National Terrestrial Carbon Sinks Assessment 2020

TECHNICAL REPORT

environment, forestry & fisheries
Department:
Environment, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

ACKNOWLEDGEMENTS

Published by the Department of Environment, Forestry and Fisheries

This report must be cited as follows: *National Terrestrial Carbon Sinks Assessment: Technical Report (2020), Department of Environment, Forestry and Fisheries, Pretoria, South Africa*

Authors and core research team

Dr Graham von Maltitz - Council for Scientific and Industrial Researc
Professor Bob Scholes - Global Change Institute, University of the Witwatersrand
Marc Pienaar and Claire Davis-Reddy - South African Environmental Observation Network (SAEON)
Dr Tony Knowles - The Cirrus Group
Liesl Wiese - Independent

Project Management

Olga Chauke - Department of Environment, Forestry and Fisheries
Hlengiwe Mbatha - Department of Environment, Forestry and Fisheries
Karabo Mokoena - Department of Environment, Forestry and Fisheries
Zane Silinda - Deutsche Gesellschaft fűr Internationale Zusammenarbeit (GIZ) GmbH
Mirko Abresch - Deutsche Gesellschaft fűr Internationale Zusammenarbeit (GIZ) GmbH
Itchell Guiney - Department of Environment, Forestry and Fisheries

Layout by

Tronimex Design

Published in Pretoria, South Africa – November 2020

Contact Information

Department of Environment, Forestry and Fisheries
Environment House, 473 Steve Biko Street
Arcadia, Pretoria, 0001
South Africa
Tel: +27 12 399 9146
Email: HMbatha@environment.gov.za

This report was kindly funded through the GIZ implemented Climate Support Programme, which is part of the International Climate Initiative (IKI). The German Federal ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports the IKI on the basis of a decision adopted by the German Bundestag.

National Terrestrial Carbon Sinks Assessment 2020

TECHNICAL REPORT

environment, forestry & fisheries
Department: Environment, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

FOREWORD

The National Land Cover is a proxy for land use and management, thus can be used to assess drivers of carbon stocks changes and fluxes. Since the development of the first National Terrestrial Carbon Sinks Assessment (NTCSA 2014), South Africa 's ability to understand land cover changes has improved due to the development of new land cover products; 2014 and 2018. As methodologies for estimating Greenhouse Gas emissions (GHG) and removals from the Agriculture, Forestry and Other Land use (AFOLU) sector requires basic understanding of how land use, changes and management drive and also provide opportunities for reducing GHG emissions, there was a need to update carbon stock data and information based on updated datasets.

The NTCSA 2020, hereafter referred to as the sinks assessment, was developed against a backdrop of international policy imperatives including Nationally Determined Contributions and Enhanced Transparency Framework, coupled with domestic policies - the development and operationalisation of the economy wide climate change mitigation system including the AFOLU sector. Moreover, the sinks assessment was developed to create better understanding of carbon stocks, their dynamics, drivers and climate change mitigation and adaptation opportunities as well as the reporting thereof.

In addition, the sinks assessment was accompanied by an update of the Carbon Sinks Atlas (CSA). The CSA is a web-based data and information tool aimed at providing the spatial distribution of carbon stocks and fluxes across South Africa. Improvements to the previous version include updated search and discovery of data, updated carbon stocks maps and baseline datasets at 1x1km resolution, as well as newly available soil organic carbon datasets including organic carbon pool profiles for South Africa's district municipalities. The online CSA is available at https://ccis.environment.gov.za/carbon-sinks/#/.

Most of the carbon in South African natural ecosystems is found in the soil, accounting for an estimated 89% of the country's total terrestrial carbon stock. It is therefore important to understand the magnitude, determinants and how land-use options will either lead to an increase or decrease of soil carbon storage over time. Further, mitigation actions including Conservation Agriculture and use of soil amendments, biochar can be beneficial to reducing GHG emissions and enhance carbon sinks. It is in this context that vertical integration can be strategic in fostering implementation of sustainable soil and land management through policies including, Spatial Planning and Land Use management (SPLUMA) and Conservation Agriculture, Resources Act (CARA) and mainstreaming of the climate change agenda in municipal plans and strategies.

Although the independent research and findings contained in this report do not necessarily represent the views, opinions and/or position of government, the Department of Environment, Forestry and Fisheries believes that this research is critical to enhance our understanding of how land use and changes affect the potential of natural ecosystems to act as carbon sinks. Hence, the department is happy to make this work publicly available and accessible.

CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

AGB	Above ground biomass
AGW or AGB_{woody}	Above ground woody biomass
AGH or ABG_{herb}	Above ground herbaceous biomass
AFOLU	Agriculture, Forestry and Other Land Use
ARC	Agricultural Research Council
B	Biomass
BGB	Below ground biomass
BGW or BGB_{woody}	Below ground woody biomass
BGH or BBG_{herb}	Below ground herbaceous biomass
C	Carbon
CF	Carbon fraction or conversion factor
CO_2	Carbon dioxide
$CO_{2-\ e}$	Carbon dioxide equivalent
DEFF	Department of Environmental, Forestry and Fisheries
DOM	Dead organic matter
DSI	Department of Science and Innovation
g	Grams
Gg	Gigagram (one thousand million grams)
Gt	Gigatonnes (one thousand million tonnes)
GIS	Geographic information system
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global positioning system
ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
kg	Kilograms
LiDAR	Light detection and ranging
LU	Land unit
M	Million
m	Metres
m^2	Metres squared (area)
m^3	Metres cubed (volume)

NTCSA 2019	this report – i.e. 2019 National Terrestrial Carbon Sinks Assessment
NTCSA 2014	2014 National Terrestrial Carbon Sinks Assessment
NC	Nitrogen content
NO_3	Nitrate
O_2	Oxygen
RP	Reporting period
SANBI	South African National Biodiversity Institute
SOC	Soil organic carbon
SOCc	Soil organic carbon content
SARVA	South African Risk and Vulnerability Atlas
SOM	Soil organic matter
t	Tonnes (Metric i.e 1 000kg)
tC	Tonnes of carbon
tCO_{2-e}	Tonnes carbon dioxide equivalent
TJ	Terajoules
VCS	Verified Carbon Standards
y	Year
Δ	Change in

COMMON CONVERSION FACTORS

1 gC/m^2 = 0.01 tC/ha	:	1 tC/ha = 100 gC/m^2
1 kg/m^2 = 10 t/ha	:	1 t/ha = 0.1 kg/m^2
1km^2 = 100 ha	:	1 ha = 0.01 km^2
1 tonne = 0.000001 Tg	:	1 Tg = 1 000 000 t i.e. 1 Tg is a million tonnes
1 Tg = 10^{12} g	:	1g = 10^{-12} Tg, i.e. 1 Tg is a million million grams
1 Gg = 1 000 000 000 g	:	1g = 0.000 000 001 Gg, i.e. 1 Gg is a billion grams

DEFINITIONS AND TERMS

Biomass: living or recently-dead organic matter of biological origin. Most is plant matter, which could specifically be called phytomass. For the purposes this report biomass refers to standing or cut plant material only, naturally fallen material is called litter. Biomass is expressed as oven-dry mass of per unit area (usually g/m^2, $kg/\ m^2$, kg/ha or t/ha or Tg (when summed over the country).

Carbon pools: stores of carbon that when summed make up the total carbon content of the AFOLU sector that include:

- Above and below ground biomass, which is predominantly woody matter
- Dead wood and leaf litter
- Soil organic carbon SOC

Carbon sequestration: the process of the capture (fixing) and storage of atmospheric carbon into terrestrial carbon pools over time that may either be part of the natural process or enhanced through management measures. It is measured in carbon per unit area per unit time and often expressed as tCO_2e/ha.yr (tonnes carbon dioxide equivalent per hectare per year).

Conservation agriculture: a concept that combines a number of land-use management practices to ensure overall agricultural sustainability and soil health.

Cropland: a land use-activity that concentrates and grows plants (cultivation) that are cropped (either whole plants or fruits) for use by humans and domesticated animals, primarily as a food source. Croplands include a variety of plants such as hay, vegetables, cereal crops, sugarcane, orchards and vineyards.

Ecological Recovery/Regeneration: the restoration of natural ecosystems through the natural cyclic processes of renewal of species and their populations (Del Marco *et al*, 2004).

Fynbos: the fynbos biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).

Grassland: the grassland biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and Mucina, *et al*., 2014).

Humic soils: soils with organic carbon values >1.8% and having a low base reserve (Soil Classification Working Group, 2018; p15).

Karoo: the Nama- and succulent karoo biomes as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).

Land-use activities: any activity upon the land that makes use of the earth surface such as cultivation, grazing, mining, urban development, etc.

Land-use management: any practice used to manage land-use activities, such as tillage, burning regimes, crop rotation, fertilisation, etc.

Mineral soils: soils that do not have a high SOC (<10%.) and cannot be classified as organic or peat .

Organic carbon: carbon that "enters the soil through decomposition of plant and animal residues, root exudates, living and dead micro-organisms and soil biota" (Edwards *et al.*, 1999) i.e. carbon within the soil from a biological source.

Organic soils: soils with a pronounced accumulation of humified organic materials where the surface horizon averages between 10% and 20% SOC and are subjected to extended periods of water saturation (permanent / near permanent). This soil type occurs mainly in valley bottoms and high-altitude plateaux / mountainous regions (Soil Classification Working Group, 2018).

Pasture: is prepared land (ploughed and fertilised) and covered (vegetated) with grass and / or other low plants suitable for grazing of primarily domesticated animals. As such the flora content and density of pastures is managed to ensure benefit for the grazing animals (appropriate grass species, legume species or root crops). Pastures may be annual or perennial, and maybe grazed or cropped (i.e. mown and baled).

Peat soils: soils where the organic carbon content is >20% and are subjected to water inundation or extended periods of water saturation – this is a rare wetland type (Soil Classification Working Group, 2018).

Primary grasslands: Grasslands that have not been significantly modified from their original state and that still retain their essential ecological characteristics and functions; even though they may no longer have their full complement of naturally-occurring species. They have not undergone significant and/or irreversible modification, (Mucina *et. al*, 2014). Essentially these are species-rich grasslands which survive today in a few isolated areas that are generally of no interest to present day anthropogenic activities and seem to have remained so for hundreds if not thousands of years (Bredenkamp *et.al*, 2006).

REDD+ reducing emissions from deforestation and forest degradation.

Rehabilitation: any attempt to restore elements of structure or function to an ecological system without necessarily attempting complete restoration to any specific prior condition (Meffe and Carroll, 1997).

Restoration: the return of a community to its pre-disturbance or natural state in terms of abiotic (non-living) conditions, community structure and species composition (English and Blyth, 1999).

Re-vegetation: replanting vegetation or sowing of seed (may be part of a restoration project).

Savanna: the savanna biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).

Secondary grasslands: grasslands that have undergone modification (e.g. through overgrazing, incompatible burning practices (i.e. season / frequency), cultivation / ploughing) but have then returned to grassland through re-colonisation by indigenous grasses (Mucina *et al.*, 2014).

Soil: weathered rock (mineral particles) mixed with decayed organic matter (humus) that contains living matter (supporting a wide range of biotic communities) and is capable of supporting plants (retaining water, providing nutrients).

Soil carbon sink: the value of the pool / accumulation / storage of carbon in the soil and is effectively the calculation of SOC.

Soil organic carbon (SOC): the carbon fraction that is stored in SOM (Edwards *et al.*, 1999); also sometimes referred to as "total organic carbon" in the literature. SOC is the main source of energy for soil microorganisms with 1% SOC content (SOCc) equating to approximately 1.72% SOM per 100 g soil (Edwards *et al.*, 1999; Soil Classification Working Group, 1991).

Soil organic matter (SOM): the organic fraction of soil ranging from undecayed plant and animal tissue through ephemeral products of decomposition to fairly stable amorphous brown to black material, known as humus, which bears no trace of the anatomical structure from which it was derived (Soil Classification Working Groups, 1991; pg 233) i.e. does not include non-decomposed plant and animal residues, but does include organic carbon, organic nitrogen, organic phosphorus etc. – nutrients in organic form. SOM has a number of pools based on turnover time or rate of decomposition, namely:

- Labile pool – fresh residues with relatively rapid turnover (<5 years).
- Resistant residues pool - physically or chemically protected residues that are
- Slower to turn over (20-40 years).
- Stable pool - protected humus and charcoal components that are effectively stable from a human life span perspective (100s to 1000s of years to turnover).

Soil system: a dynamic system that includes the soil type, classification, chemistry, texture, soil activities and environmental setting that impact on land use, function and carbon sequestration.

Stocking rate: the number of animals (wild or domestic) of a particular class (often defined by weight and function) allocated to a unit area of land for a specified period (usually the growing period of the vegetation type in question). It can be expressed either in terms of animal numbers per unit of land (animals/ha) or as land area available for each animal (ha/animal) and is usually converted to a standard animal mass, the Large Stock Unit (LSU).

Subsoil: mineral horizon/s below the topsoil that is/are usually characterised by a diverse range of properties including the accumulation and concentration of quartz in the clay and silt fractions, lower colloidal matter and obliteration of the rock structure. Defined as the soil layer from 0.3 to 1 m depth in this report.

Thicket: the Albany thicket biome as per the South African National Biodiversity Institute (SANBI) 2012 VEGMAP (based on Mucina and Rutherford; 2006 and 2014).

Topsoil: the surface horizon, usually mineral, with a greater or lesser amount of humified organic matter. Defined as the top 0.3m soil layer from this report.

Vegetation cover: the fraction of the land surface covered by vegetation.

Vegetation structure: the physical nature of the vegetation such as height, the mix of plant forms such as trees, shrubs, grass, the degree of woodiness etc.

Veld / grassland management: refers to the stocking rate and burning regime applied to an area of grassland or savanna.

SUMMARY

This project, the National Terrestrial Carbon Sinks Assessment 2020 (NTCSA 2020) updates the NTCSA 2014. It includes a number of improvements in core datasets and methodology, as well as providing users with an easily usable, public domain modelling interface that runs as a plugin in the QGIS open source Geographical Information System (GIS) program. This document is a technical report on the project which gives extensive background and the details of running the models involved.

A summary for policy makers, data files, a spreadsheet of soil loss factors and an atlas based website https://ccis.environment.gov.za/carbon-sinks/#/ are available in addition to this report.

Key differences and improvements between NTCSA 2020 and NTCSA 2014 are given in Table 1. Key limitations of the methodology are given in Table 2.

Table 1: Comparison of data and methods between NTCSA 2014 and NTCSA 2020

Property	NTCSA 2014	NTCSA 2020
Soil Carbon reference	Used a beta version of the 1km AfSIS database	Used the ISRIC 250m database. This is an updated and improved version of AfSIS
Soil carbon loss factors	Used a common factor for each land cover	Uses specific values for different biome and climatic regions
Land cover drivers	Used a single land cover database (SANBI 2009) which was a composite of multiple year data	Used the NLC 1990, 2014 and 2018 products
Change detection	No	Compares 3 time periods 1990, 2014 and 2018. Has detailed land cover change per 1km pixel or summarised by municipality, district province or nationally
Tree cover	Used crude estimate based on tree high and cover, using 1km products.	Open source programming interface allowing for user defined scenario analysis. Uses proportional land cover data per 1km pixel.
Modelling	Proprietary program	-0.1266
Herbaceous cover	Based on models for natural vegetation and municipal crop data	Based on biome, but with estimates of woody dead biomass included
Litter data	Based on biome	Based on biome, but with estimates of woody dead biomass included

Table 2: Key limitations and potential solutions from the current study

Limitations	Potential solutions
Methods for detecting degradation (and resultant soil and vegetation carbon loss) within land use classes remains problematic.	Methodologies are needed to reliably and repeatably detect degradation within land cover classes, particularly within the natural vegetation class. The UNCCD is currently refining methodologies, but as yet none of these has proved reliable for the South African situation.
Data on the spatial location of conservation agriculture products is not available.	A field level database of sustainable agricultural activities in needed. This needs to include crop data, practices employed and duration.
Carbon loss from agriculture and gains from sustainable agriculture is still poorly researched.	Since NTCSA 2020 there have been substantive increases in research interest around carbon dynamics in agriculture. This has been summarised in the NTCSA 2020, but ongoing updating of this understanding will improve future products.
Despite great improvements to the tree cover data, and the ability to run the product for multiple (recent) time periods, the high variance in the product does not allow for reliable comparisons over time. In addition the method saturates at about 130 t/ha and therefore will underestimate biomass in the tiny parts of the country that exceeds this. It is also not fully calibrated for all biomes and all locations.	Satellite derived tree cover products are continually improving and in the future should have sufficiently reduced variance to allow for comparisons between time periods.
Greatly improved reference soil data is available, but there is still a lot of scope for improving this data by running a South African specific analysis. In addition there is a need to correctly stratify data based on land use.	ISRIC and other international organisations should be engaged to work with the ARC to improve South African specific soil maps.
New NLC classes differ from older NLC classes. This results in slight discrepancies between land cover products, especially related to the introduction of fallow lands.	Fallow land should be backwardly engineered into the 1990 and 2014 land cover to strengthen comparisons with NLC 2018 and future land covers that will use the same methodology as NLC 2018.

