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agriculture, land reform & rural development
Department: Agriculture, Land Reform and Rural Development
REPUBLIC OF SOUTH AFRICA

Soil nutrient maps of South Africa: mapping soil nutrient at 250m spatial resolution using machine learning

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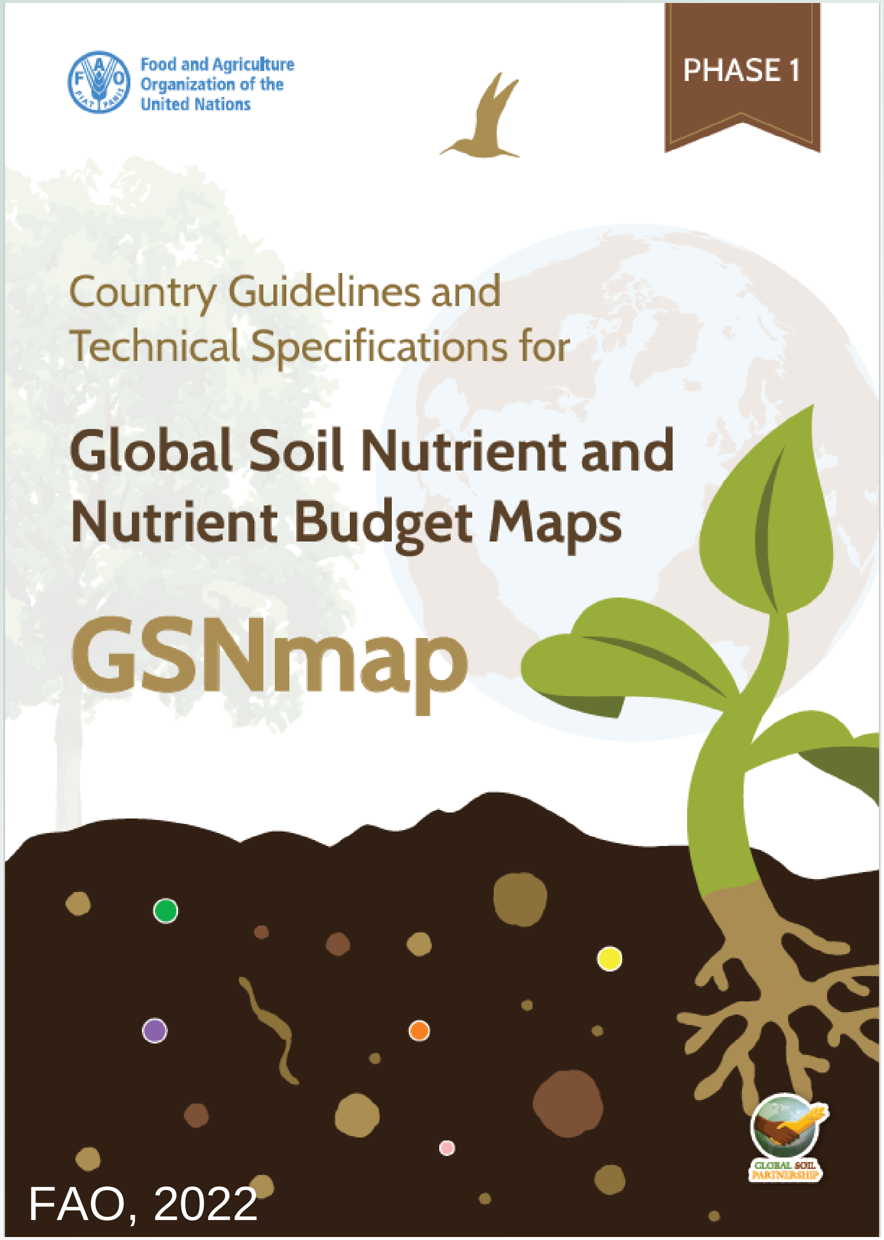
Project objectives

Phase 1 – production of gridded national maps for soil properties at a resolution as close to 250 m as possible.

Phase 2 – Generation of soil nutrient budget maps, covering various nutrient inputs, such as fertilizers and atmospheric N deposition, and outputs, such as soil erosion.

Global Soil Partnership: action framework

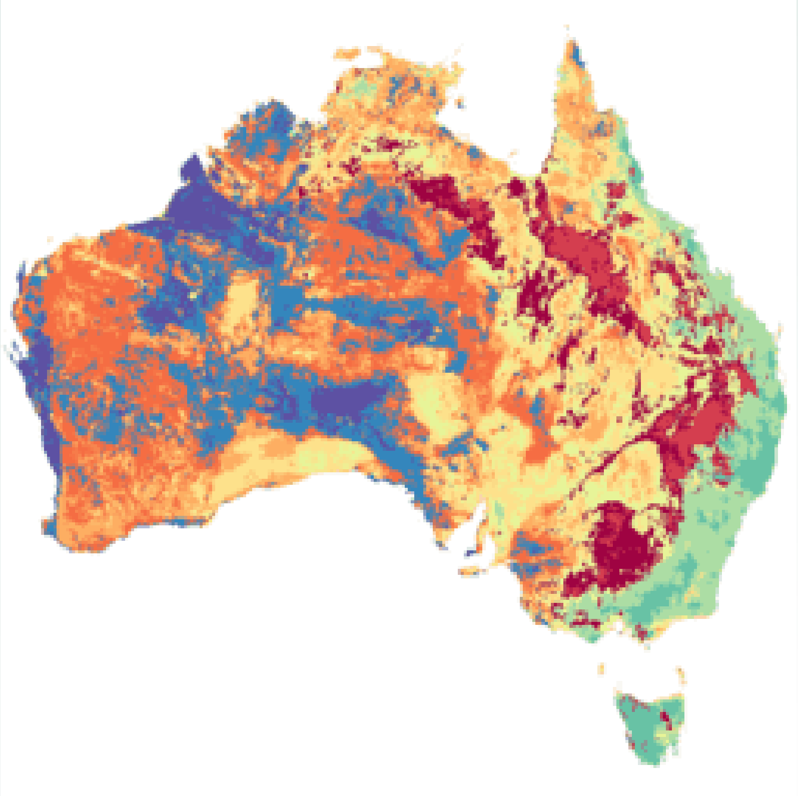


FAO, 2022

Soil attribute	Unit	Laboratory method
Total Nitrogen	ppm	Dumas dry combustion method (FAO, 2021a) or Kjeldahl method (FAO, 2021b)
Available Phosphorus	ppm	Bray I and II, Mehlich I, Olsen (FAO, 2021c; FAO, 2021d; FAO, 2021e)
Available Potassium	ppm	Mehlich III (Mehlich, 1984)
Cation exchange capacity	cmol$_c$/kg	Ammonium acetate (Schollenberger and Simon, 1945)
pH	-	Soil pH in H_2O, KCl, $CaCO_2$ (FAO, 2021f)
Soil fractions (clay, silt, sand)	g/100g	Hydrometer (e.g. Bouyoucos, 1962)
SOC	%	Dumas dry combustion, Walkley-Black, Tyurin spectrophotometric (FAO,2019a; FAO,2019b; FAO, 2021g)
Bulk density	g/cm^3	Overview of methods provided by Blake (1965)
Nutrients (Ca, S, Mg, Fe, B, Cl, Mn, Zn, Cu, Mo, Ni, Si)	ppm	DTPA extraction method (FAO, 2022), Mehlich III (Mehlich, 1984), aqua regia extraction (Berrow and Stein, 1983)

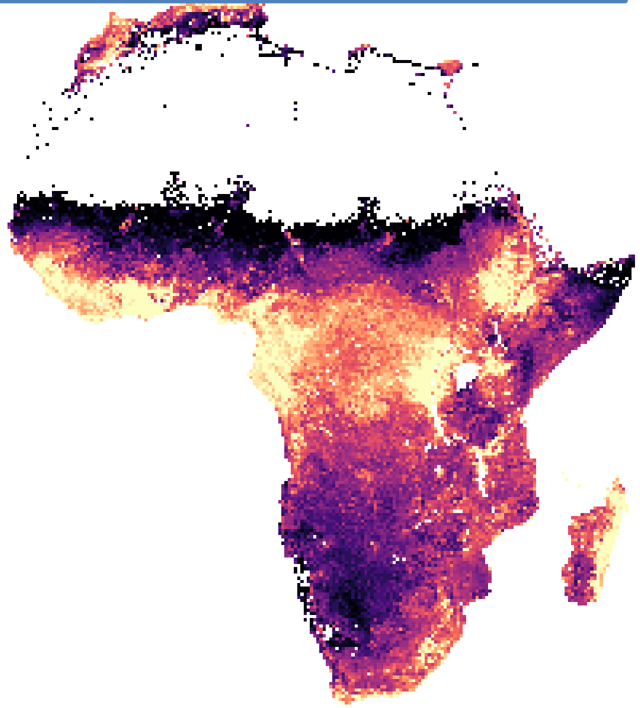
Examples of soil nutrient mapping projects

GlobalSoilMap project



Rossel et al., 2015

Innovative Solutions for Decision Agriculture Ltd (iSDA)

