts that accumulate in soil over time. Poor drainage conditions, low rainfall and excessive irrigation that raises the water table all contribute to the build-up of salts. Rehabilitation of saline soils is costly: changing to irrigation methods that deliver less water directly to plant roots and not raise the water table, installing sub-surface drainage systems, lowering the groundwater table by growing deep-rooted salt-tolerant crops, occasionally flushing the salts beyond the root zone with copious amounts of clean water or alternating strips of crops with 'sacrificial' fallow strips.

Sodic soils have high amounts of sodium adsorbed on clay particles. When wet, sodic soils swell, and the colloids disperse. On drying, these small particles block soil pores, leading to formation of hard crusts, poor infiltration and waterlogging.

Salinisation and sodification are caused by poor agricultural management (specifically irrigation) practices and are not an issue in the project area. Natural salinity (and a tiny measure of sodicity) occurs at coastal and inland salt pans, the terminal playas of rivers and washes, and around some springs. These are natural features of hyperarid regions and not a consequence of poor management practices. These areas may harbour salt-tolerant natural vegetation such as *Tamarix* and *Salicornia*.

## Deterioration of Soil Structure, Compaction and Capping

Silty and fine sandy soils are prone to compaction and capping. Repeated pressure on the soil surface, such as from heavy agricultural machinery and trampling by grazing animals – especially when the soil is wet – and ploughing to a constant depth break down soil aggregates and compact the soil to form a subsurface 'hardpan' that has very low porosity and permeability. As macropores collapse and become disconnected, the flow of water and air is impeded, thus compaction interferes with aeration, water infiltration, percolation and storage, nutrient uptake, root growth and biological activity. Compaction increases surface water run-off and consequently accelerates erosion. Topsoil compaction is partly reversible and controllable, but subsoil compaction is cumulative and not completely reversible, as pore function cannot be fully restored. Deep ripping can break up the cement-like hardpan, while adding organic matter, planting deep-rooted trees among crops and using tined tillage instruments, rather than traditional mouldboard ploughs, can help prevent and alleviate compaction.

Soil compaction occurs in the SCNP as a result of off-road driving on gypsic soils.

Soil capping refers to the formation of a thin, hard surface crust when aggregates of bare soil are broken down by the impact of raindrops and fine, detached particles clog soil pores. Accumulations of silica and salts, together with the drying effect of sun and wind, further harden such a crust. It reduces aeration and water infiltration and impedes germination. Silty and fine sandy soils are most susceptible to capping.

Soil capping is widespread in the project area outside the park, due to overgrazing and subsequent loss of vegetation cover, raindrop impact during infrequent thunderstorms, loss of organic material from the topsoil by water and wind erosion, and desiccation of the soil by high temperatures and wind. Capping of rangeland soils can be minimised by more sustainable grazing practices, and in crop fields by using cover crops and mulches and working organic matter into the soil.

## Acidification

Sandy soils with low clay, organic matter and lime content in areas of relatively higher rainfall tend to be naturally somewhat acidic. The low cation exchange capacity and sandy texture mean that basic cations (calcium, magnesium, potassium, sodium) are easily leached out beyond the reach of plant roots. Under intensive crop production, such soils quickly become more acidic through addition of ammonium-based fertilisers and, to a lesser extent, phosphorus and sulphur fertilisers. Harvesting of crops and removal of their residues effectively take basic cations out of the system and promote acidification. The problem can be corrected by working agricultural lime into the soil before planting and applying fertilisers in small increments throughout the growing season.

Acidification is not a problem in the project area, due to the basic nature (high pH) of the soils and the very low prevalence of crop farming.

## Soil Pollution

Soil pollution refers to emissions of toxic chemicals from industries and mines, accumulation of organic toxins following planting of certain crops, accumulation of excess agro-chemicals (especially pesticides and herbicides), and nutrient imbalances and toxicities arising from using inappropriate types and quantities of fertilisers. In Namibia, soil pollution is at present only significant near mines and smelters, such as the heavy metal contamination found around Tsumeb, Kombat and Berg Aukas. Rocks that naturally contain heavy metals are brought to the surface by mining and crushed to extract the ore. The heavy metals enter soil, surface and groundwater and most are toxic, to varying degrees and depending on their concentrations, to living organisms – from soil microbes to humans. In addition to being inhaled with dust and ingested with water, heavy metals enter the food chain through crops – especially root vegetables – and the meat and milk of herbivores.

Soil pollution is not a significant problem in the project area at present, but future mining operations may change this situation.

# References

## Photos

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CvH – Cornie van Huyssteen

ED – Endré Dobos

EM – Erika Michéli

HM – Heiner Mouton

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JB – Joggie Briedenhann

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MG – M Gerasimo

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