BACKGROUND TO THIS STUDY

In 2014 the CSIR (in partnership with a number of other organisations) produced the National Terrestrial Carbon Sinks Assessment for South Africa (NTCSA 2014). This work was undertaken because it had become obvious that attempting to account for the land-based terrestrial carbon stocks and flows using IPCC tier 1 or 2 methodologies was problematic in the South African context.

The CSIR in collaboration with SAEON later converted the NTCSA outputs into an atlas format to make the data more widely accessible, i.e., 'The South African Carbon Sinks Atlas 2017' (hereafter referred to as the Carbon Sinks Atlas).

Since the development of the NTCSA 2014 there have been a number of changes and developments. Most importantly the land cover of the country has changed, and as such, there is an associated change in carbon stocks. Our ability to understand land cover change is enhanced through a new National Land Cover product produced from 2014 data (NLC 2014), which only became available after the NTCSA was completed. In addition, new 2018 NLC data is now available.

There has also been a great deal of development around some of the uncertainties associated with the NTCSA 2014. For instance, the CSIR has created updated maps of above-ground woody biomass for the Savanna biome that are far more detailed and accurate than the maps used in the NTCSA 2014. Further, there has been ongoing research in many of the components related to the initial assumptions on which the NTCSA 2014 was based. In some areas, significant progress has been made, whilst in other areas, there are still substantive data gaps. All maps of carbon stocks as developed in the NTCSA 2014, will be reviewed to decide which ones can be updated based on improved datasets and methodologies, and a new set of maps will be developed for all biomes.

The data referred to above will be used to develop a better understanding of where opportunities exist for enhancing carbon sequestration within the terrestrial landscape and how biomes and agricultural systems can be managed to enhance this carbon uptake.

1.1. Rationale for assessing terrestrial carbon stocks

The contribution of the AFOLU sector to global GHG emissions and mitigation Requirements

The recent IPCC Special Report on Climate Change and Land (2019, reiterated the importance of intact landscapes to humankind and the important interaction between land and climate. Approximately 23% of all anthropogenic GHG emissions generated over the period 2007 to 2016 were from activities within the AFOLU sector (IPCC 2019). These accounted for 13% of all carbon dioxide (CO_2), 44% of all methane (CH_4) and 81% of all nitrous oxide (N_2O) emissions globally. If emissions associated with pre- and post-production activities within the global food system are included, the estimated amount of GHG emissions attributable to AFOLU increases to 21-37% of total net anthropogenic GHG emissions. Importantly, land-use based regulatory and management responses are crucial if both global climate change mitigation and adaptation targets are to be met. Whereas the combustion of fossil fuel remains the largest source of anthropogenic GHG emissions and urgently needs to be addressed, addressing land degradation is also a crucial component to limiting global warming to 1.5-2.0 oC (IPCC 2019). Furthermore, in terms of contributing to humankind's ability to adapt to climate change, in world where approximately 70% of global fresh water is used for the production of crops, the restoration of degraded land and its associated ecosystem services, such as the sustained yield of high quality water, is viewed as an essential component of humankind's ability to adequately adapt to climate change. Adaptation to climate change through the restoration of degraded land is particularly pertinent in Southern Africa, where climate change projections indicate warming and drying over the next century.

Although reversing land-use based emissions is seen as critical for reducing global emissions, it is important to emphasise that this activity on its own cannot come close to solving the problems of global climate change, neither in South Africa nor globally. If global warming is to be limited to 1.5-2.0 oC, it needs to be accompanied by substantively reduced fossil fuel emissions (IPCC 2019).

Contribution of the AFOLU sector to South Africa's national GHG emission profile

South Africa's National Inventory Report reported the AFOLU sector was a net source of GHG emissions in 2000, accounting for approximately 6% of country's total GHG emissions at the time. The sequestration of carbon within the sector was reported to have increased to the extent that in the years 2016/2017, the net GHG emissions from the AFOLU sector fell below zero (National Inventory Report (NIR) 2017, in DEA 2019). The GHG emissions from Livestock and Aggregated and non-CO_2 emissions amount to an estimated 46 600 $GgCO_{2e}$ per year (IPCC National Inventory Classes 3A and 3C), the net emissions from Land (3B) are approximately -53 700 $GgCO_{2e}$. The reason for this was attributed to carbon sequestration within certain biomes, particularly Forest Land[1], accounting for 70% of sequestration, and Grasslands accounting for 27%. However the tier 1 and 2 IPCC methodologies used to calculate these changes relied on a number of assumptions that may not be true in the South African situation. The validity of these conclusions is questionable.

In the IPCC National Inventory Framework (2006, 2019), carbon sequestration is reflected in two broad ways. Firstly, through the conversion of a land cover class with lower carbon stocks to one with larger carbon stocks (for example, the conversion of Bare land to Grassland or Grassland to Forest). Secondly, through a net increase in carbon stocks within a land cover class. The latter is applicable where vegetation is still in the process of growing and sequestrating carbon. In a mature, intact ecosystem, for example a primary grassland or old-growth forest, there will not be a net sequestration of carbon, since annual inflows match outflows on average. In contrast, a rehabilitating system (i.e. one recovering from prior disturbance) will show a net increase in carbon stocks over time as vegetation and soil organic carbon increase towards their mature, equilibrium state.

In the South African national GHG reports, the conversion of the "other land use" classes to Forest Land is responsible for 45% of reported carbon sequestration within the Forest class. The remainder is due to an increase in carbon stocks within the Forest Class (Forest Land remaining Forest Land). The net amount of carbon within the Grassland class has remained consistent over the reporting period. Where Grassland replaces the Bare land class this leads to an increase in carbon stocks, as is the case where there is a shift from Grassland to Forest (including bush, woodlands and thicket). However, these transactions change the spatial extent of grasslands and hence should reflect in the amount of carbon in the Grassland Class. There are a number of limitations in the methodology used, chief amongst these being land cover class changes between national land cover (NLC) products. In particular, the NLC products are poor at resolving boundaries between visually similar, but with different carbon stocks, natural vegetation classes (Thompson 2014). In addition, mean carbon stock values are used for entire class – a grassland changing to a forest therefore changes from the grassland mean to the forest mean (in accounting terms, instantaneously although in fact there is a time delay).

In the South African situation there is a carbon stock continuum between classes such as shrub land, thicket, savanna and forest. Therefore the parcel of land that has changed class from a land cover classification perspective may have undergone very limited change from an ecological and carbon perspective (e.g. may have changed canopy cover by 1 %, from just below the threshold to just above). Further, the methodology fails to account for natural vegetation reaching an equilibrium state. It assumes that it continues to grow with carbon uptake offset by fire and harvesting. Both these latter parameters are poorly

1 Note that 'Forest Land' in this context follows the Marrakesh Accord definition, which is more than 10% cover by woody plants taller than 2m. This means that for GHG accounting purposes most of the South African and surface are classified as forests, including the fynbos, thickets, karoo and savanna biomes. Vegetation ecologists, forest legislation in South Africa and the general public would not consider most of this area to be forests.

quantified at the biome level and change in intensity across a biome, despite uniform factors typically being applied to the entire biome.

Climate change mitigation opportunities within South Africa's AFOLU sector

The National Terrestrial Carbon Sink Assessment 2014 (NTCSA 2014) (DEA 2015) identified nine principle climate change mitigation opportunities within the AFOLU sector (DEA 2015)(Table 3). If implemented at a full national scale, climate change mitigation within the sector was estimated to be able to reach 14 Million tCO_{2e} per year. Although this may be a small fraction of required GHG emission reductions to meet South Africa's Voluntary National Contributions, most of the opportunities come with a set of further climate change adaptation, ecosystem service and socioeconomic benefits. In particular, many provide employment opportunities in rural areas through the restoration of degraded landscapes. The restoration and sustainable management of landscapes, be they open rangelands, forests or areas under commercial agriculture, requires a broad set of activities to be implemented and sustained over time, for example, the implementation of erosion control measures, replanting degraded areas, and monitoring and reporting over time. Each of these presents an opportunity for skills development and employment over the long-term in remote rural areas. In addition, the sustainable management of landscapes will improve water services to local residents and downstream urban and industrial sectors as well as improve production, be it livestock or crops within the commercial and informal sectors.

The national Carbon Sinks Atlas is particularly important in understanding the potential spatial extent of certain activities, for example, the restoration of sub-tropical thicket and scarp and coastal forest. If repeated on regular basis over time, it has the potential to provide useful data into the national forest reference levels (FREL/FRLs) required for the development of a national REDD+ program and to understand further background baseline trends, for example, bush encroachment or the clearance of alien invasive plants, that may influence the magnitude and nature of South Africa's terrestrial carbon stocks. Further, the use of biomass from clearing of bush encroached areas and also from clearing of alien invasive

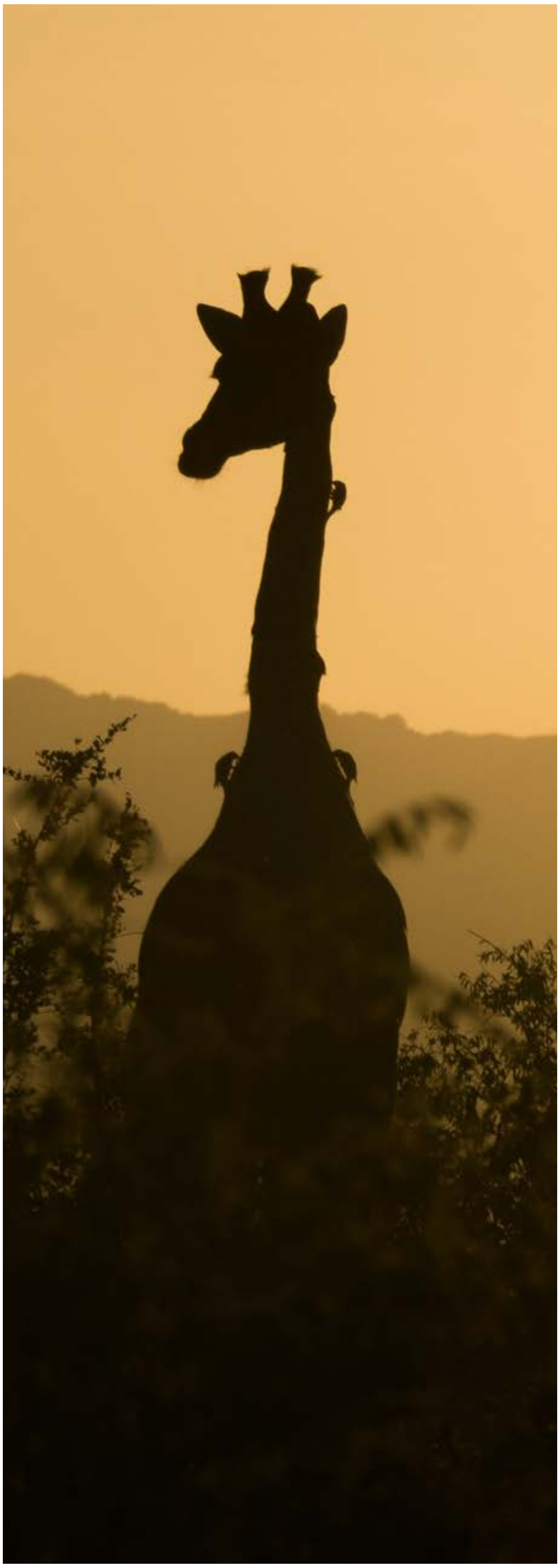


Table 3: AFOLU sector climate change mitigation opportunities within South Africa as identified in the 2014 National Terrestrial Carbon Sink Assessment (DEA 2015).

Activity	Sub-class	Spatial extent (ha)*	Reduction per unit area per yr (tC)	Emission reduction per yr (tCO_{2e})	Reduction in emissions over 20yr (tCO_{2e})
Restoration of subtropical thicket, forests and woodlands	Sub-tropical thicket	500 000	1.2	2 200 000	44 000 000
	Coastal and scarp forests	8 570	1.8	56 562	1 131 240
	Broadleaf woodland	300 000	1.1	1 210 000	24 200 000
Restoration and management of grasslands	Restoration – Erosion Mesic	270 000	0.7	693 000	13 860 000
	Restoration - Erosion Dry	320 000	0.5	586 667	11 733 333
	Restoration-Grassland Mesic	600 000	0.5	1 100 000	22 000 000
	Avoided degradation mesic	15 000	1.0	55 000	1 100 000
Commercial small-grower afforestation	Eastern Cape	60 000	1.5	330 000	2 750 000
	KwaZulu-Natal	40 000	1.5	220 000	1 833 333
Biomass energy (IAPs & bush encroach.)	Country-wide			328 955	6 579 099
Biomass energy (bagasse)	Country-wide			328 955	6 579 099
Anaerobic biogas digesters	Country-wide			3 642 408	72 848 160
Biochar		700 000	0.3	641 667	12 833 333
Conservation Agriculture		2 878960	0.1	1 055 619	21 112 373
Reducing deforestation and degradation		unknown			
Total				**14 110 193**	**275 787 189**

plant species to rehabilitate ecosystems and also through creation of value added industries.

Background to terrestrial carbon pools and the adopted methodology

Dry biomass and soil organic matter are both approximately 47% carbon (IPCC 2006). On a day-to-day basis plants take up carbon dioxide from the atmosphere through the process of photosynthesis. Most of is released back into the atmosphere shortly thereafter through the process of plant respiration. However, a small fraction is assimilated to form the carbohydrate 'building blocks' of plant matter. As it would be inefficient to measure all the flows of carbon (fluxes), including photosynthesis, respiration, fire, litter fall, herbivory, harvest and so forth on a short-term basis such as daily or even seasonally, a "stock-based" approach is used to understand the net change in carbon over time. The amount of carbon located within biomass and soils is typically estimated once every few years. The difference in carbon stocks between two times is reported as the net flux (expressed annually but dividing by the number of years between estimates). The frequency at which estimates are made is determined by the frequency with which the data needed for the estimates is produced, with major cost considerations. In the case of South Africa, The National Land Cover (NLC) is a key driver of the carbon stock estimates. In the past, the NLC has been sporadically produced, or average about every five years. It is anticipated that it will be produced at two-yearly intervals in the future.

Terrestrial carbon stocks take a number of forms. The main ones are the biomass of trees and herbaceous plants, their litter and dead wood, and the soil organic carbon. Stocks such as the carbon in animals are small by comparison, while stocks such as microbial biomass are already included in soil organic carbon. As each of these forms has different dynamics in terms of size, growth and turnover, ecologists consider the terrestrial carbon stock as a system of distinct, but linked carbon pools (Figure 1). Typically, the first separation is between biomass and soil organic carbon. Thereafter, biomass carbon is separated into woody plants (trees and shrubs), herbaceous plants (including grasses), litter and dead wood. Often in the course of carbon accounting or modelling exercises, the woody and herbaceous pools are further separated into their above- and below-ground components.