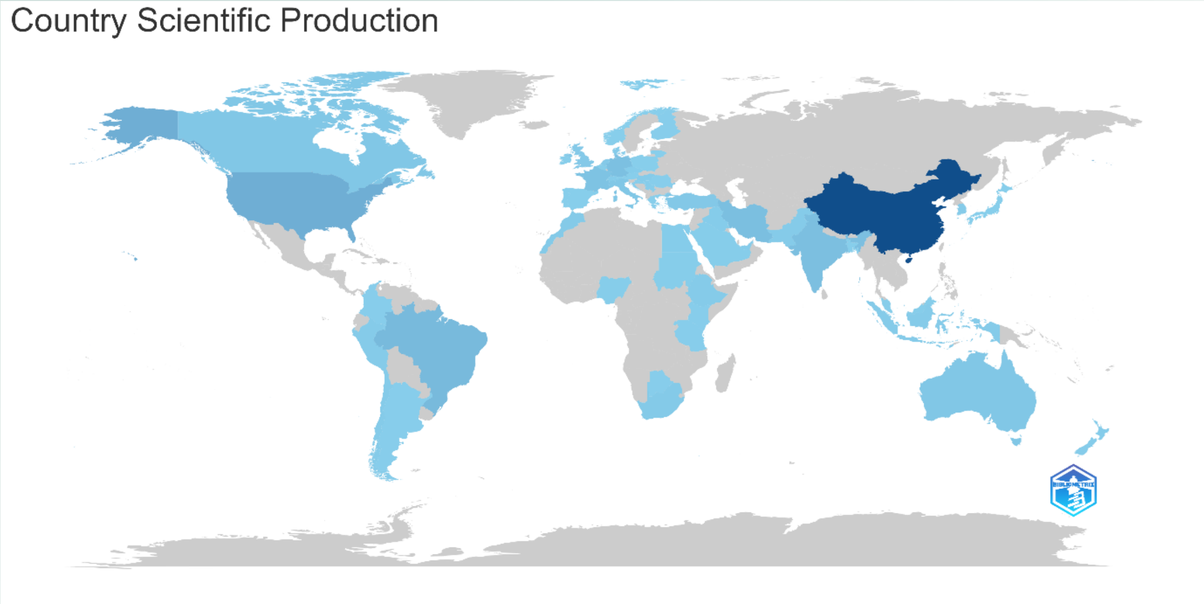


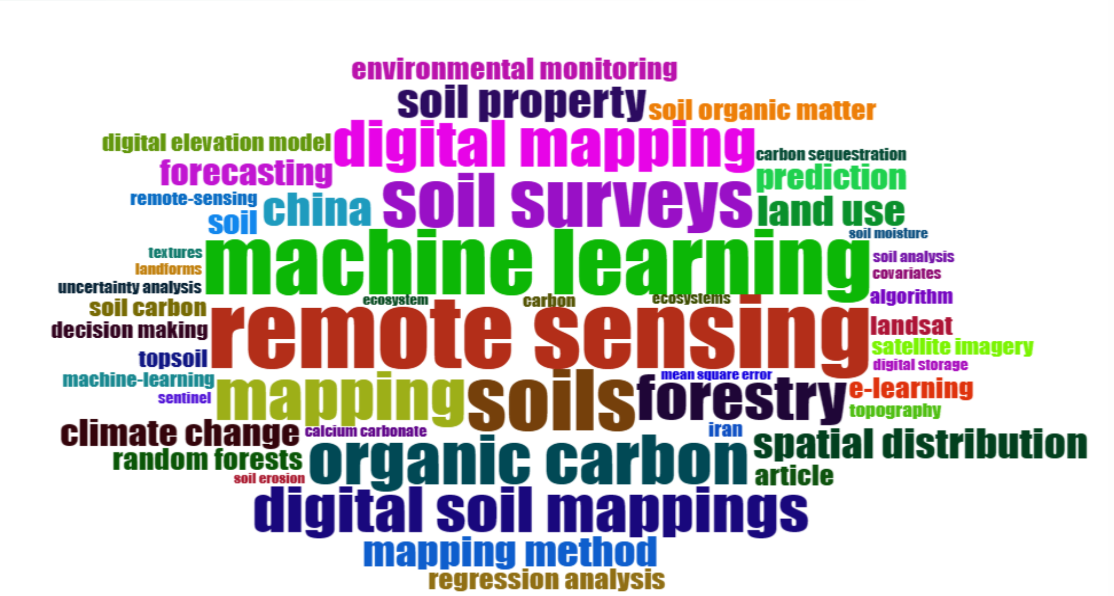
Hengl et al., 2021

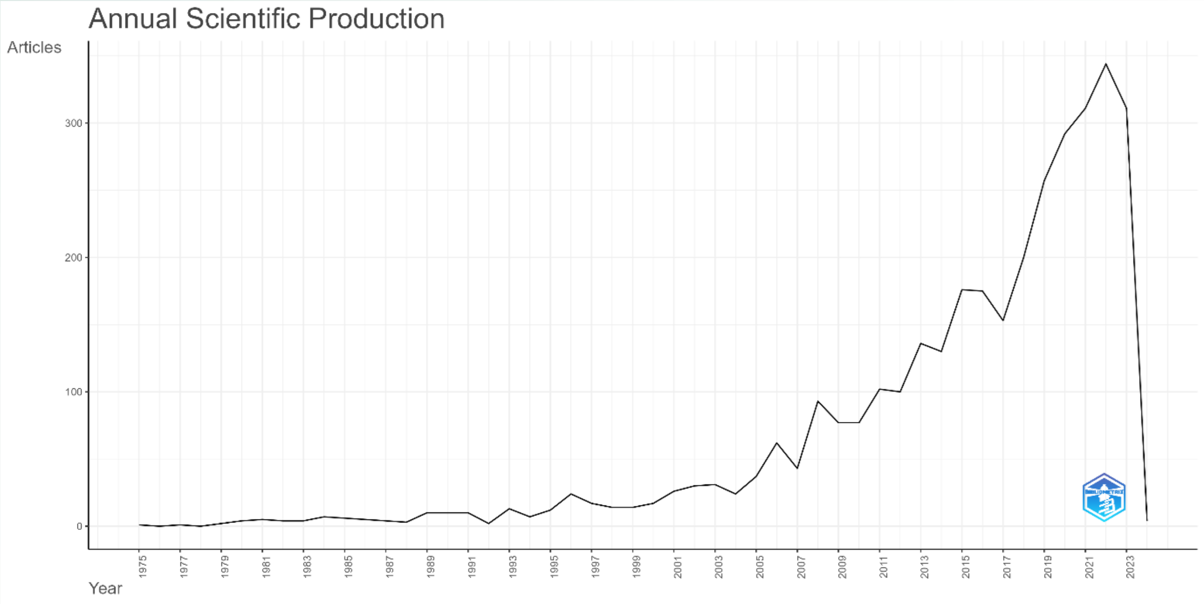
The World Soil Information Service (WoSIS)

Batjes et al., 2022

Global scientific outlook on soil nutrient mapping







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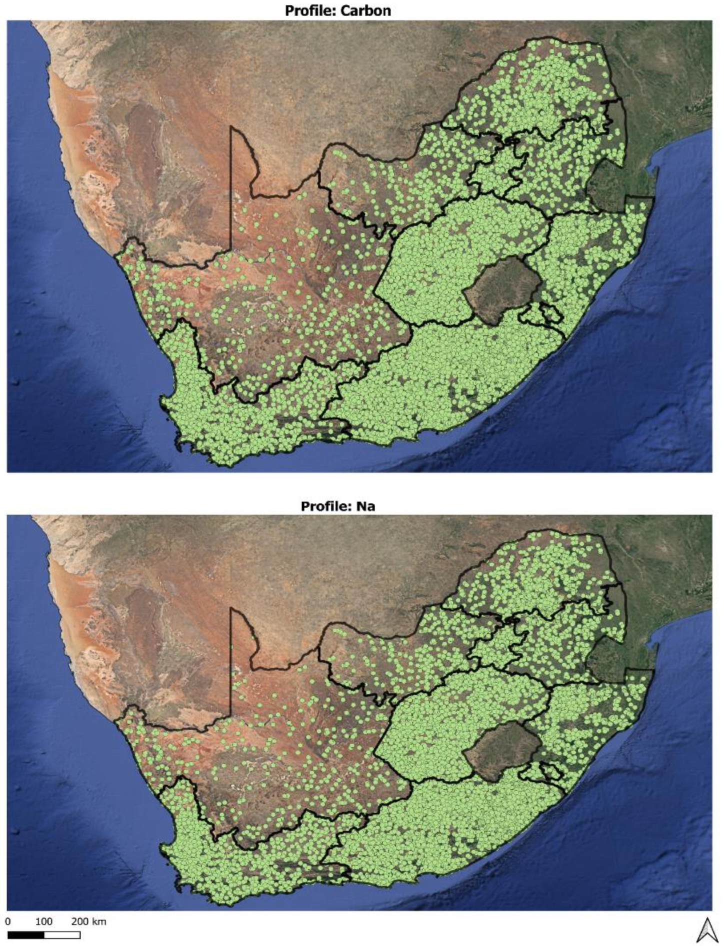
Environmental covariates as derived from MODIS Data. Total of 72 was used.