SCOPE OF THE PROJECT

The CSIR proposed to GIZ, working with the Department of Environment, Forestry and Fisheries, to update the NTCSA 2014 and the web-based Carbon Sinks Atlas 2017 that hosts the data based on deliverables outlined below. In essence five (5) components were proposed:

1. The functionality and usability of the Carbon Sinks Atlas user interface;
2. Improve the accuracy of data and estimates based on new data sources—this would include updating baselines and collating learnings from ongoing studies in the AFOLU sector;
3. Re-run the models used in the NTCSA 2014 to update outputs based on changes in land cover since the original runs. Since the model assumptions and datasets are improved, this will need to be run for both the new as well as the original land cover data;
4. Assess the limits and data gaps to the NTCSA 2014 and propose solutions to filling these gaps.
5. Advise on policy instruments to reduce emissions and/or enhance carbon sinks in the land agriculture, forestry and other land use (AFOLU) sector.

IMPROVED CARBON SINKS ATLAS INTERFACE

The 2020 version of the carbon sinks atlas is available at https://ccis.environment.gov.za/carbonsinks/#/

Objectives and deliverables

To improve the functionality of the current Carbon Sinks Atlas interface so that it is both faster and allows the users to do more advanced queries on the data so that it can be used for their specific applications. Allowing users to extract subsections of the data will greatly assist download speeds.

The South African Environmental Observation Network (SAEON) currently hosts the Carbon Sinks Atlas, together with a number of other atlases and has contractual agreements with the DEFF in this regard, which greatly reduced the costs related to this project.

The deliverable from this task will be an improved user interface for the Carbon Sinks Atlas web that allows for interactive queries of the data. In addition, existing data will be updated when it becomes available and new data will be added.

Context

SAEON (South African Environmental Observation Network) is mandated by national government to perform long-term environmental observations, and to preserve and provide data in respect of earth and environmental observations. In pursuit of this, SAEON has established an Open Data Platform (ODP) capable of supporting a wide range of stakeholder needs and applications in respect of data management, research data infrastructure, decision-support tool development, and general web based resources[2].

SAEON is also increasingly assisting stakeholders with decision-making, planning, and policy support, and in doing so has developed, and is continuously improving, a portfolio of support tools aimed at tasks such as Atlas-, Indicator-, and Spatial- Profiling.

The ODP can be used, inter alia, to rapidly construct and deploy planning and decision support websites using currently available functionality, and if required, funders can contribute new functionality that becomes available to all end users in a shared resources environment.

DEFF and SAEON have recently entered into a wide-ranging collaboration agreement in respect of data infrastructure – more information is available in Appendix A. This agreement makes provision for additional project-based collaborations, and also provides some backbone services that could be used by this project.

SAEON has agreed to support the refinement of the DEFF's Carbon Sinks Atlas based on a number of considerations. In summary, these considerations are:

1. Some of the tasks and development of infrastructure associated with or required by the Carbon Sinks Atlas are already funded by government in a number of ways. We do not foresee that preparation of metadata, standardisation of datasets for publication, or hosting of data will require additional funding.
2. SAEON will also revise its Atlas application, and is in the process of specifying the requirements for DSI/DEFF support tools for:
    a. Profiling of Risk and Vulnerability; and,
    b. Construction of indicators, including multi-criteria indicators based on distributed data sets. Indicators will need to be agreed on with relevant sections within DEA including its monitoring and evaluation (M+E) requirements.
3. Tasks not directly covered in the SAEON-DEFF agreement but needed for the DEFF Carbon Atlas are funded through this task's budget.

For this reason, SAEON is in a position to offer a specific development and deployment pathway that is likely to

2 https://docs.google.com/document/d/1GQxCt9iWi-74kHtDIc1CNIb_1pvIGA9S_MltntE4XXE/pub

be cost-effective and results in re-use of publicly funded infrastructure, with options on how to extend this infrastructure dependent on funder and client preferences.

3.1. Carbon Sinks Atlas interface (CSA 2.0)

In collaboration with the CSIR, SAEON has undertaken to improve the functionality and usability of the current Carbon Sinks Atlas interface (Deliverable 1 of Project Proposal) so that it is more user-friendly, faster and allows the users to do more advanced queries on the data. CSA 2.0 will be linked to the National Climate Change Information System and the look of the Atlas is currently being revised to match the look and styling layout of the NCCIS. CSA 2.0 can be accessed here:

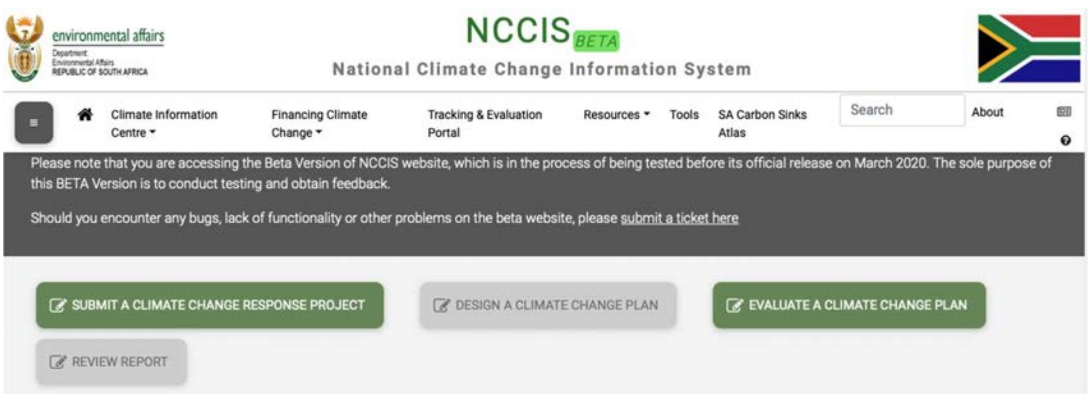
https://ccis.environment.gov.za/beta/carbon-sinks/#/.

Interactive Atlas Gateway

A downloadable portfolio of online Atlases, including links to other thematic atlases such as the BioEnergy Atlas, South African Risk and Vulnerability Atlas are being developed by SAEON, which can be searched and filtered for data and the spatial extent of interest. The Carbon Sinks Atlas is currently being updated with new data produced through this study.

National Climate Information System (NCCIS)

A Beta Version of NCCIS, including the NCCRD and NDAO systems as well as the Tracking and Evaluation Portal was released in August 2019. The NCCIS was tested before its official release and transfer to DEFF. The sole purpose of this Beta Version is to conduct testing and obtain feedback. A ticket logging system to report bugs, lack of functionality or other problems on the beta website.



Climate Change Resource Library

An extensive climate change resource library has been generated for the NCCIS which includes government resources such as policy, legislation, guidance and research documents, sector documentation from domain experts, links to additional South African climate change online tools and links to the international agreements South Africa is a party to and the country's voluntary contributions. An extensive keyword network was developed such that resource can automatically be piped into interactive tables in relevant sections across the NCCIS. All of the resources have now been added to the list and a template of key metadata fields has been added to them.

Standardised Vocabularies

Standardised vocabularies serve as a common frame of reference for climate change reporting and monitoring. Work on a variety of standardised vocabularies is currently underway and have already been established for:

- Regions
- Hazards
- Climate Trends
- Climate Change Variables.

Search and Discovery of Data

Data services are loosely coupled via search and discovery mechanisms and/ or visualisation tools to themes of interest to stakeholders. The process to date has been utilised in the QGIS plugin services to easily search carbon sinks database at SAEON and discover and subset data (refer to section 2.5 for more information).

3.2. Updated carbon stocks maps and datasets

Existing data is being updated and new data will be added when it becomes available (Deliverable 2 of the Project Proposal). Updated Carbon Sinks datasets: A 1km x 1km resolution aggregate of the Biodiversity Directorate and STATS SA 100m Basic Spatial Unit or BSU raster was used to resample both existing and updated carbon stocks (CS) data using a fractionally weighted resampling algorithm (based on hi-res block statistics, rather than vector intersection)(Figure 3.1). Python code has been developed (and bug tested) to provide different nestings of the BSU grid - including the ability to polygonize, rasterise, and mosaic - and to perform desegregations and aggregations from different projections and spatial resolutions using fractional weights, sums, and class based resampling. The resampling is highly accurate, maintaining >99% of the original volume of information, and optimised to run for about ~5 days per resampling to a 1km BSU resolution. All datasets used in the carbon sinks atlas are resampled into a 1km BSU grid aggregate and clipped to a ROI (region of interest) surrounding South Africa. Resampling is done using block statistics in 20kmx20km chunks (shown in Figure 1). The code for resampling can be found at https://github.com/SAEONuLwazi/Block_statistics_resampling. For simplicity the procedure can be illustrated according Figure 3.2. Input data is continuously being processed.

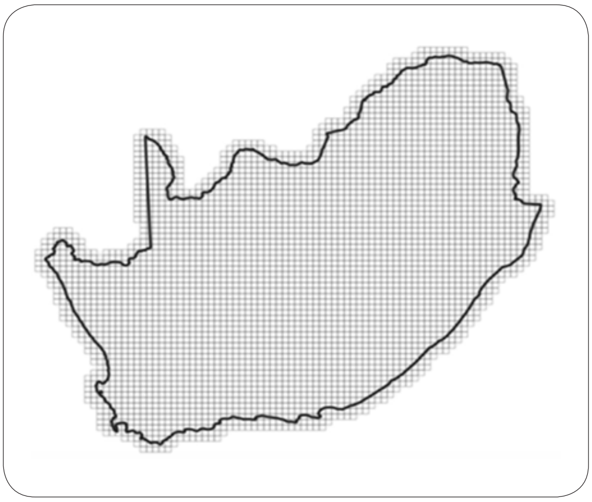


Figure 3.1: Representation of the 20km x 20km chunks covering South Africa used for carbon sinks data resampling overlaid with the South African clipping mask.

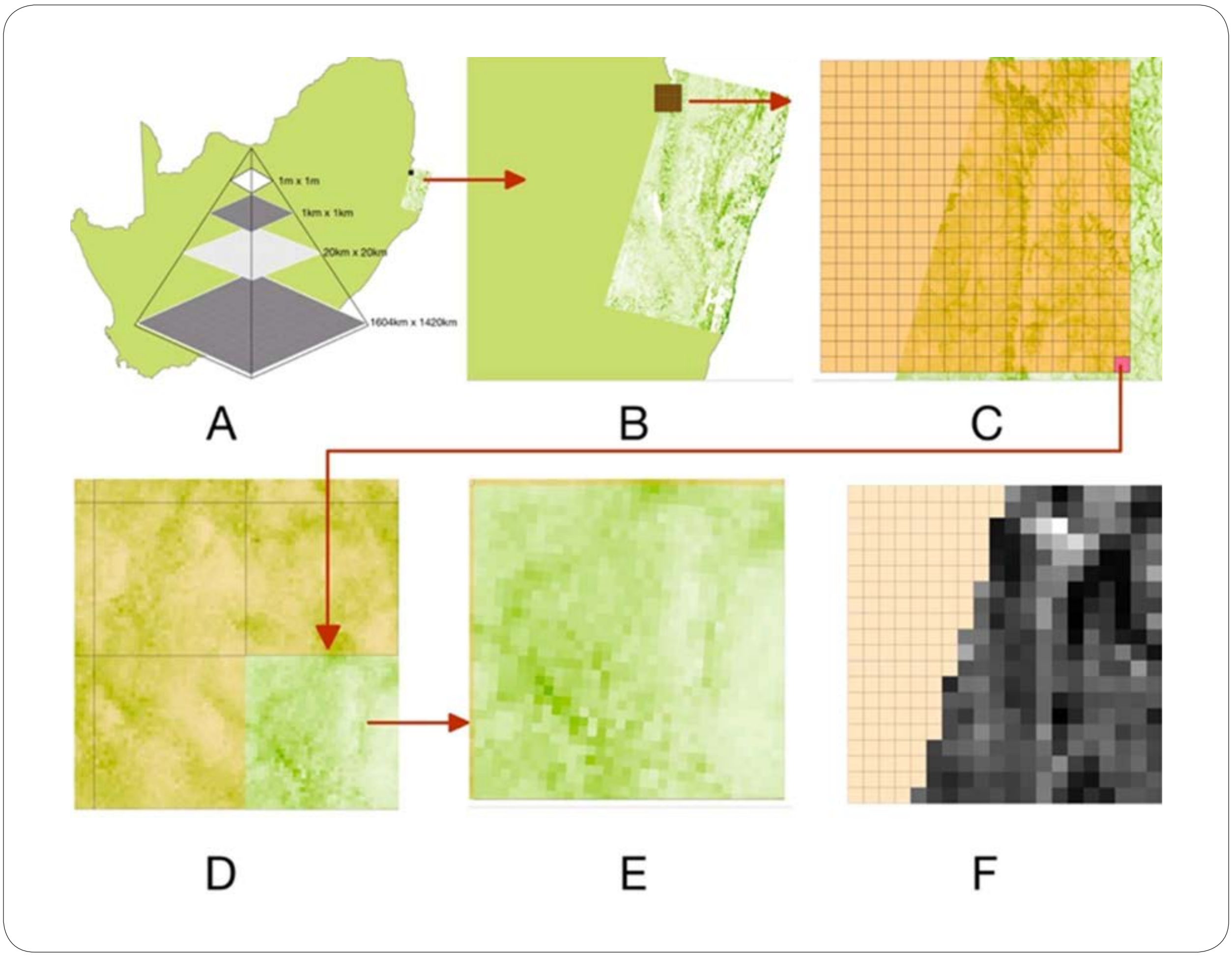


Figure 3.2: Resampling is done using block statistics in 20km x 20km tiles shown in Figure 1. For each 20km x 20km tile, the input data is clipped and divided into 1km x 1km blocks. Each 1km x 1km is clipped again and expanded into a 1m resolution grid. The 1km x 1km grid (at 1m resolution) is then resampled (weighted mean, weighted sum, or class counts depending on data requirements) back into a 20km x 20km BSU tile. Each 20km x 20km tile (there are 3780 covering South Africa) is then merged to create the resampled product. This conceptually illustrates the nested resampling approach, and B—D provides an example of resampling a single 20km x 20km tile from an input raster back into a 20km x 20km BSU tile.

3.3. Soil organic carbon (SOC) information and datasets - Model Development

This task involved rerunning the models used in the NTCSA to update outputs based on changes in land cover since the original runs. The SOC layers that have been created by the CSIR using ISRIC data have been resampled, as well as, the land cover products. In reduced form the updated total soil carbon (CSIR alg) = (LC1+LC2+LC3 … LC16) X 0.01+ SOC30_100, where LC1…LC16 represents a land cover area (i.e. LC1area) x a factor (i.e. LC1factor) x SOC_30 (the top SOC layer). SOC30_100 is the SOC layer from depth 30cm to 1m. The land cover areas have been created for 16 classes (NL 1990 and 2014) and 17 classes (NL 2018).

3.4. QGIS Plugin

Integration of the resources in the Carbon Sinks Atlas with QGIS plugin allows for the use of the data in a non-web environment (Figure 3.3 and 3.4). The QGIS Plugin fetched data from relevant SAEON carbon sinks databases and loads data into the users QGIS map view.

The Plugin provides services specifically for querying, sub-setting, and downloading data based on preferences in respect of spatial selection (rectangle, circle, square). SAEON is in the process of providing functionality to subset by administrative areas (such as municipalities or provinces), biomes, or any other spatial hierarchy that the stakeholders deem important.

The QGIS plugin allows you to search SAEON's Carbon Sinks data repository, and enables you to calculate the different carbon pools for the national carbon sinks assessment. This system implements an approach for the search and discovery of Carbon Sinks data, as well as, the ability to calculate the different carbon pools for the national carbon sinks assessment. The conceptual background is given in the assessment report. The design characteristics satisfy the following criteria:

- Simple to use
- Highly integrated with the Carbon Sinks Atlas (data can be loaded directly into QGIS from online metadata resources)
- Spatially explicit
- Adaptable with changing priorities
- Carbon sinks outputs are able to be modified by end users.

The system will run on any PC loaded with QGIS 3.8 and below. In the plugin menu item of QGIS, click the 'Manage and Install Plugins…' to open the plugins dialog. Navigate to the settings option and make sure 'Show also experimental plugins' is checked, then choose the 'Install from zip' option and select the 'carbon_sinks.zip' file. Click the 'Install Plugin' button to install the plugin.

The plugin has two main interfaces:

- The Carbon Sinks window (a search and discovery interface which opens when the plugin is clicked); and
- The Model builder (accessible from the 'Model' button in the main Carbon Sinks window).

The search and discovery mechanism has been tested against the previous Carbon Sinks data, but once the new datasets have been published (both metadata and determination of a suitable endpoint for data retrieval to allow server-side sub-setting [potentially THREADS or standard WCS – depending on which can handle the BSU projection best]), still needs to be added. A custom algorithm builder ('model' in the interface) has now been developed to house all the latest CS algorithms and datasets, but also for end-users to test, run, or customise Carbon Sinks algorithms within the QGIS environment, and thus maintain transparency. The plugin is now complete and meets the requirements of the CSIR, and hence the client (https://github.com/SAEON-uLwazi/Carbon-Sinks). A full description of the plugin and how to use it can be found in the User Manual.

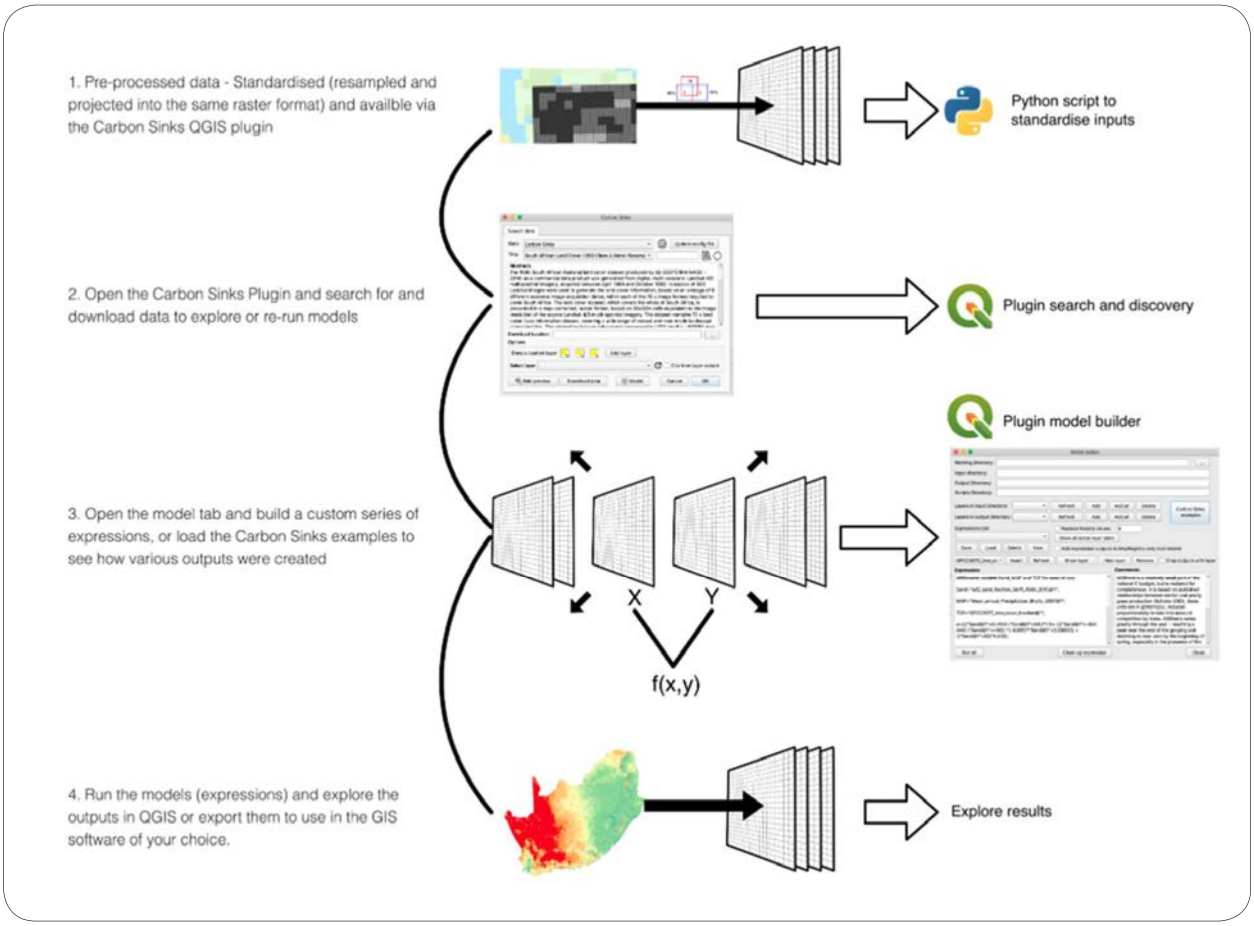


Figure 3.3: Overview of how the QGIS plugin works

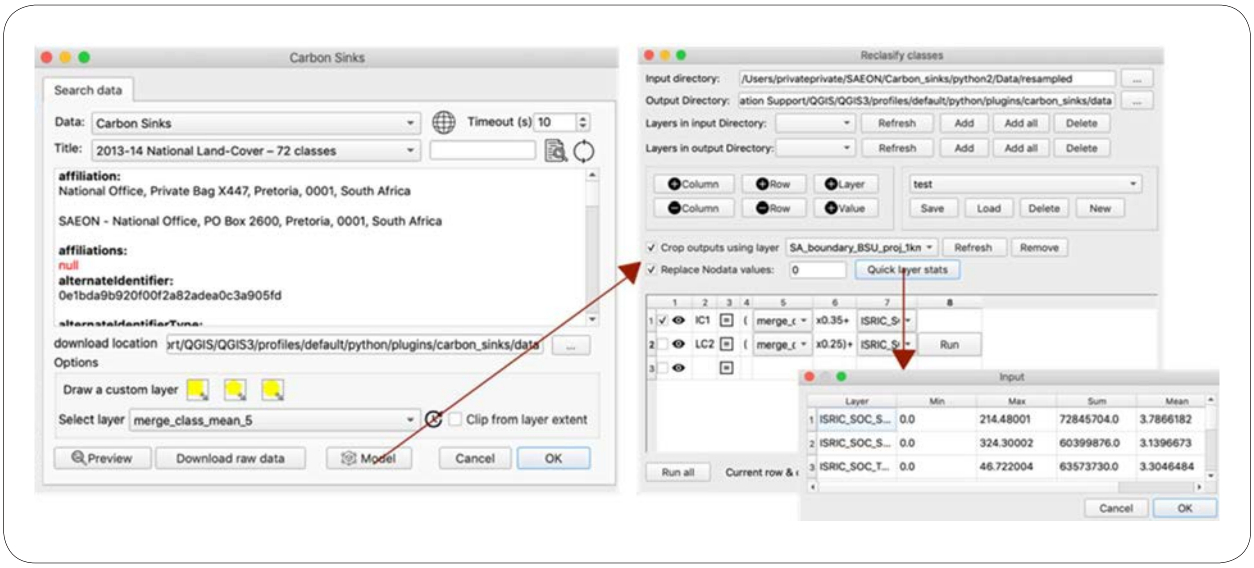
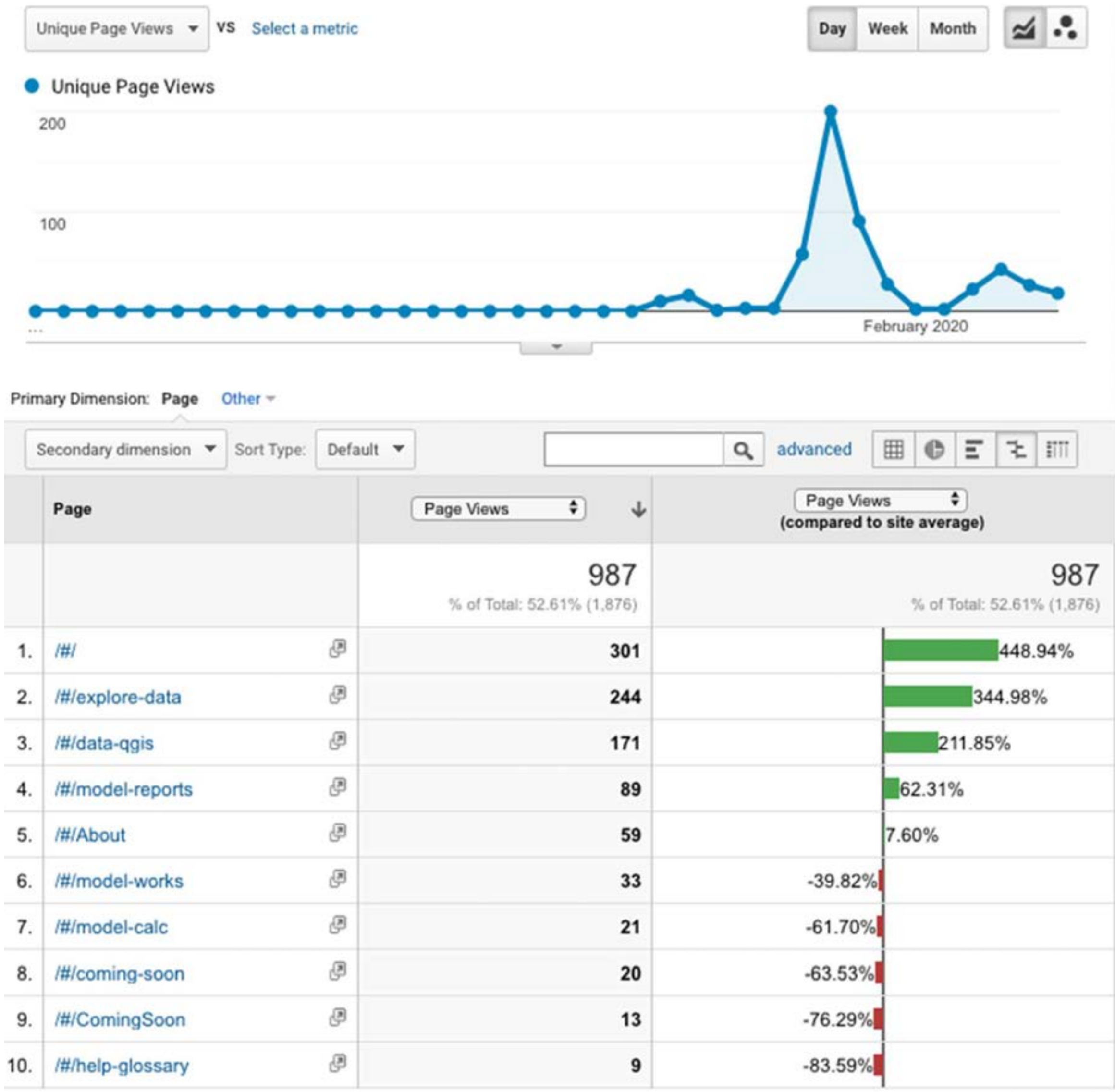


Figure 3.4: Example screenshots of the QGIS plugin. The model builder always unlimited columns (raster calculator expressions or equations) and columns (unlimited layer mixing) to be performed and loaded / saved as outputs. Source code available at https://github.com/SAEON-uLwazi/Carbon-Sinks

3.5. Website Analytics

Basic website analytics (Figure 3.5) demonstrates that the majority of users access the explore data page or the Atlas. The new CSA has been viewed a total number of 1,876 times with unique page views being 1,071. The average duration of each user's session is approximately 5 minutes. More detailed analytics are still being implemented at SAEON and in future more details on the type of user, time spent on page, download details, and number of project uploads, project views, project edits to name of few.



	Page	Page Views	Page Views (compared to site average)
		987 % of Total: 52.61% (1,876)	987 % of Total: 52.61% (1,876)
1.	/#/	301	448.94%
2.	/#/explore-data	244	344.98%
3.	/#/data-qgis	171	211.85%
4.	/#/model-reports	89	62.31%
5.	/#/About	59	7.60%
6.	/#/model-works	33	-39.82%
7.	/#/model-calc	21	-61.70%
8.	/#/coming-soon	20	-63.53%
9.	/#/ComingSoon	13	-76.29%
10.	/#/help-glossary	9	-83.59%

Figure 3.5: Carbon Sinks Atlas (https://ccis.environment.gov.za/carbon-sinks/) analytics based on all website data since the new release.

UPDATED CARBON STOCKS MAPS AND DATASETS

Objectives and deliverables

The objective of this task is to update the existing carbon stocks and sinks data (as developed in the National Terrestrial Carbon Sinks Assessment (NTCSA 2014) with new data (based on changes since the original data was obtained) and improved accuracy based on improvements in underlying datasets and methodologies.

The deliverables from this task are updated maps and associated datasets following similar methodologies as those used for the 2014 version of the Carbon Sinks Atlas, with data for all carbon pools.

Context

The NTCSA was completed in 2014 and based on the best available data at that time. Since then a number of new datasets (including new land cover maps as well and a refined understanding of land cover change impacts) have become available as well as new analytical techniques. This, therefore, allows for refinement of measures and methodologies and where possible the detection of change in carbon stocks based on a change in land cover and management.

4.1. The conceptual framework

Atmospheric carbon dioxide (CO_2) is taken up by plants through the process of photosynthesis. Some of this is lost by the plants' respiration, but the balance is stored in the plant as biomass. This biomass might be eaten by herbivores or die over time contributing to litter and soil organic biomass, some of which gets lost to respiration. This process is summarized in Figure 4.1. Over time equilibrium tends to be reached where the amount of biomass in the different pools remains relatively stable, though disturbances such as fires may lead to large amounts of above ground organic carbon losses over short periods of time. Our biomes differ in how they respond to fire, but for most of the fire prone biomes, the biomass is relatively constant when viewed over a period of multiple years. In Fynbos systems above ground plant biomass builds up over a number of years, then is almost totally destroyed by fire, before building up again. In Savanna systems, the impact of fire is typically far less and in most fires, only a small proportion of above ground biomass is lost. In Grasslands, the loss of above ground biomass is rapidly replaced over one or two seasons. Soil organic matter tends to be far more stable than above ground biomass but will change over time if the vegetation changes significantly. Converting natural vegetation to cropland can have major impacts on soil carbon (see Appendix 4).

For this assessment total ecosystem organic carbon (TEOC) is calculated as the sum of a number of individual organic pools as listed below and represented in Figure 4.1 and 4.2.

*TEOC = SOC + (AGBwoody +BGBwoody + DW + AGBherb +BGBherb + AGL)*CF*

TEOC= total ecosystem organic carbon

SOC=Soil Organic Carbon to a depth of 1 m

AGBwoody=Aboveground biomass in woody plants (leaf+stem biomass of perennial, lignified plants, regardless of height – trees, bushes and shrubs)

BGBwoody=Belowground biomass in woody plants (fine+coarse roots of perennial, lignified plants)

DW = Dead wood

AGBherb=mean annual maximum aboveground biomass of herbaceous plants (predominantly

grasses, but also forbs, restios, sedges etc.)

BGBherb=mean annual maximum belowground biomass of herbaceous plants.