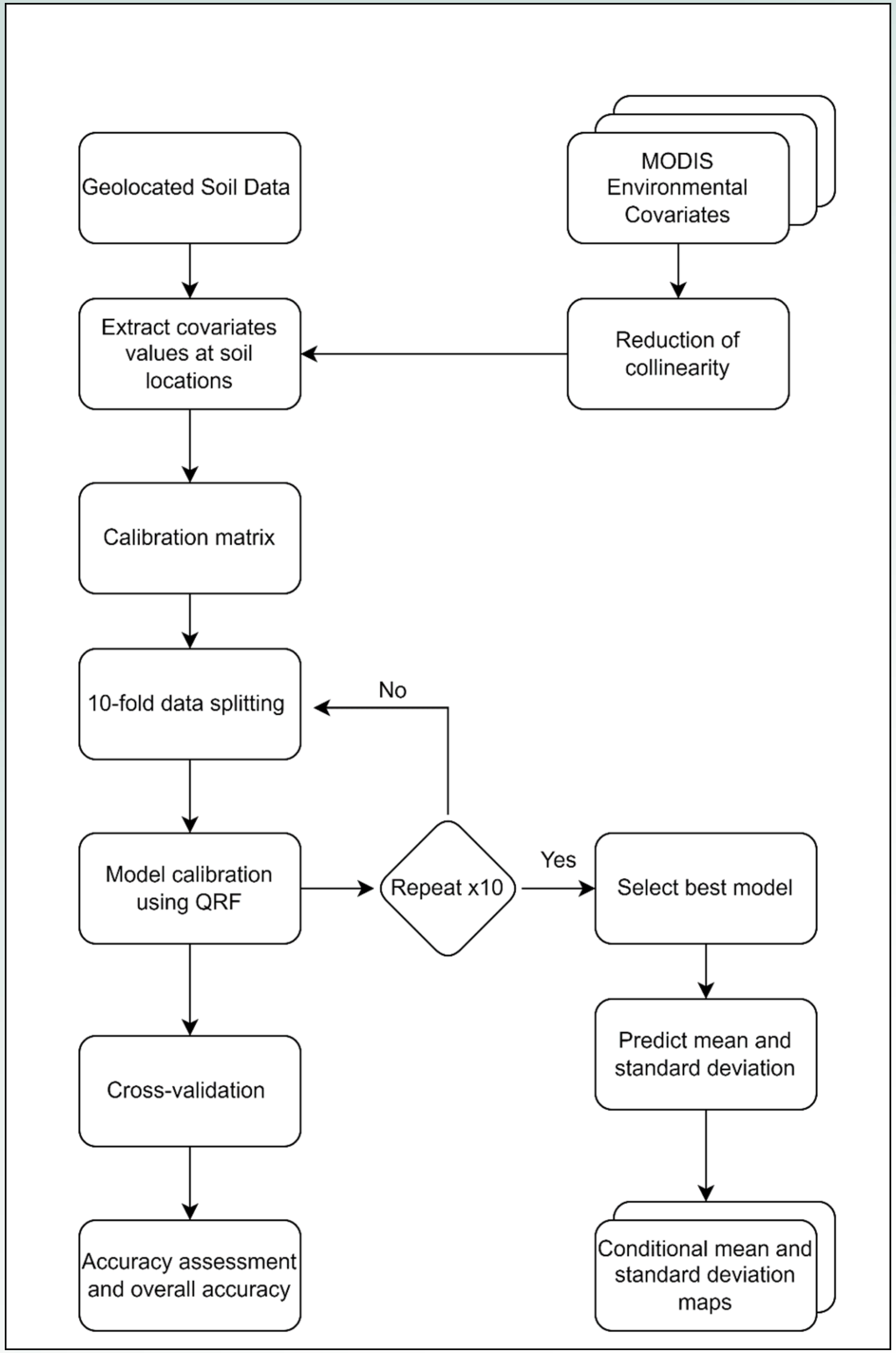
Factor	Environmental covariate	Freely available source
Soils	Legacy soil maps of different scales, soil property maps produced with an independent dataset	Global layers https://gitlab.com/openlandmap/global-layers SoilGrids https://soilgrids.org/
Climate	Climatic data such as monthly/yearly/seasonal temporal mean and standard deviation of precipitation, temperatures (min, max, mean, etc.), evapotranspiration, radiation, snow occurrence, aridity index, etc.	Chelsa climate https://chelsa-climate.org/
Organism	Vegetation temporal and spatial patterns are the main proxies of the effect of living organisms. They can be characterised by remote sensing data from optical sensors such as vegetation indices (NDVI, EVI, SAVI), visual bands, NIR, SWIR, TIR bands from, as well as other band ratios. Land cover and land cover change maps are also included in this category.	Landsat mission; MODIS mission; Sentinel 2 mission; ESA global land cover; Dynamic World; https://code.earthengine.google.com/
Relief	Terrain attributes derived from digital elevation models including elevation, slope, terrain curvatures, channel network base level, vertical distance to channel network, terrain wetness index, etc.	Multi–Error–Removed Improved–Terrain DEM (MERIT DEM): http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/
Parent material and age	Geological maps might be used to derive surface parent material data, including their age, but these are the least available type of data	

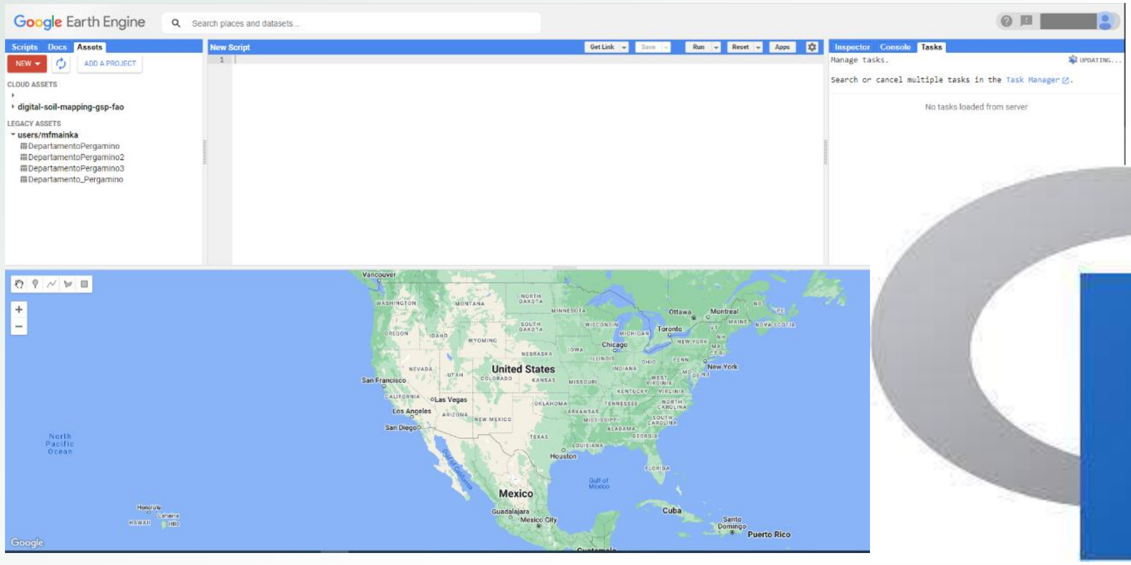
Soil Nutrient data.

Variable Name	Variables	# of points	Unit
Soil Organic Carbon	Carbon	8307	%
Calcium	Ca	6998	ppm
Potassium	K	8090	ppm
Magnesium	Mg	7140	ppm
Sodium	Na	7819	ppm
Cation Exchange Capacity	CEC	9507	cmol/kg
Clay	Clay	8768	%
Cobalt	Co	1893	ppm
Copper	Cu	1867	ppm
Manganese	Mn	2012	ppm
Zinc	Zn	1855	ppm
pH-Water	pH	8010	None
Sand	Sand	10113	%
Silt	Silt	10023	%



Example of distribution of soil sampling sites.





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Statistical description

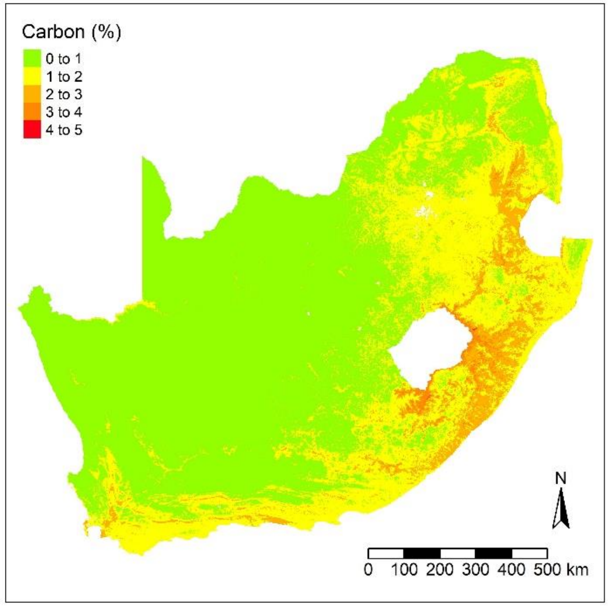
Statistical description of different variables