AGL = Aboveground litter

*CF = carbon fraction i.e C=CF*DM ; = 0.42 (references: Safari 2000, Parton et al.)*

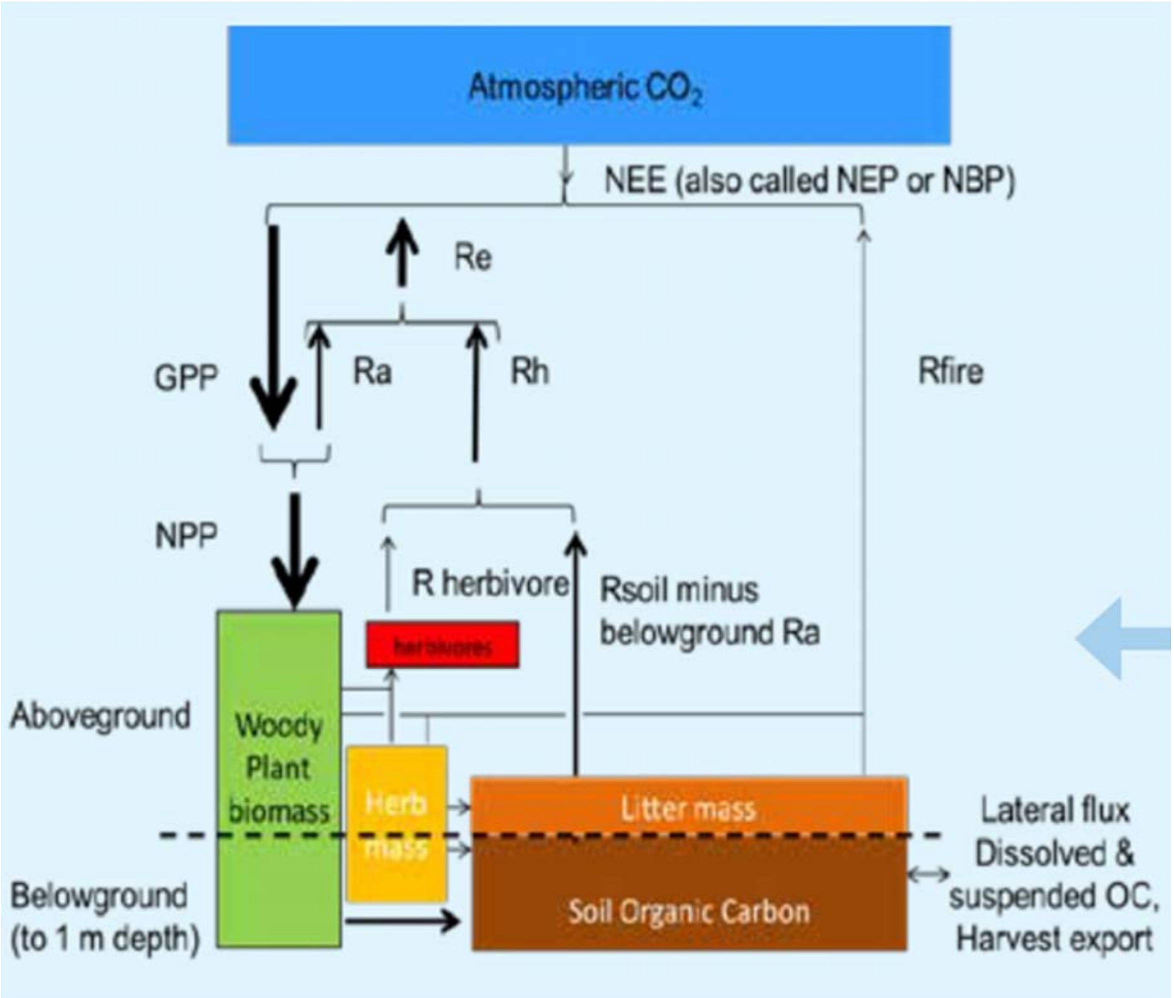


Figure 4.1: Components of a generalized terrestrial carbon cycle, with box sizes (representing stocks) and arrows (representing fluxes) roughly indicative of their relative size in South Africa, where NEE = Net Ecosystem Exchange; NEP = Net Ecosystem Productivity; NBP = Net Biome Productivity; GPP = Gross Primary Production; Ra = Autotrophic Respiration; Rh = Heterotrophic Respiration; Re = Ecosystem Respiration; Rfire = Fire Emissions (Department of Environmental Affairs, 2015)

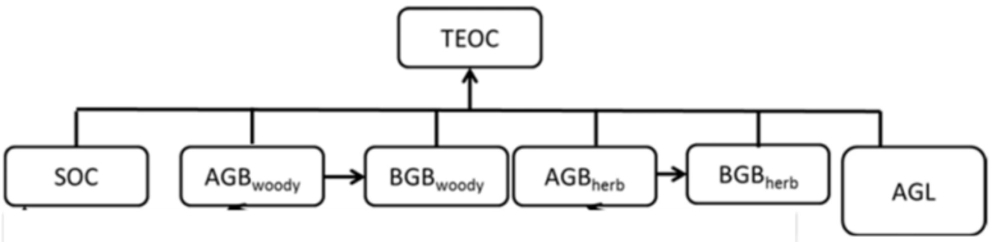


Figure 4.2: Summary of the individual carbon pools that will be combined to give the total ecosystem organic carbon. TEOC = Total Ecosystem Organic Carbon, SOG = Soil Organic Carbon, AGB = Above Ground Biomass, BGB = Below Ground Biomass, AGL = Above Ground Litter (which will include Dead Wood).

The error in TEOC is determined from the error in its parts, using a combination of additive and multiplicative rules. Note that since BGB is in both cases derived from AGB, they are not independent.

All carbon pools are calculated based on individual land units (LU). In essence the country is divided into a grid of 1 km x 1km to form what in GIS terminology is referred to as a raster file (Figure 4.3). The grid resolution of 1 km x 1 km is chosen for simplicity, but in fact the program is scale independent and alternative resolutions can be used. The grid used is the same projection as used by the DEFF Biodiversity Directorate and STATS SA 100m Basic Spatial Unit or BSU raster in its valuing of ecosystem services project. The BSU used a one ha grid and as such 100 grid cells from the BSU grid will fitting exactly into a single 1km X 1km grid cell as used by the NTCSA.

The total organic carbon within South Africa, or within any specific sub-region of South Africa such as a biome or province, is calculated by summing all the land units within that biome or province.

The assessment uses South Africa's nine biomes (Figure 4.4) as its key stratification. This differs from many of the IPCC approaches that use FAO based land cover classes for their methodologies. It also differs from the classes as defined by land cover maps. We use land cover in conjunction with the biomes as a second tier of stratification.

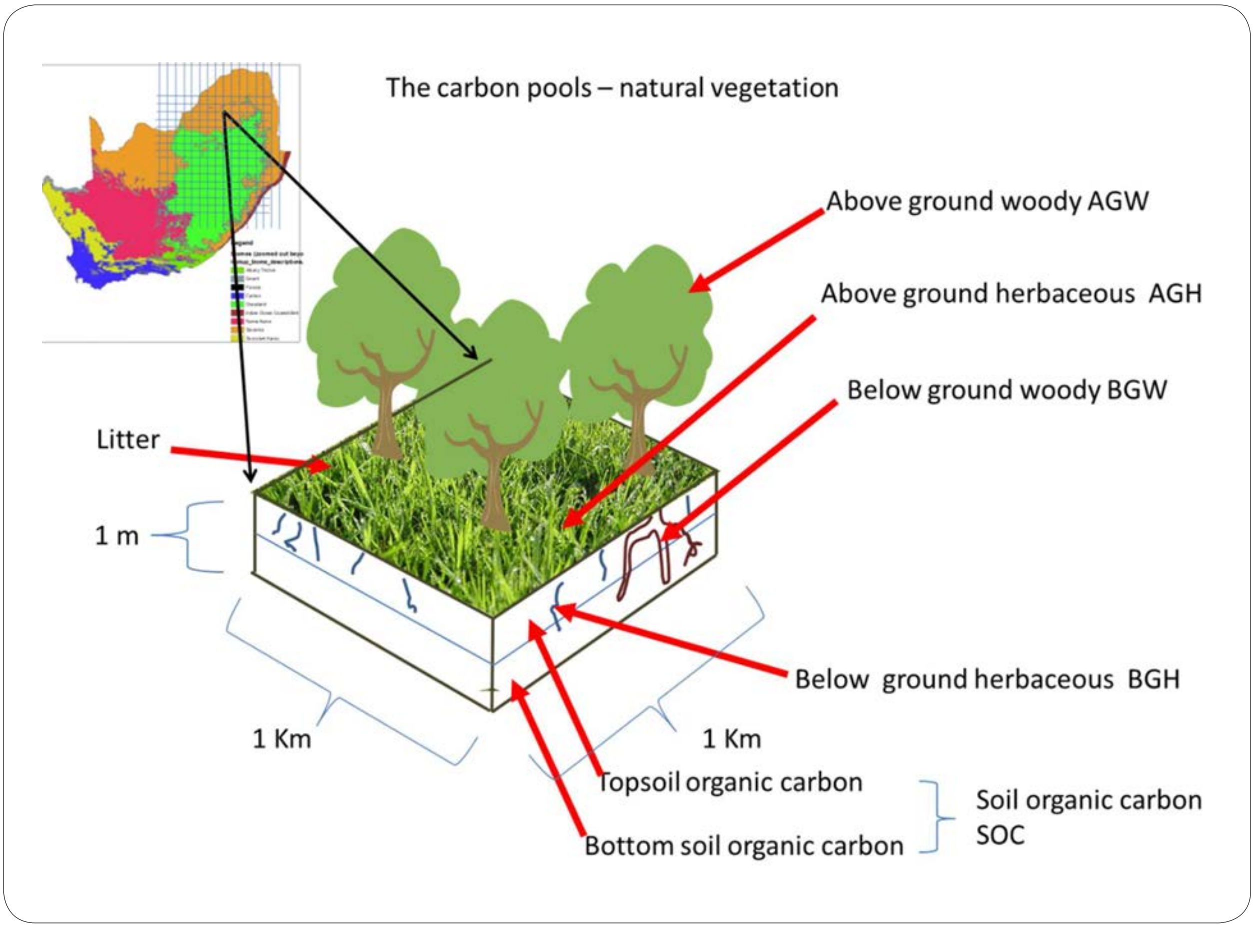


Figure 4.3: Schematic representation of carbon pools within a single land unit.

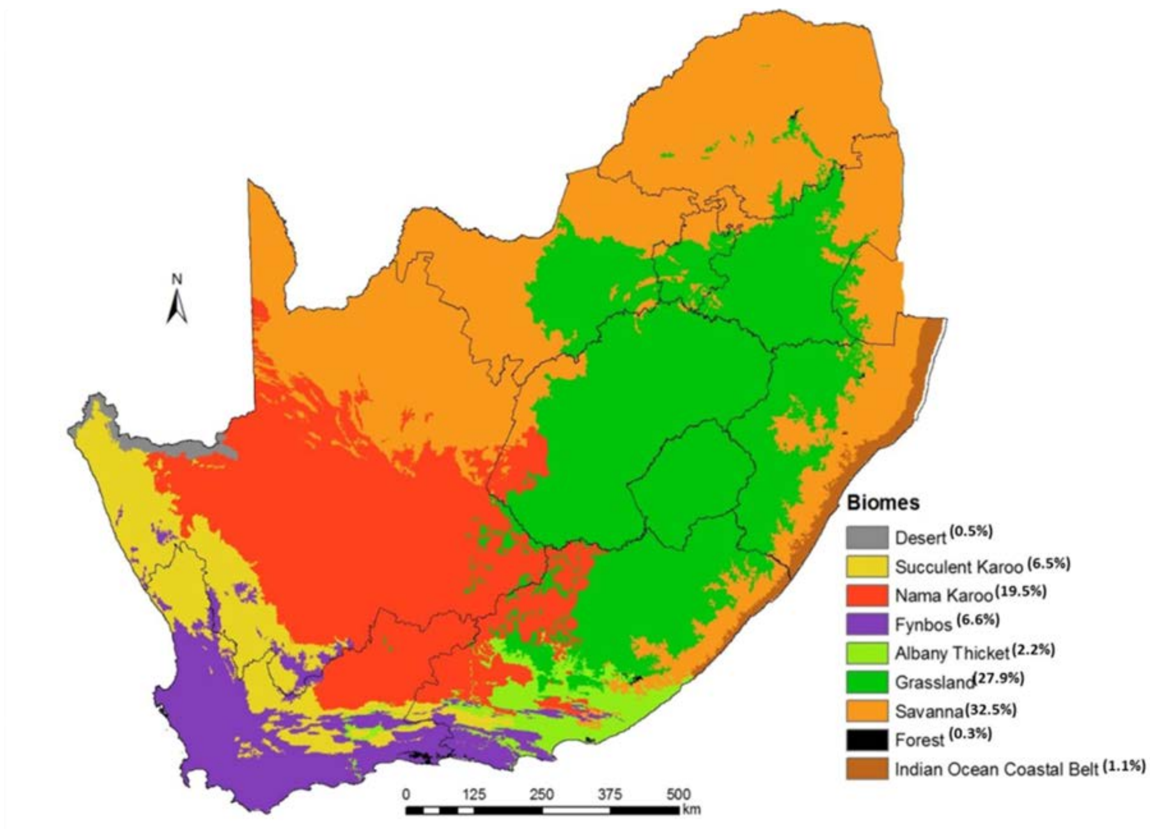
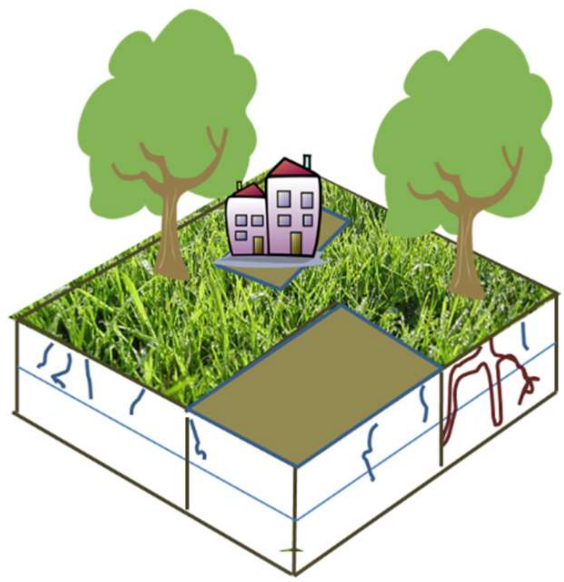


Figure 4.4: The biomes of South African based on Musina and Rutherford 2006. The latest 2018 version of the vegmap will be used for all analysis.

4.2. Total organic carbon



Three land cover products, NLC 1990, NLC 2014 and NLC 2018 were used in calculating total terrestrial carbon stocks. These were run using two different soil organic carbon estimates as discussed in Section 4.5. Results from this, are given in Table 4 to 6 and Figures 4.5 to 4.8. In addition all outputs at the 1km resolution, all input files needed to generate the results as well as the code and modelling interface are available as downloadable files from the carbon sinks atlas at https://ccis.environment.gov.za/carbon-sinks/#/ . In keeping with the findings of the initial NTCSA 2014, most of South Africa's organic carbon is to be found in the SOC pool, which accounts for over 89% of all terrestrial organic carbon (Figure 4.6). It is the grasslands and savanna systems which contain the largest share of this carbon, accounting for approximately

1/3 of the national total carbon stock each (Figure 4.7). Deserts, due to their aridity and small spatial area, have the smallest carbon stock of all biomes, with indigenous closed canopy forests and azonal vegetation both having only about 1% of terrestrial carbon stocks each (Mucina and Rutherford 2006).

The suppressing increase in carbon stocks between 1990 and 2014 is due to the huge change in areas mapped as bare land in 1990 versus 2014, as well as the decline in commercial agriculture during this period. When changes of soil carbon (the largest driver of change) are investigated per land cover class (see section 7) then it is clear that substantive losses have occurred, especially within some districts.