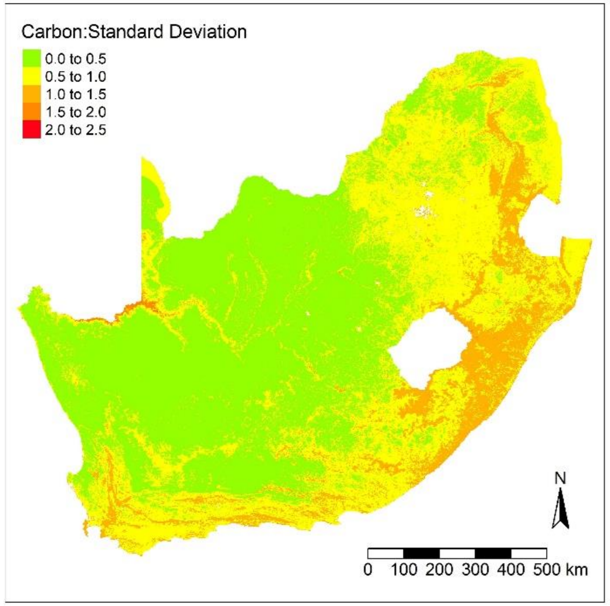
Variables	mean	sd	median	min	max	range
Carbon	1.21	0.98	0.9	0.1	5.84	5.74
Ca	3.68	2.86	2.81	0.09	11.5	11.41
K	0.41	0.29	0.33	0.04	1.75	1.71
Mg	1.54	1.08	1.29	0	4.49	4.49
Na	0.16	0.17	0.1	0	1	1
CEC	10.62	7	8.99	1.33	40.96	39.63
Clay	21.84	14.23	18.44	1.37	64.71	63.33
Co	1.93	1.78	1.34	0.01	6.96	6.95
Cu	1.6	1.06	1.41	0.09	4.5	4.41
Mn	81.02	77.24	57.44	0.28	292.24	291.96
Zn	0.43	0.25	0.38	0.03	1.1	1.07
pH	6.67	1.11	6.5	4.53	9.2	4.67
Sand	50.04	27.84	54.86	0	104.7	104.7
Silt	16.57	12.2	15.26	0	51.18	51.18

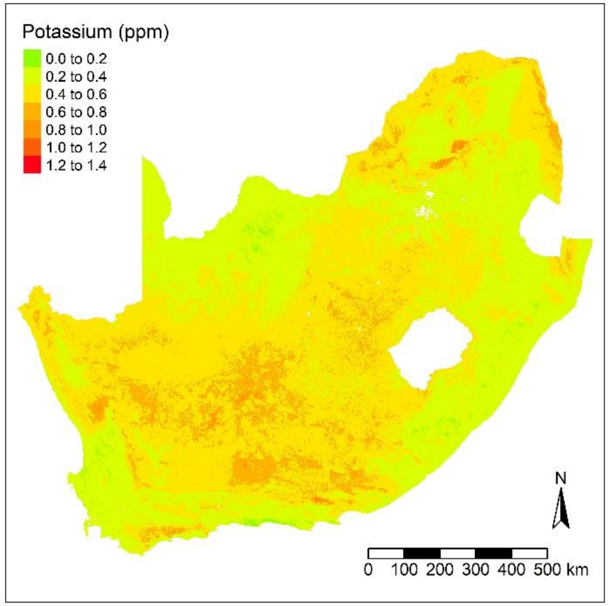
Model results for different variables

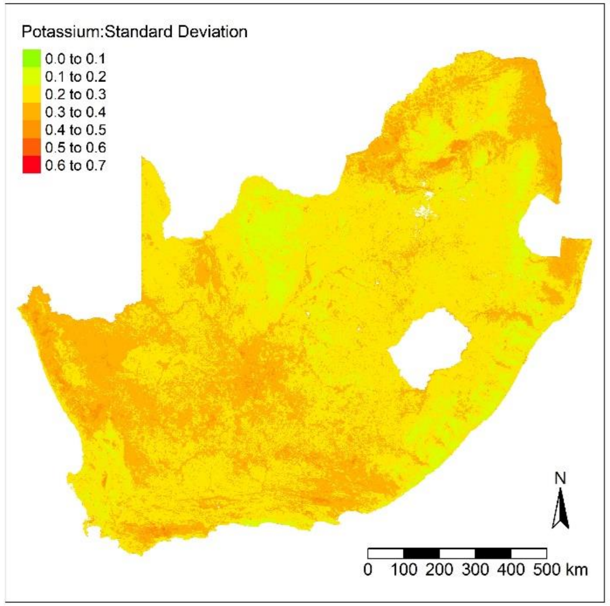
Variable	ME	MAE	RMSE	R	R^2	MEC
Carbon	-0.02	0.46	0.66	0.74	0.55	0.55
Ca	-0.7	1.75	2.25	0.6	0.38	0.38
K	-0.01	0.18	0.24	0.55	0.3	0.3
Mg	-0.03	0.7	0.98	0.58	0.33	0.33
Na	0	0.1	0.15	0.47	0.22	0.22
CEC	-0.19	4.16	5.63	0.6	0.36	0.35
Clay	-0.32	8.55	10.93	0.64	0.42	0.41
Co	0.01	1.2	1.56	0.48	0.23	0.23
Cu	-0.03	0.72	0.91	0.51	0.26	0.26
Mn	0.54	53.81	68.68	0.46	0.21	0.21
Zn	-0.01	0.19	0.24	0.31	0.09	0.09
pH	-0.01	0.54	0.69	0.78	0.61	0.61
Sand	0.45	14.47	19.63	0.71	0.51	0.5
Silt	-0.08	6.87	8.96	0.68	0.46	0.46

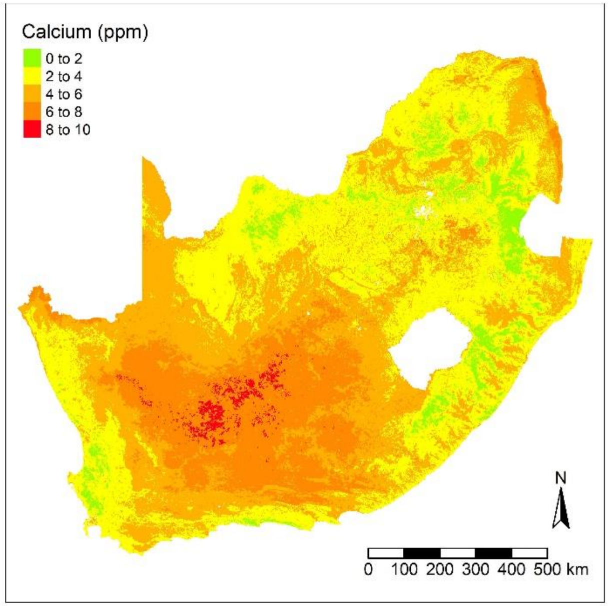
Results

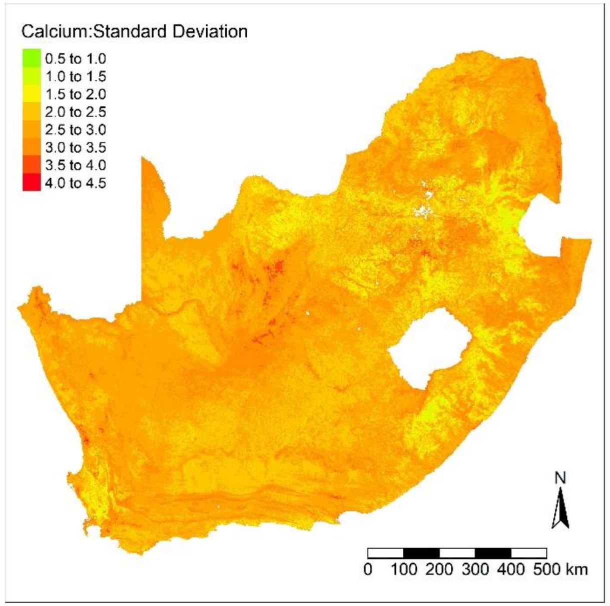

Carbon (%)
0 to 1
1 to 2
2 to 3
3 to 4
4 to 5
N
0 100 200 300 400 500 km

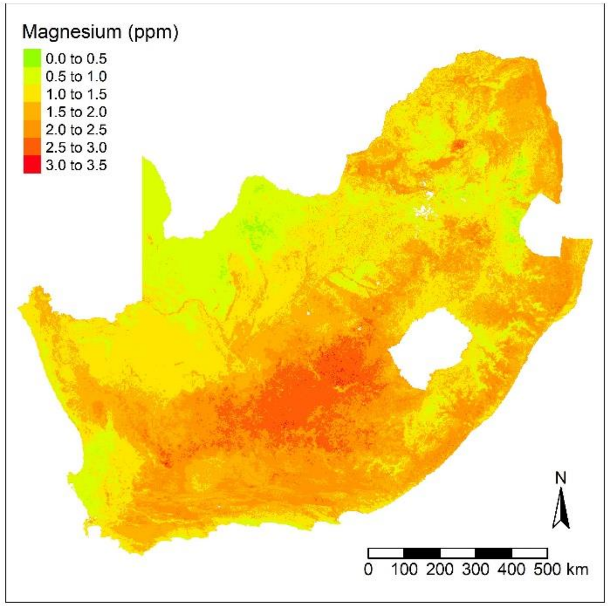

Carbon:Standard Deviation
0.0 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2.0
2.0 to 2.5
N
0 100 200 300 400 500 km

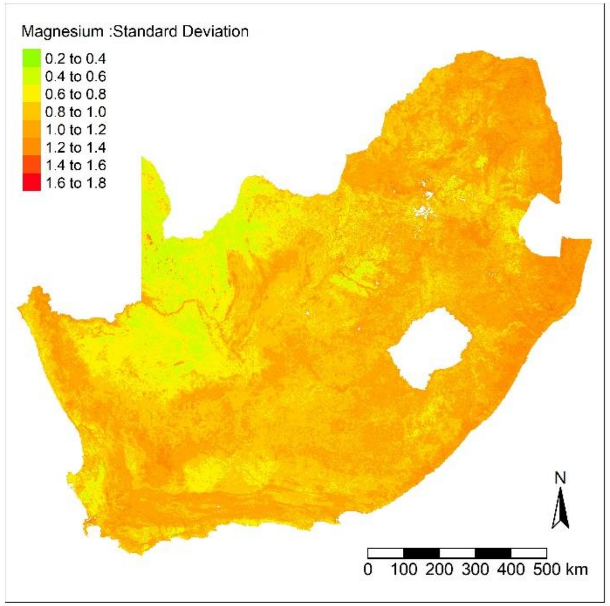

Potassium (ppm)
0.0 to 0.2
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1.0
1.0 to 1.2
1.2 to 1.4
N
0 100 200 300 400 500 km


Potassium:Standard Deviation
0.0 to 0.1
0.1 to 0.2
0.2 to 0.3
0.3 to 0.4
0.4 to 0.5
0.5 to 0.6
0.6 to 0.7
N
0 100 200 300 400 500 km

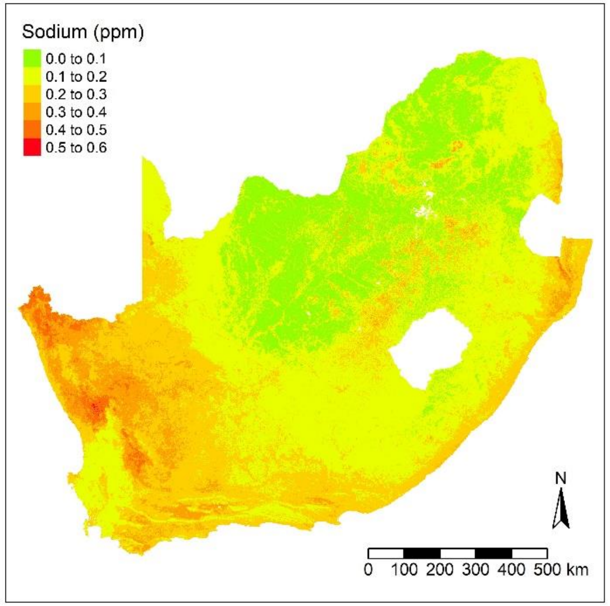

Calcium (ppm)
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
N
0 100 200 300 400 500 km

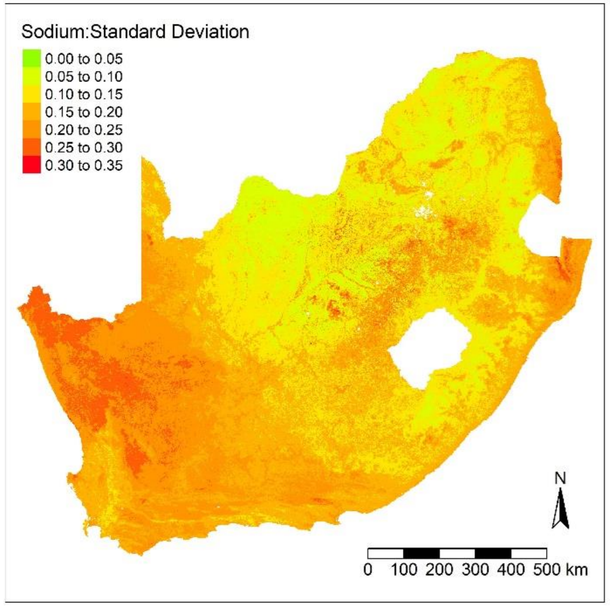

Calcium:Standard Deviation
0.5 to 1.0
1.0 to 1.5
1.5 to 2.0
2.0 to 2.5
2.5 to 3.0
3.0 to 3.5
3.5 to 4.0
4.0 to 4.5
N
0 100 200 300 400 500 km

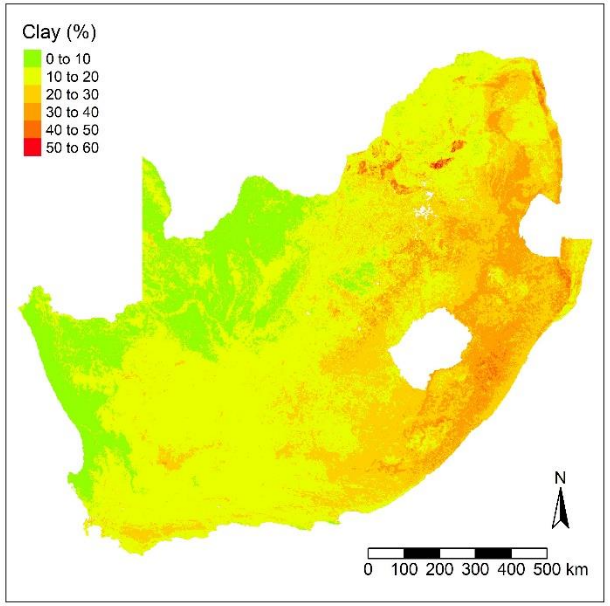

Magnesium (ppm)
0.0 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2.0
2.0 to 2.5
2.5 to 3.0
3.0 to 3.5
N
0 100 200 300 400 500 km

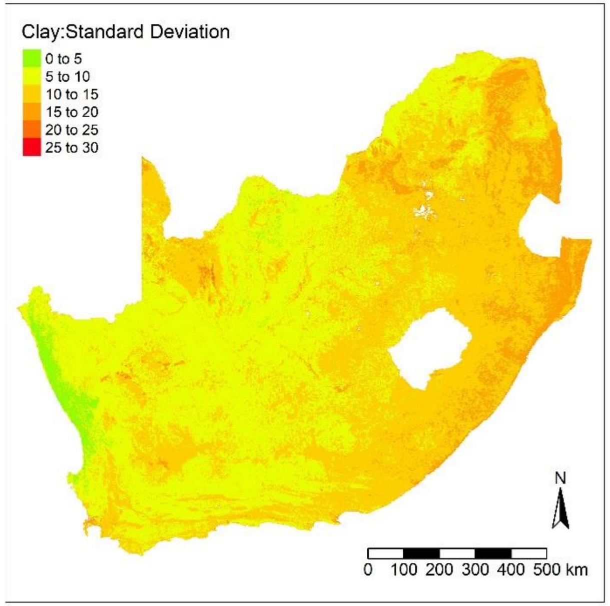

Magnesium :Standard Deviation
0.2 to 0.4
0.4 to 0.6
0.6 to 0.8
0.8 to 1.0
1.0 to 1.2
1.2 to 1.4
1.4 to 1.6
1.6 to 1.8
N
0 100 200 300 400 500 km

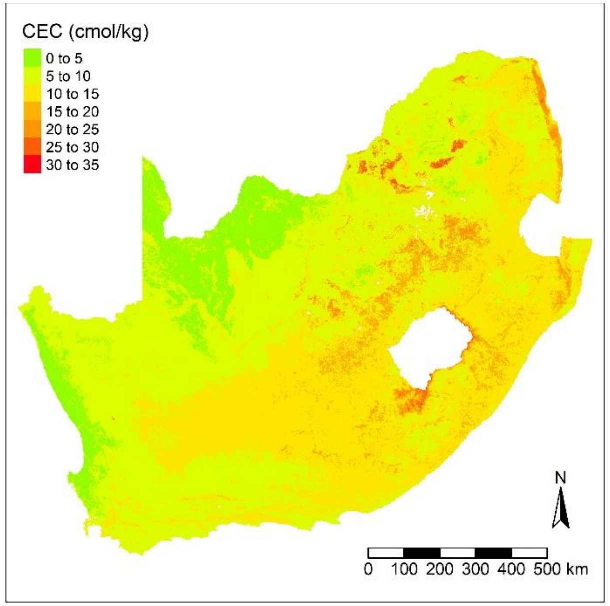
Results

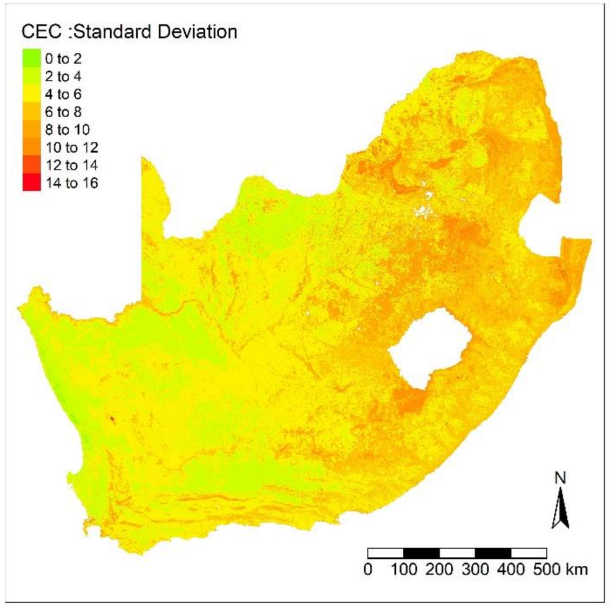

Sodium (ppm)
0.0 to 0.1
0.1 to 0.2
0.2 to 0.3
0.3 to 0.4
0.4 to 0.5
0.5 to 0.6
N
0 100 200 300 400 500 km