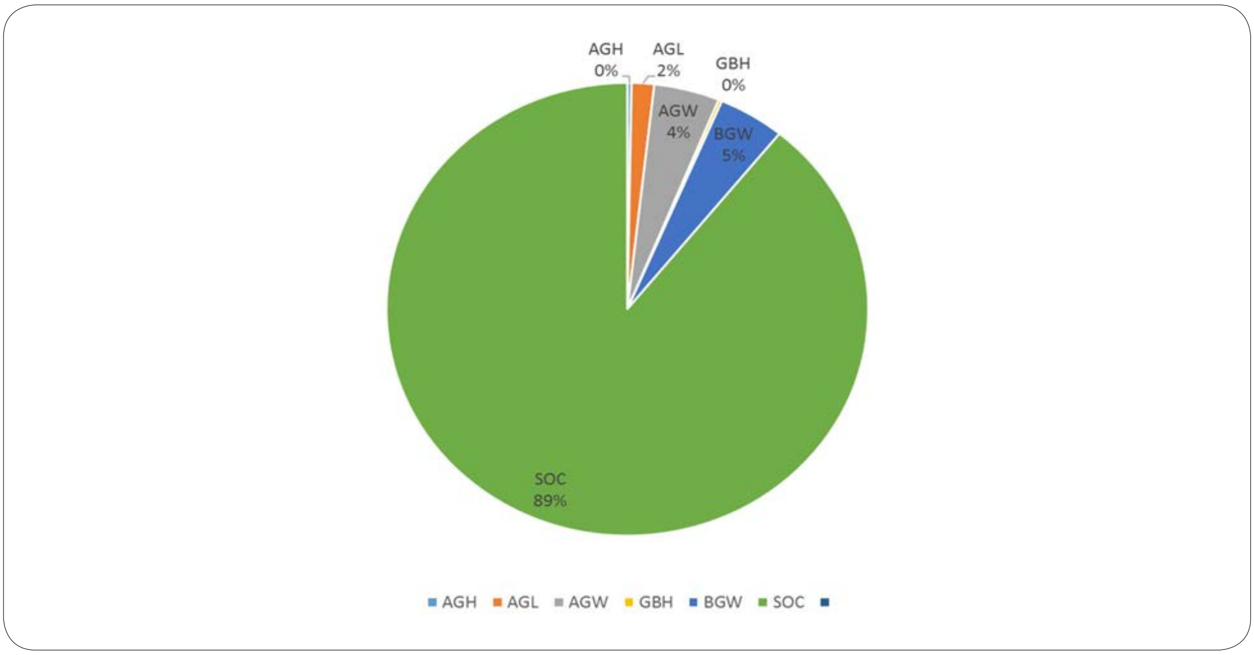


Figure 4.5: Organic carbon by carbon pool based on the ISRIC reference soil carbon data and 2018 land cover.

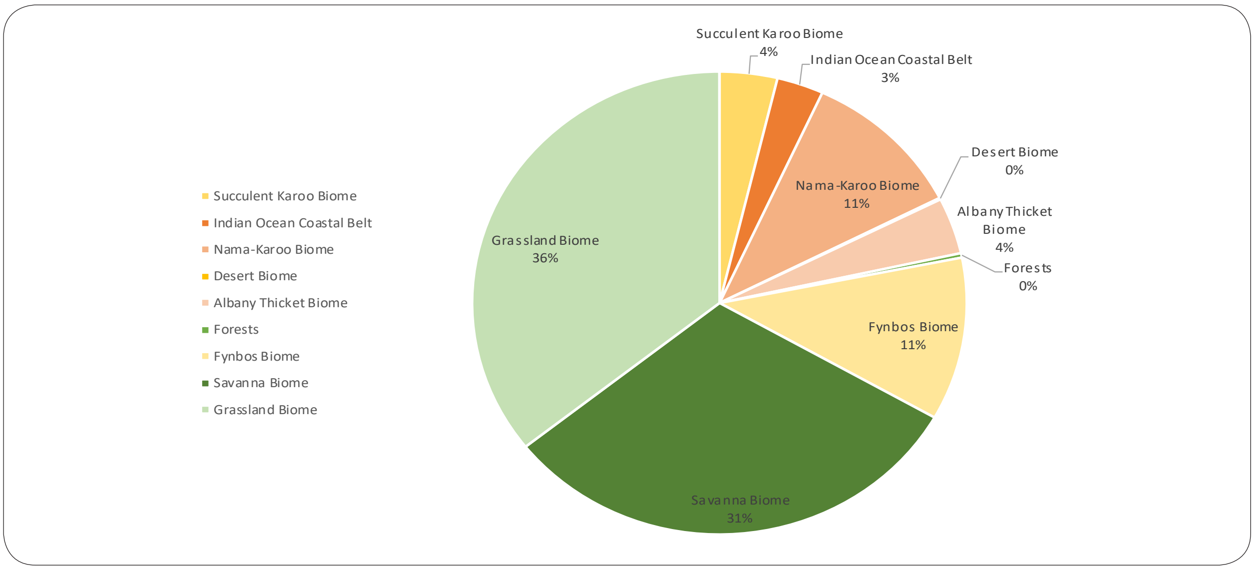


Figure 4.6: Total organic carbon split by biome using 2018 land cover data and ISRIC reference soils data.

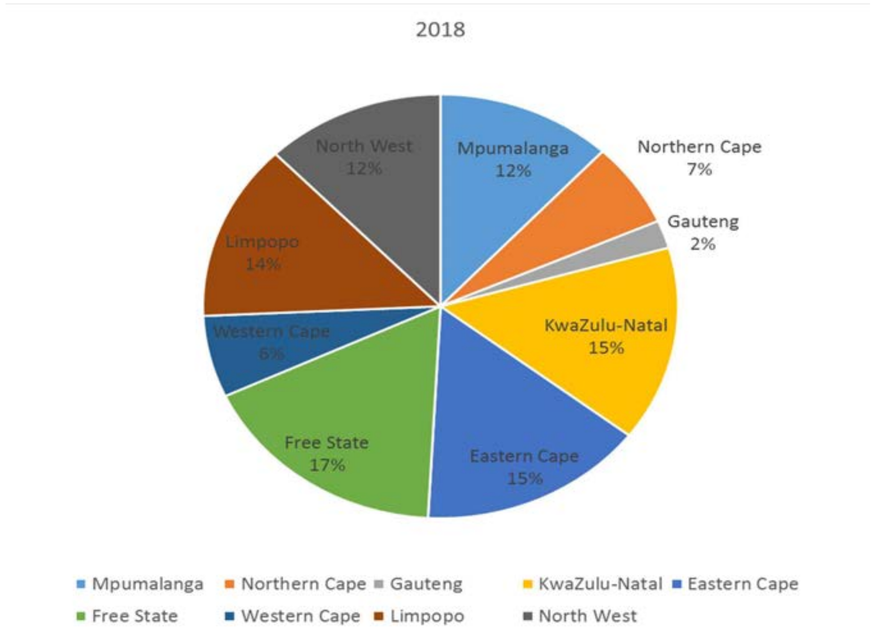


Figure 4.7: Total organic carbon split by province using 2018 land cover data and ISRIC reference soils data.

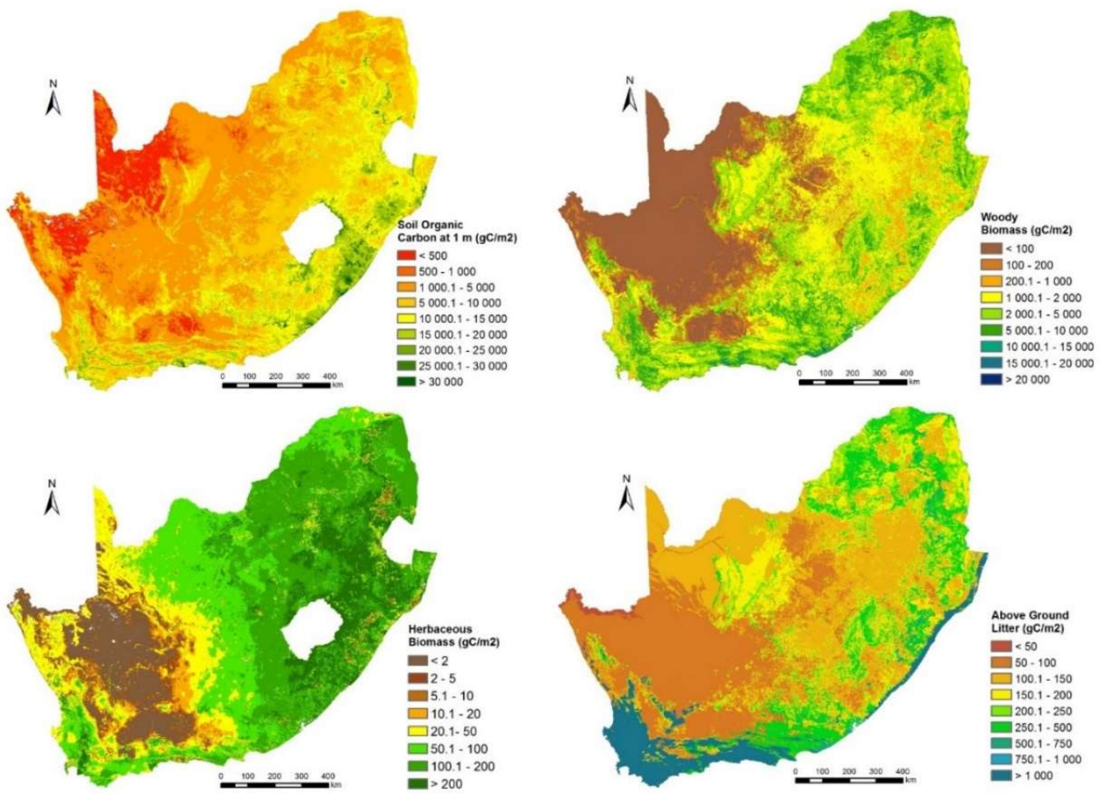


Figure 4.8: Spatial distribution of the key components of the total organic carbon.

In South Africa land cover change has been estimated to have caused a loss of 277 Tg of SOC since the beginning of the colonial period. Most of this loss has occurred prior to 1990, with losses between 1990 and 2014 being relatively small in comparison to the total loss (Table 4 – Table 6). The inclusion of the fallow land class in 2018 NLC products gives the appearance of extensive SOC loss between 2014 and 2018, but this is an incorrect interpretation of the data due to the changed methodology. This fallow land class may well date back to 1990 or earlier, with the available land cover data not being able to provide information of the rate. As such the inclusion of this class gives a better understanding of likely carbon loss, but since this class was not mapped in previous products, it is unclear as to when this loss occurred. The dynamics of soil change within fallows is poorly understood, but given sufficient time, soil carbon should revert to the reference value. The rate of this recovery is, however, likely to be slow and situation dependent.

Table 4: Total carbon by year in Tg c .

Year	AGH	AGL	AGW	BGH	BGW	Total
1990	26	137	387	21	405	9 316
2014	26	137	387	21	405	9 324
2018	26	137	387	21	405	9 258

Table 5: Carbon by carbon pool per province for 2018 in Tg c.

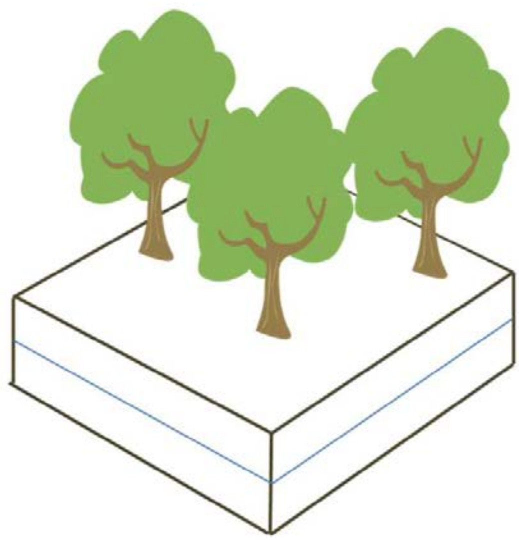
Year	AGH	AGL	AGW	BGH	BGW	Total
Albany Thicket	0.5	5.1	20.0	0.4	26.4	357
Desert	0.0	0.0	0.0	0.0	0.1	11
Forests	0.0	0.6	2.6	0.0	0.8	29
Fynbos	1.6	55.8	49.3	1.1	63.0	1048
Grassland	11.9	25.7	129.5	9.1	93.9	3317
Indian Ocean Coastal Belt	0.4	8.9	15.9	0.4	4.2	292
Nama-Karoo	1.3	8.0	22.5	1.1	42.7	1002
Savanna	9.7	33.9	159.9	8.5	160.3	2844
Succulent Karoo	0.4	4.3	13.8	0.3	27.3	358

Table 6: Carbon by carbon pool per province for 2018 in Tg c.

Year	AGH	AGL	AGW	BGH	BGW	Total
Eastern Cape	4	23	89	4	88	2041
Free State	4	7	24	3	30	925
Gauteng	1	1	6	0	4	139
KwaZulu-Natal	4	15	63	3	22	1436
Mpumalanga	3	6	32	2	18	872
Northern Cape	2	18	32	2	61	1234
Limpopo	3	12	68	3	83	1022
North West	3	7	22	2	27	472
Western Cape	2	48	51	1	71	1118

4.3. The above ground woody carbon pool

The above ground woody estimate is based on a full national coverage of satellite based woody vegetation estimates (Figure 4.8. and 4.9.). It used a 2015 satellite imagery dataset, making it comparable with the 2015 land cover data. A 2018 dataset is also available making it comparable with the 2018 data. Results are available as downloadable files from the carbon skinks atlas at https://ccis.environment.gov.za/carbon-sinks/#/. Above Ground Woody Biomass (AGB woody) is the total dry biomass of woody plants above 1m height and is expressed in tonnes per hectare. It is converted into tonnes carbon by multiplying by the carbon content of wood, i.e. 0.48. This woody carbon ratio is relatively robust regardless of species. The product was developed through the integration of 2015 ALOS PALSAR-1 synthetic aperture radar images, SRTM30m DEM parameters (elevation, slope and aspect), LiDAR tracks, and field data of woody biomass. The LiDAR tracks were processed to derive



a canopy height model for woody vegetation above 0.5 m at 1m pixel size. A detailed LiDAR (AGB woody), product was generated at 30m pixel size using LiDAR woody cover and height products and field data. The dualpolarized (HV, HH) SAR bands and DEM parameters were modelled using the LiDAR woody aboveground biomass as reference data for calibration and validation of the final SAR woody aboveground biomass (AGB woody) map. A mean value of all the 30m pixels within the 1km grid cell is used to derive the 1km woody biomass value for each specific land unit. This approach is preferable to simply summing pixel values as it is better able to deal with some pixels being only partly aligned, and only partly contained, within the 1km grid.

Dead wood is assumed to be 10% of live wood in commercial and conservation areas, but only 2% in customary areas where it is assumed most is collected as fuel. This deadwood value is represented as a proportion of the litter layer, not the aboveground woody layer.

The method described above is known to saturate at woody densities of over about 130 t/ha. This means it is not appropriate for plantation forestry during late rotational periods and for indigenous forests. Alternative methods for these two forest types need to be considered. For the commercial forestry it is relatively easy to calculate the standing biomass of the entire forest industry based on the detailed statistics supplied by Forestry SA. This gives a good national estimate, but it is difficult to break this down to location specific estimates. Methods for developing satellite based assessments of site specific growth characteristics will be discussed in Section 6.3. A large concern within the forestry industry is the potential carbon tax implication once carbon taxes are implemented. It must be emphasized that current data is not of sufficient resolution to be used for this purpose.