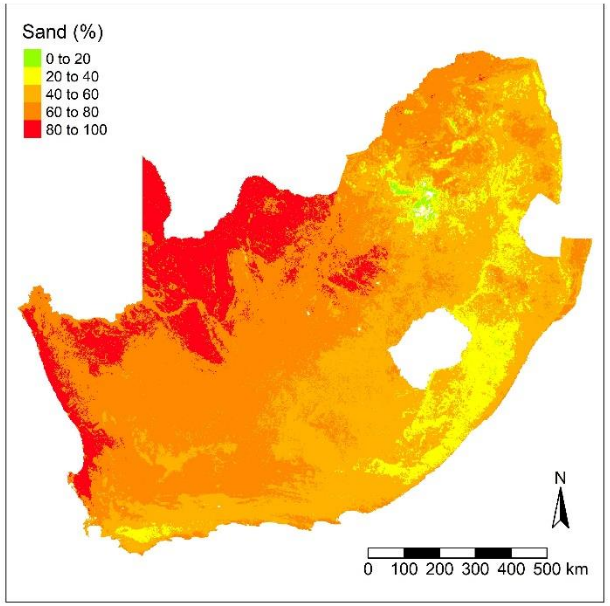

Sodium:Standard Deviation
0.00 to 0.05
0.05 to 0.10
0.10 to 0.15
0.15 to 0.20
0.20 to 0.25
0.25 to 0.30
0.30 to 0.35
N
0 100 200 300 400 500 km

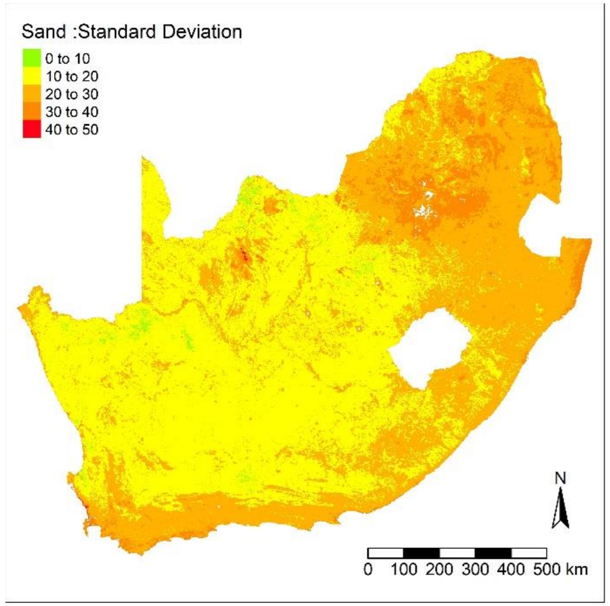

Clay (%)
0 to 10
10 to 20
20 to 30
30 to 40
40 to 50
50 to 60
N
0 100 200 300 400 500 km


Clay:Standard Deviation
0 to 5
5 to 10
10 to 15
15 to 20
20 to 25
25 to 30
N
0 100 200 300 400 500 km

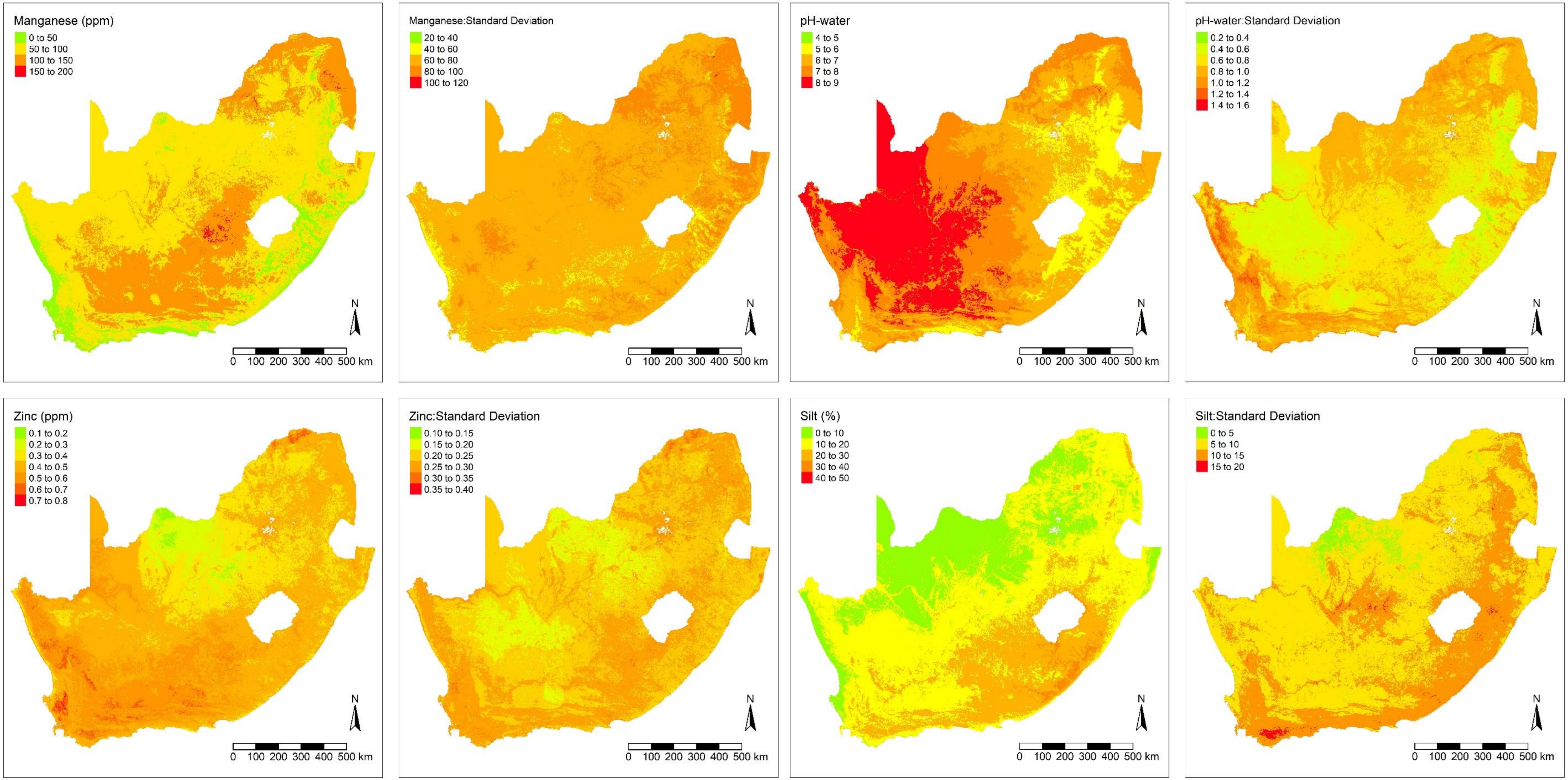

CEC (cmol/kg)
0 to 5
5 to 10
10 to 15
15 to 20
20 to 25
25 to 30
30 to 35
N
0 100 200 300 400 500 km


CEC :Standard Deviation
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
N
0 100 200 300 400 500 km


Sand (%)
0 to 20
20 to 40
40 to 60
60 to 80
80 to 100
N
0 100 200 300 400 500 km


Sand :Standard Deviation
0 to 10
10 to 20
20 to 30
30 to 40
40 to 50
N
0 100 200 300 400 500 km

Results



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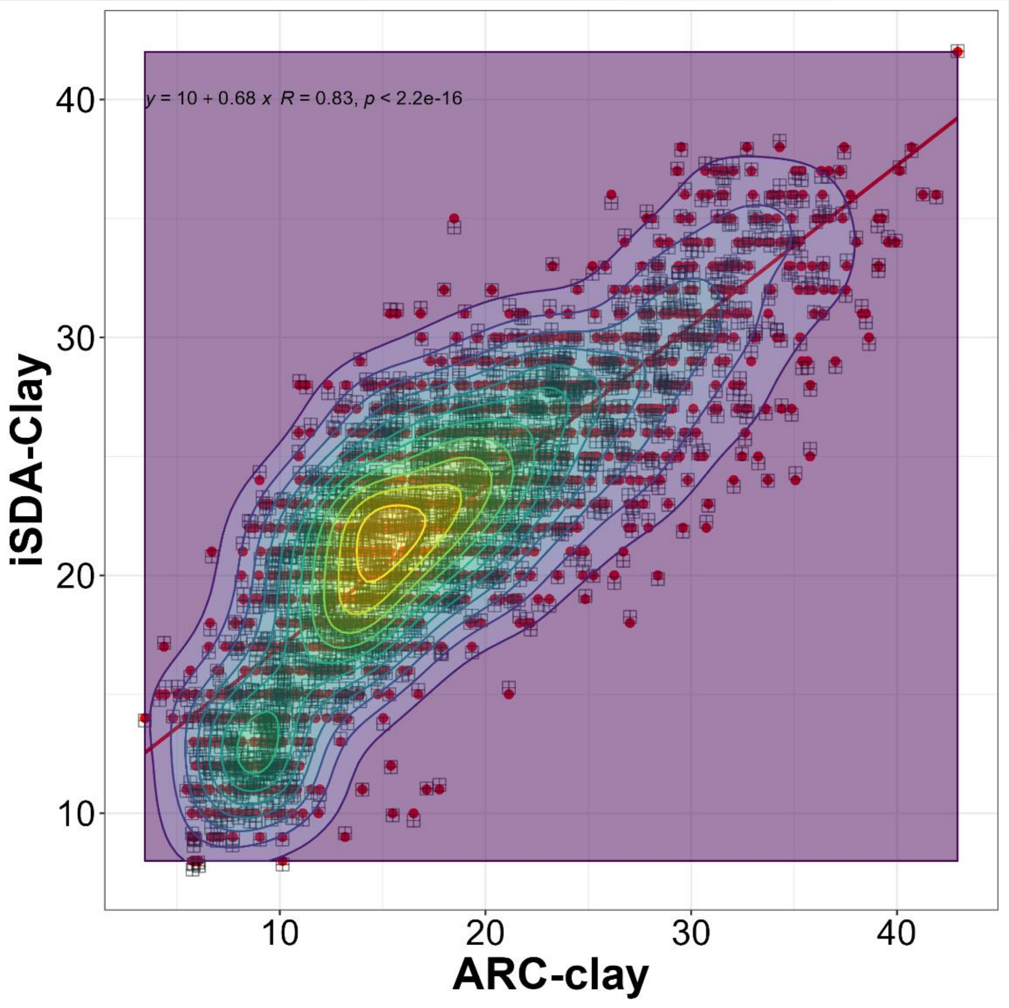
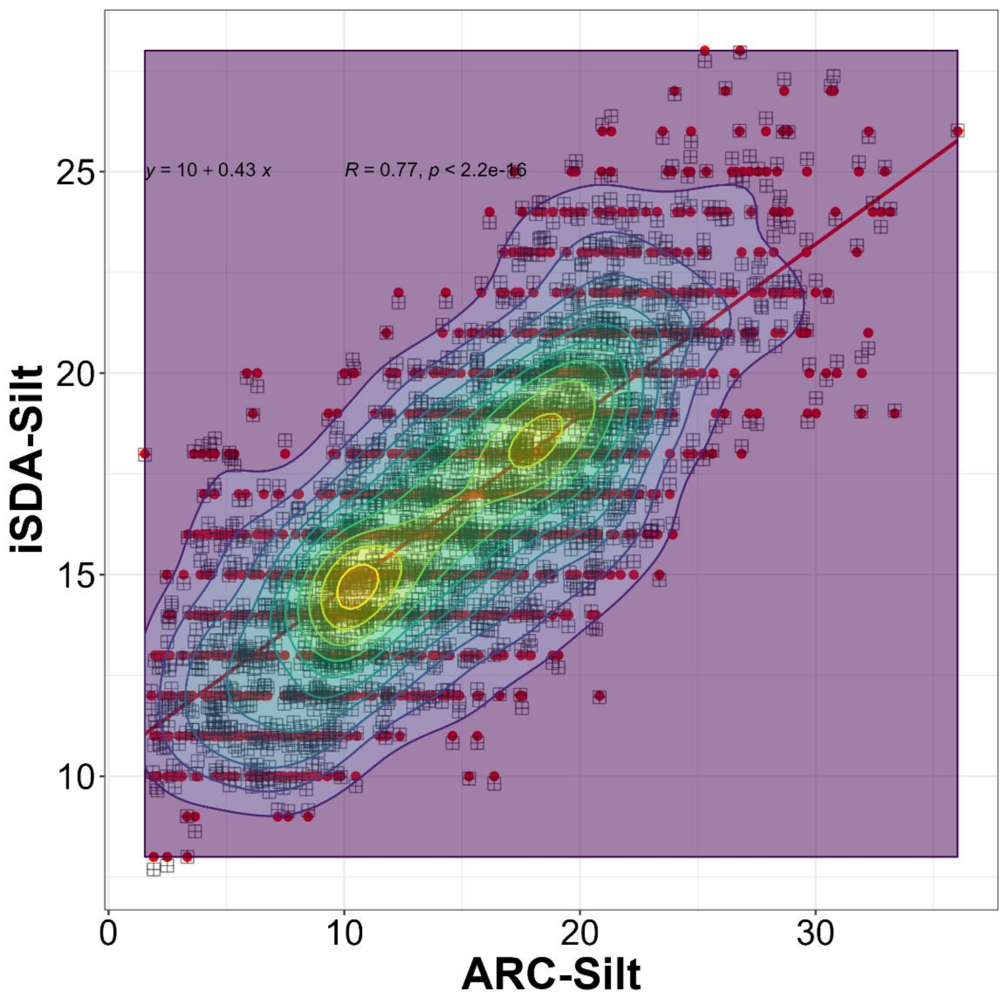
Comparison of iSDA and ARC products





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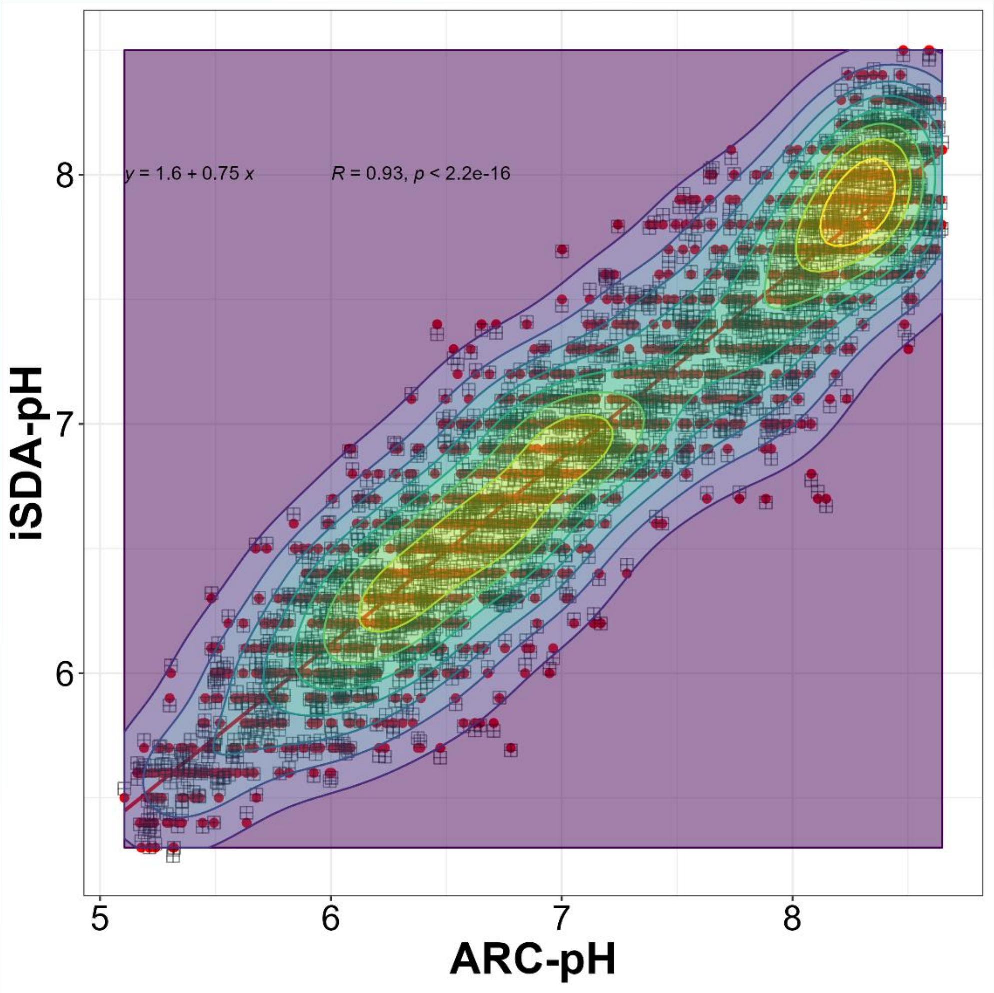