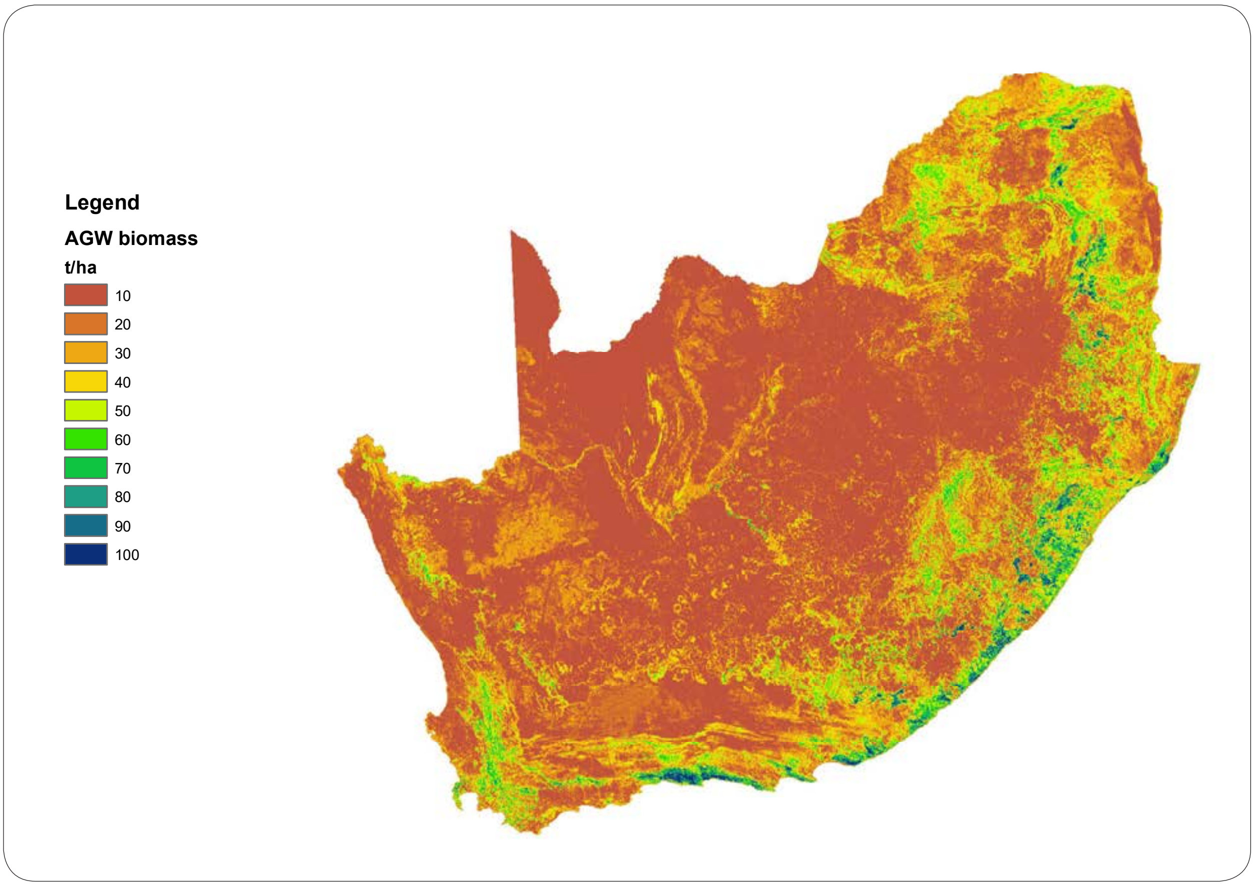


Figure 4.9: 2015 estimate of national tree biomass. Note plantations and indigenous forests are likely to be under-estimates. A mask was also applied to limit high tree biomass in arid hilly areas (see Figure 4.8).

Arid areas with a hilly terrain were found to have an over-estimate of woody biomass, and this was masked out during final calculations.

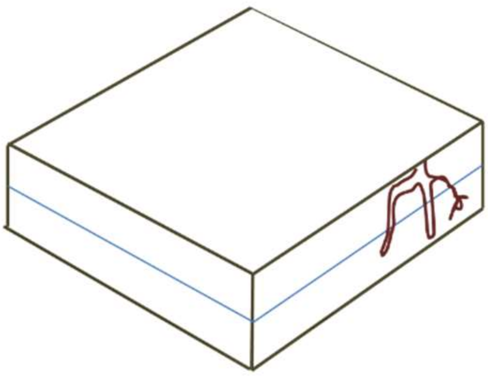
The above method is also poor at determining tree densities within urban areas as the houses induce miscalculations in canopy heights as derived from satellite based radar data. The approach as used in the NTCSA 2014 will be used as a default for urban areas due to a current lack of better data.

AGBurban = FAPARannual mean * 5000 [gC/m^2] (the value of the multiplier will be adjusted to match estimates for the urban areas which have been surveyed, e.g. Johannesburg and eThekweni.)

BGBurban = 0.5 AGBurban (assumes a mix of trees and herbaceous)

4.4. The below ground woody carbon pool

Below ground woody carbon pools will be based on above ground woody carbon stocks with corrections for mean annual precipitation as per the equations below. The Schulze 2007 data was used for precipitation. Results are shown in Figure 4.10 and as downloadable files from the carbon sinks atlas at https://ccis.environment.gov.za/carbon-sinks/#/ which also contains the input files, code and modelling framework for generating the coverage.



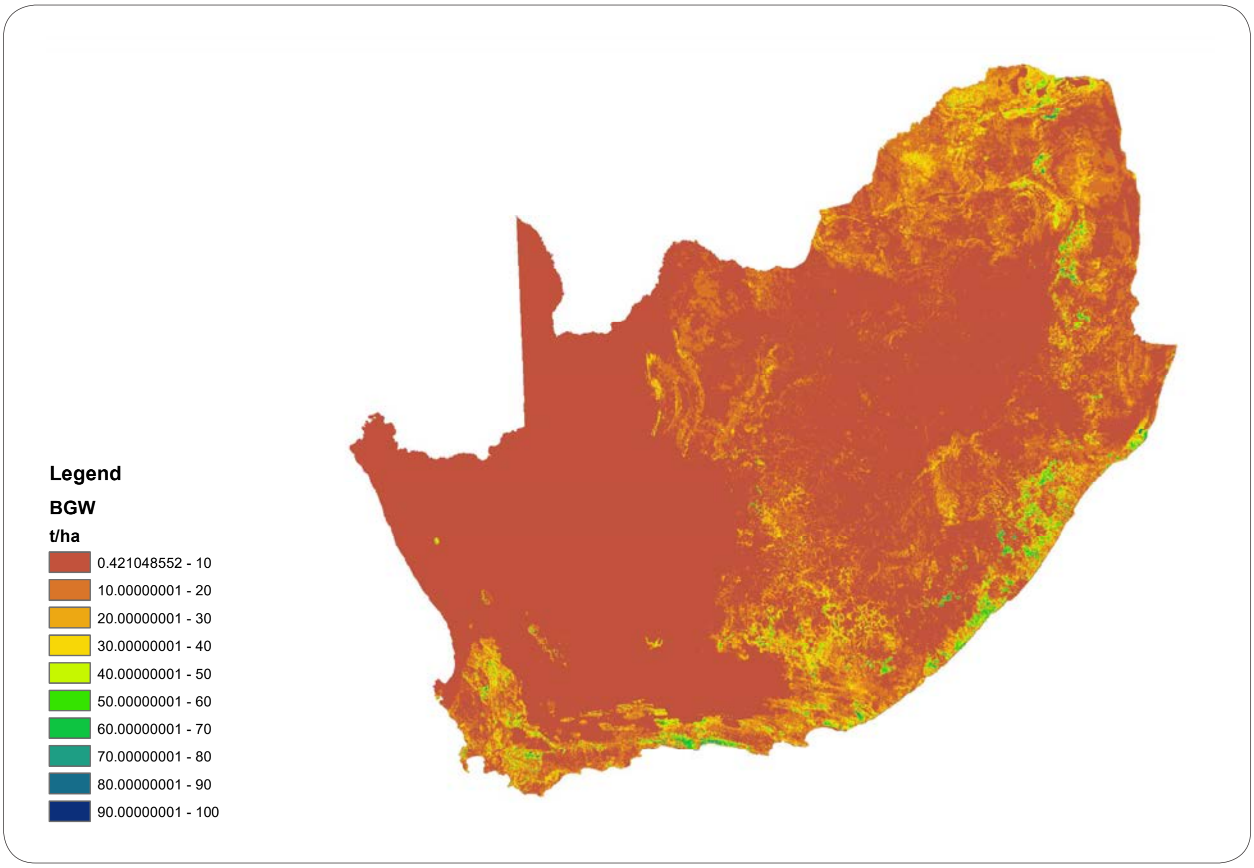


Figure 4.10: Estimates of below ground woody biomass

For all biomes, BGBwoody is a function of mean annual rainfall (MAP).

For MAP>800 BGBwoody=0.25AGBwoody

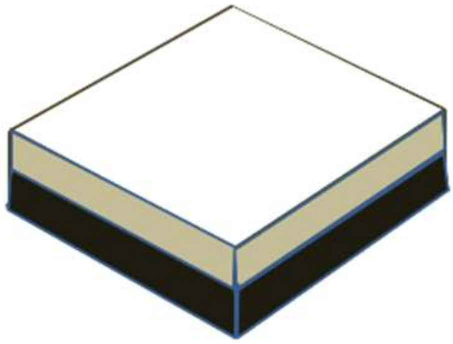
300< MAP<800 BGBwoody= -0.0035AGBwoody+3.05

MAP<300 BGBwoody=2.0*AGBwoody

4.5. The Soil Organic Carbon Pool

A comprehensive review was undertaken of available national level soil organic carbon (SOC) data (see Appendix 4). From this, two products were identified that could potentially fulfil the requirements of the NTCSA 2020. These were the ISRIC World Soils Information's (ISRIC) world soils database and a database prepared by Schulze and Schütte 2018 when they mapped areas of high organic soil for the country. The products used substantively different methods, and each had advantages and disadvantages.

The undisturbed baseline soil organic carbon expected in the natural vegetation was calculated using both the ISRIC world soils database as well as a 1km grid derived from Schulze and Schütte 2018. The ISRIC data is available at 1 km and 250 m resolution and is an improved and updated version of the AfSIS database used in the initial 2014 NTCSA. The 250m ISRIC data was re-projected and re-sampled to the NTCSA 1km grid. The Schulze and Schütte 2018 data was projected, rasterized using a 50m grid and resampled to the NTCSA grid based on mean SOC. Further corrections were necessary as described in the methods section.



The SOC data comes in the form of %SOC, which must be converted to absolute gC/m^2 using the following formulae for the topsoil and subsoil respectively. This process is demonstrated in the equation below for a two layer soil profiles, although in fact the ISRIC data is based on a 7 layer profile split into 0-5 cm 5-15 cm, 15-30cm 30-60 cm 60-100cm 100-200 cm.

SOC0-300 = ρ0-300 *0.3*%SOC/100*1 000 000

SOC300-1000 = ρ300-1000 *0.7*%SOC/100*1 000 000

SOC to 1 m = SOC0-300+SOC300-1000

ρ is the soil bulk density (Mg/m^3)

Loss of soil carbon due to agricultural and other land transformations (Figure 4.11 and 4.12) was based on land cover data, using National Land Cover (NLC) 1990, 2014 and 2018 data. Look up tables based on best available South African data (see Appendix 4 and available as an Excel file database) was used to determine the soil carbon loss. It used a stratification of the country based on vegetation type, type of land cover change and rainfall (see Figure A4.1). The 2018 NLC includes a class "fallow" not used in the 1990 and 2014 land cover and estimates of likely soil change for this class were also defined. This methodology is described in further detail below:

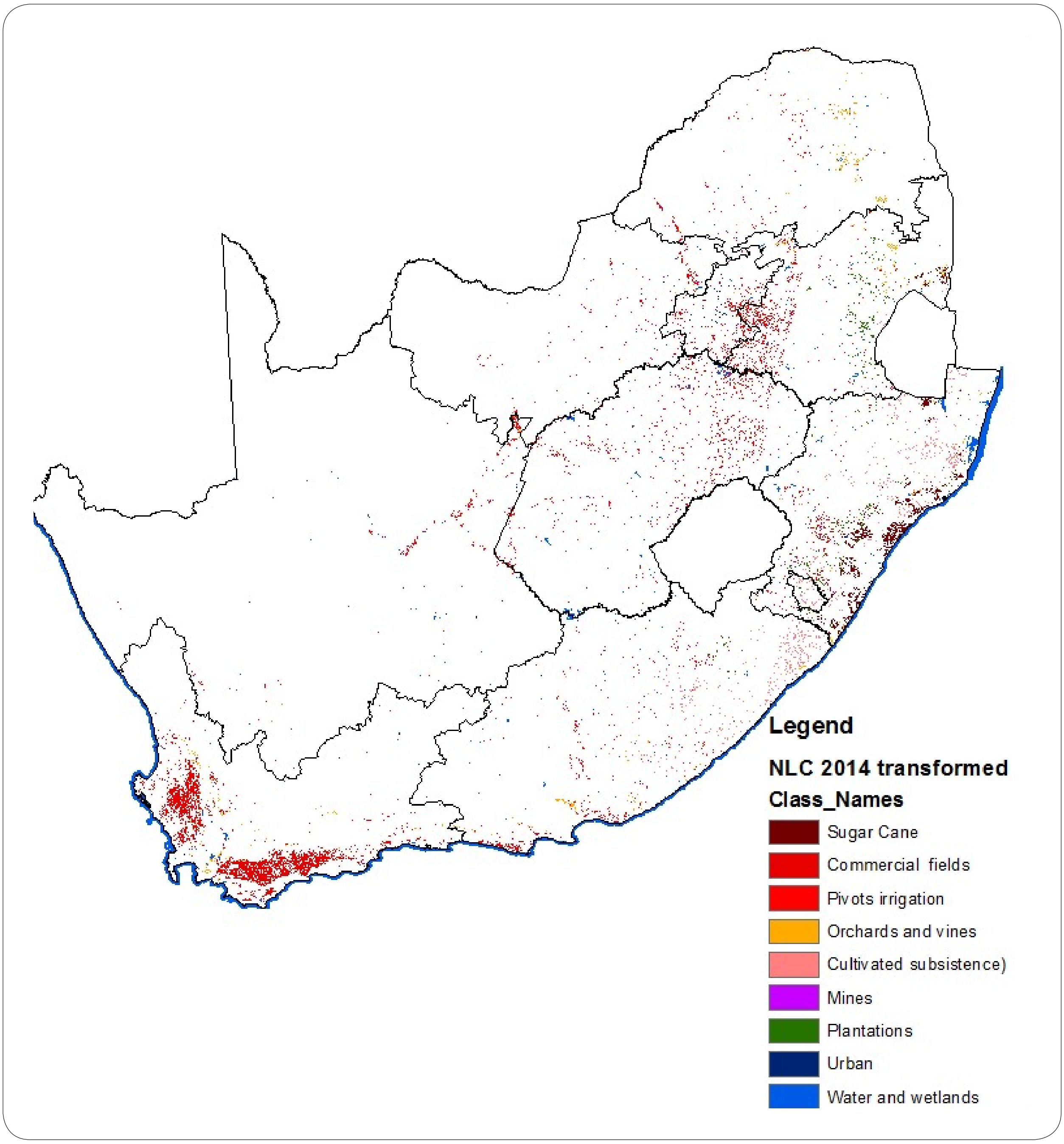


Figure 4.11: Land transformation classes (from NLC 2014) that will be considered to have had a loss of SOC as a consequence of land use change.

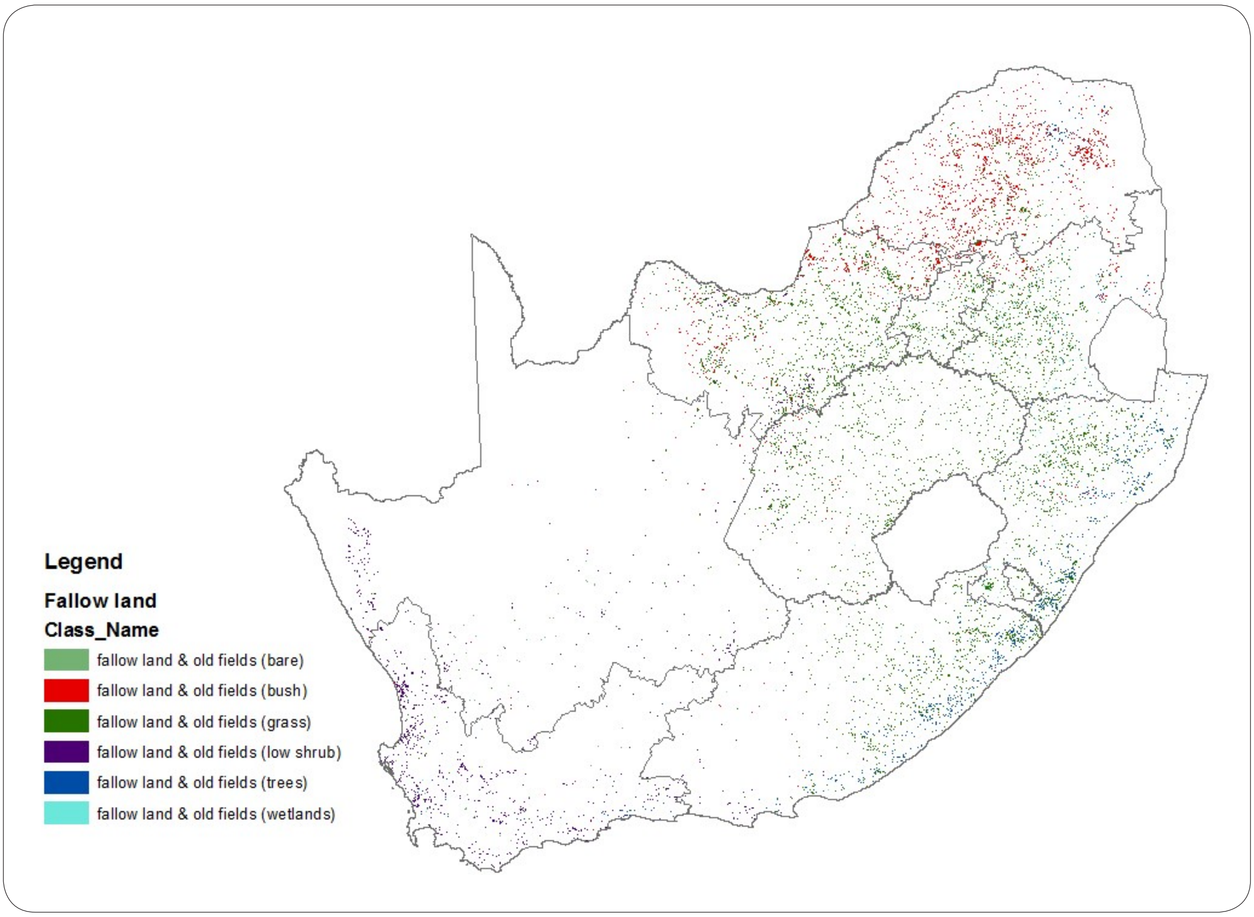


Figure 4.12: Fallow land as given in NLC 2018. Note, this widespread class was mostly mapped as natural vegetation in previous land cover products.