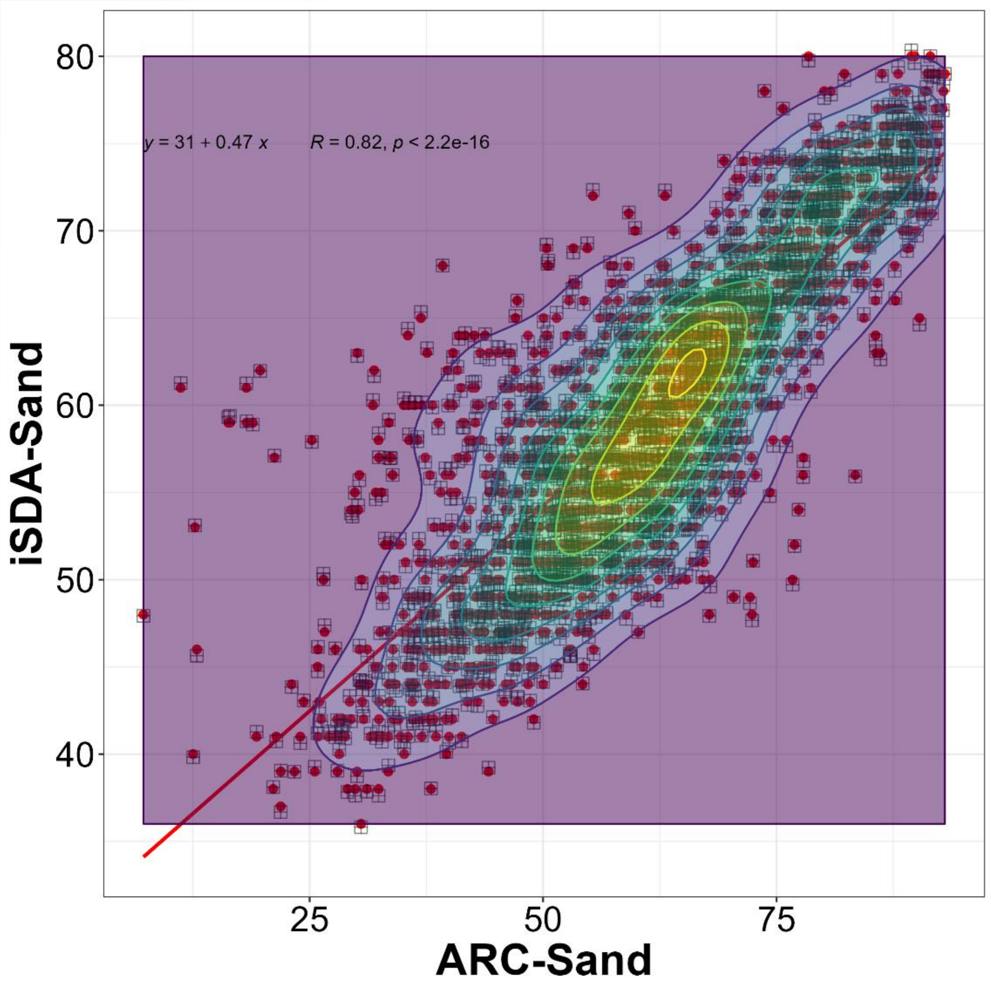

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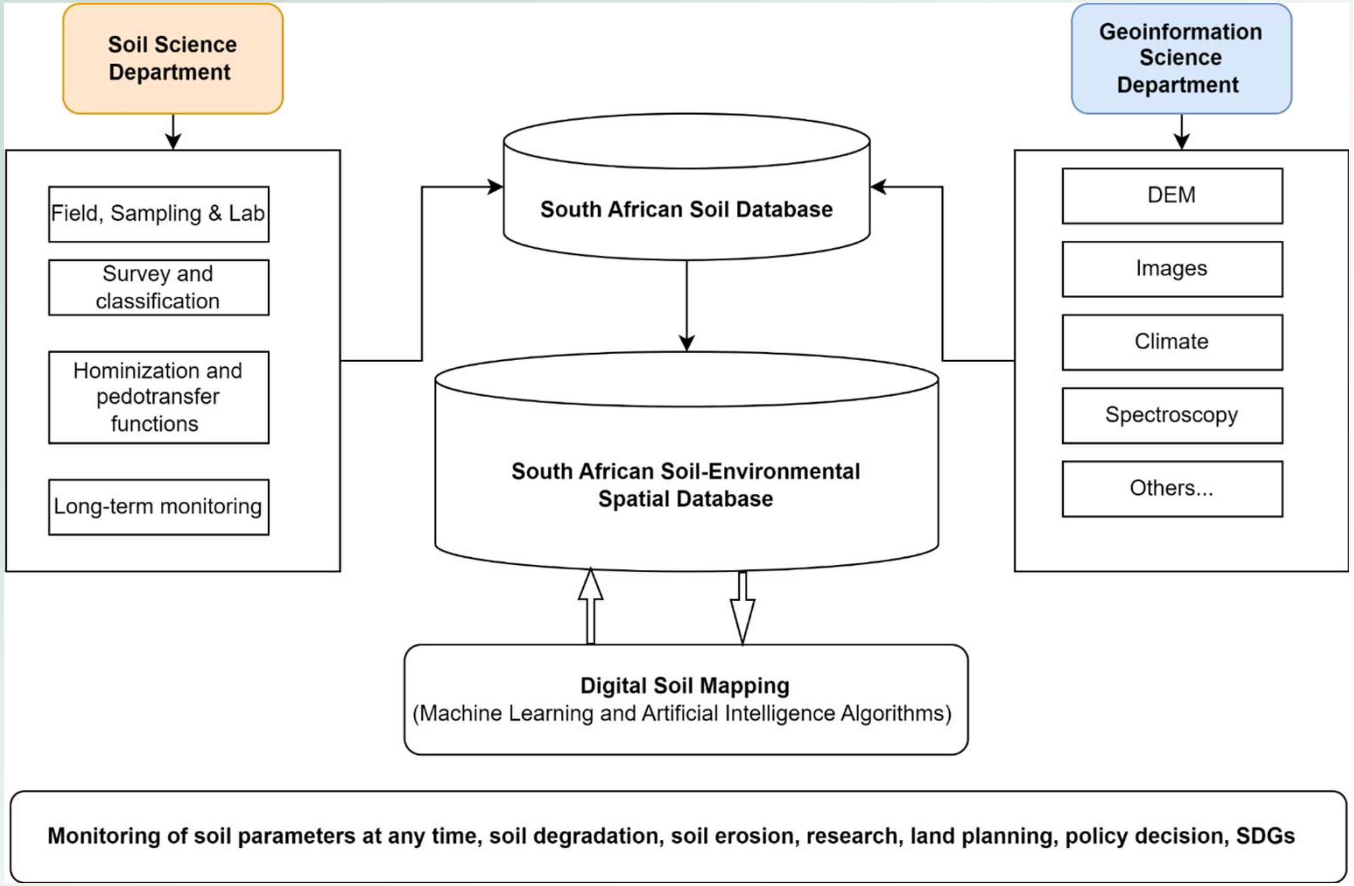
Future Work



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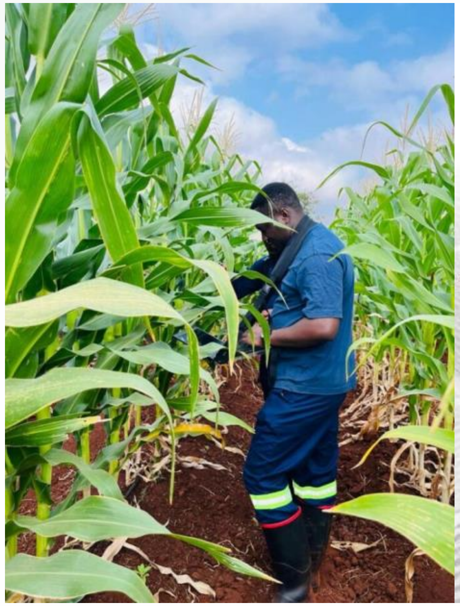
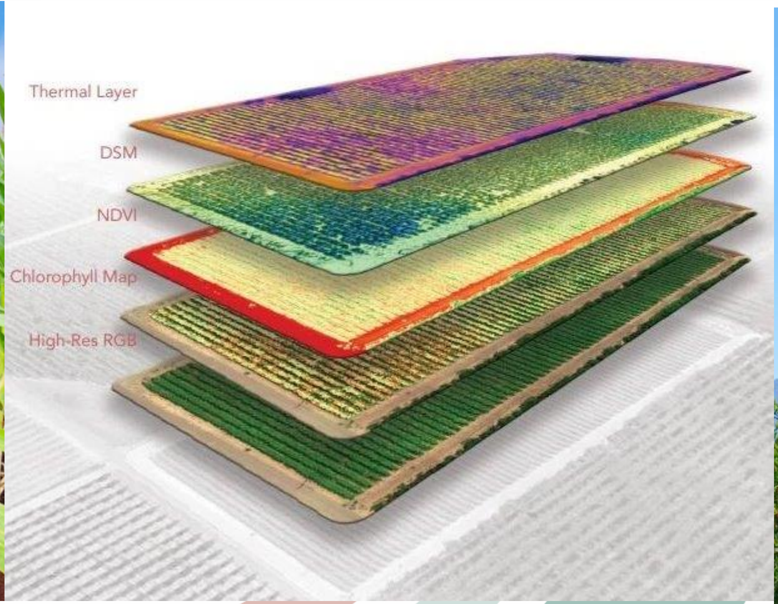
Available Potassium	ppm	Mehlich III (Mehlich, 1984)
Cation exchange capacity	$cmol_c/kg$	Ammonium acetate (Schollenberger and Simon, 1945)
pH	-	Soil pH in H_2O, KCl, $CaCO_3$ (FAO, 2021f)
Soil fractions (clay, silt, sand)	g/100g	Hydrometer (e.g. Bouyoucos, 1962)
SOC	%	Dumas dry combustion, Walkley-Black, Tyurin spectrophotometric (FAO,2019a; FAO,2019b; FAO, 2021g)
Bulk density	g/cm^3	Overview of methods provided by Blake (1965)
Nutrients (Ca, S, Mg, Fe, B, Cl, Mn, Zn, Cu, Mo, Ni, Si)	ppm	DTPA extraction method (FAO, 2022), Mehlich III (Mehlich, 1984), aqua regia extraction (Berrow and Stein, 1983)

Policy implications

- Soil nutrient maps will provide a baseline for identifying areas where nutrient levels are critical for crop growth and will thus serve as an important decision–making tool
- Updating and upscaling of soil fertility management recommendations for farmers
- Improved sustainable land management
- Contribute towards realization of SDG’s for the country and National Development Plan 2023

Thank you!

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