Estimating and monitoring changes in soil organic carbon (SOC) over time.

The soil organic carbon (SOC) pool is the principle carbon pool in almost all South African ecosystems (NTCSA 2014), accounting for an estimated 89% of the country's total terrestrial carbon stock. This is important to understanding its magnitude, determinants and how land-use options either lead to increases or decreases over time.

To understand the magnitude of SOC in an intact, non-disturbed state, the ISRIC dataset adopted in this study, is based on a contemporary statistical model that predicts the spatial distribution of soil carbon based on an extensive set of South Africa soil pit data linked to a set of co-variates, including slope, aspect, temperature and rainfall. The methodology is viewed as world class and luckily South Africa has a relatively large set of soil data for calibration.

To estimate the likely impact of change in land-use on SOC, this study has significantly expanded the initial review undertaken during the NTCSA 2014. Particular focus has been paid to how cultivation and land degradation (as represented by bare and eroded land cover classes) may impact SOC under different climatic and soil conditions. For a particular land-use class in the NLC 2018 (for example dryland cultivation) a general SOC change factor was applied to the ISRIC baseline data. This factor was determined based on South African specific data if available or IPCC guidelines when no local data was available. The review and adopted SOC change factors can be found in Appendix 4 or the spreadsheet that accompanies this report.

These improvements and moving to an IPCC Tier 3 level based on local carbon stock and change estimates is a substantive improvement on previous estimates, but the current process still has limitations. These are not necessarily limited by scientific understanding, but by the availability of required input datasets and resources as illustrated in the three South African contexts: croplands, rangelands and urban areas discussed in greater detail below.

Croplands

The conventional ploughing and turnover over of soils leads to the release of sequestered carbon into the atmosphere. The general "rule of thumb" based on global meta-analysis and reviews by the IPCC (2006) is that conventional ploughing leads to the release of 50% of the SOC pool in the top 30cm of soil. This source of carbon emissions can, to a certain extent, be reversed through the adoption of the principles of conservation agriculture (CA), that is, minimal soil disturbance (no tillage), maintaining organic cover year round, and planting a variety of commercial and cover crops.

Estimating both the initial release of soil carbon and potential carbon sequestration following the adoption of CA are dependent on understanding a number of factors. To understand the magnitude of the initial release, data is required on soil type, soil depth, ploughing method and potential additional of organic inputs. To estimate the potential impact of CA, an understanding of the soil type, soil depth, tillage type, crop types and planting and management regimes is required. Whereas the general crop planted in each field is known in limited areas, for example, the Western Cape, there is no national scale understanding of the type of crop planted in each field as well as planting and tillage regimes. It is therefore neither possible to estimate the current impact of CA on SOC in South Africa, nor to track it over time, especially in a spatially explicit manner. Whereas the model could be expanded in future to include these processes, the principle limiting factor is available input data, especially records that are updated on a regular basis to allow the impact of CA to be tracked over time.

Rangelands

Due to their relative extent, the majority of South Africa' terrestrial carbon stock is located below ground in the form of SOC in open grassland and savanna ecosystems (NTCSA 2014). In a similar manner to croplands, the ISRIC dataset provides a robust estimate of carbon stocks in an intact, non-disturbed state.

In terms of understanding the impact of disturbance on SOC in rangelands, the Mararakanye and Le Roux (2011) map of gully erosion shows areas where it can be safely assumed that the whole top soil layer and associated SOC have been removed. The NLC products also identify areas of extreme degradation as given by erosion and bare land classes. It is, however, known that extensive degradation of natural vegetation that takes place is not mapped by the land cover products. Attempting to map this land degradation in South Africa has proved challenging and at present there is no available product to show the extent of this degradation. Aboveground biomass and primary production estimates using satellite based remote sensing have found that impacts from rainfall variability mask impacts from land degradation (Wessels *et al.* 2009). Von Maltitz *et al.* (2018) has shown that the global indicators for land production as recommended by the UNCCD for monitoring land degradation neutrality (LDN) do not pick up rangeland degradation in the South African context. Certain proxies have been proposed as indicators of changes in soil carbon, for example, basal cover, but these remain to be tested and mapped at a significant scale.

In addition to mapping changes in soil carbon, greater knowledge is required of each driver of SOC and how they interact, for example, grazing and fire. Whereas intense overgrazing in dry periods can impact basal cover and soil carbon over time, changes in grazing intensity within a typical commercial management range, has little impact on soil carbon over time. Further research is required on the relationship between SOC and grazing and fire regimes in a South African context to understand potential additional measures that will deliver a real climate change mitigation benefit.

Lastly, the avoided degradation of grasslands has been suggested as a potential mitigation activity within the country. In a similar manner to "traditional REDD+"

focussed on forests, halting and reducing the degradation of rangelands is at least 10 times more efficient than allowing them to be degraded and then implementing restoration measures thereafter (IPBES 2018). However, significant research is required to develop baseline scenarios and reference levels, before such projects can be realised.

Urban areas

The IPCC 2019 guidance on National GHG Inventories provides a range of estimates of changes in SOC following conversion to settlements. Whereas it is assumed that 20% of SOC is released from areas under hard surfaces (e.g. paved, roads, buildings), is also assumed that there is a 14% - 17% increase in areas converted to lawns, parks and so forth. As data on the exact ratio of hard surfaces to gardens, parks and golf courses is not known in South African urban areas, it has been conservatively assumed that it is approximately a 50/50 relationship and that the net impact of urban areas on SOC is zero. However, this is an area that requires future research.

Approach used to deal with land transformation

A statistical approach was taken to calculate land cover change within a land unit. The area of the land unit undergoing a change from one land class to another was computed for each period for which there is a NLC product (Figure 4.13).

Inclusion of a management factor allows corrections to soil carbon loss to be made based on how the cropland is managed (this has been set to 1 for all runs due to a lack of management specific data). Practices such as no-till agriculture lead to less carbon loss than found through

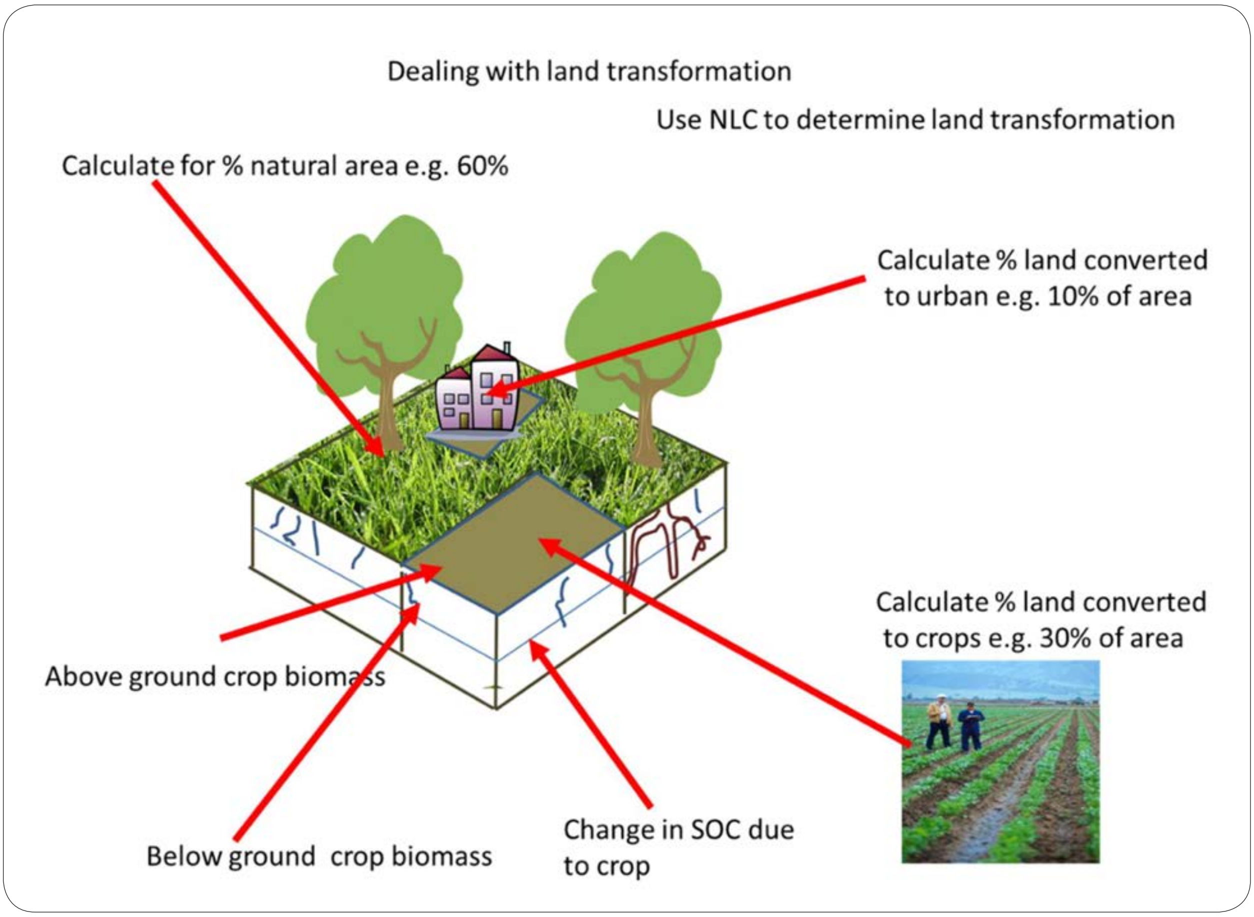


Figure 4.13: Dealing with land transformation within a land unit. Land transformation from the natural vegetation to a different land cover class will be determined from the national land cover maps.

conventional tillage and may over time help regain carbon in soil that has previously undergone conventional tillage. Provision is made for management interventions to reduce carbon losses, though it is recognized that presently there is no ability to spatially track the management practices on individual parcels of land. It will be useful for municipal scale analysis where individual farmers can be allocated management practices based on their farming methods.

ISRIC and Schulze data showed similar trends in SOC across the country, however at the level of individual land parcels the values between these two products varied significantly (Table 7 and 8 and Figures 4.14 and 4.15). As can be seen from the data, the ISRIC values tended to be higher for the moist areas on the country, whilst the Schulze data was higher for the arid areas. Overall, the Schulze data was about 40% lower than the ISRIC data.

Table 7: A comparison between the ISRIC and Schulze SOC data per province and per biome in TgC.

Province	ISRIC	Schulze	Biome	ISRIC	Schulze
Gauteng	1413	883	Forests	254	71
Free State	8700	5226	Grassland Biome	31488	15501
Eastern Cape	19093	8617	Savanna Biome	25561	17317
Western Cape	9588	5691	Nama-Karoo Biome	9284	9943
Northern Cape	11104	13115	Desert Biome	112	291
North-West	4363	4021	Fynbos Biome	8900	4061
Mpumalanga	8559	4086	Indian OCB	2705	1547
KwaZulu-Natal	13271	6540	Succulent Karoo Biome	3152	3236
Limpopo	8402	5263	Albany Thicket Biome	3146	1508
Total	84601	53475	Total	84601	53475

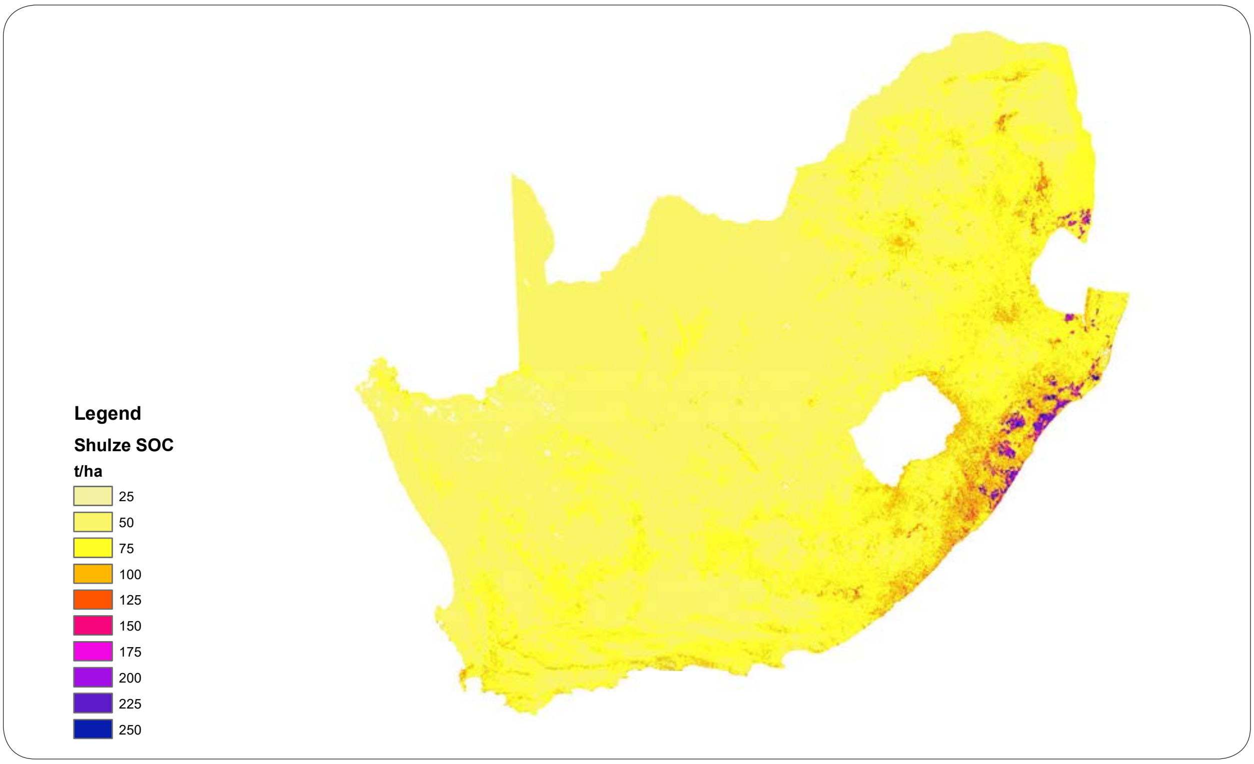


Figure 4.14: Topsoil (to 30cm) carbon in t/ha using from the Schulze and Schütte 2018 data after including the Desmid data-filling.

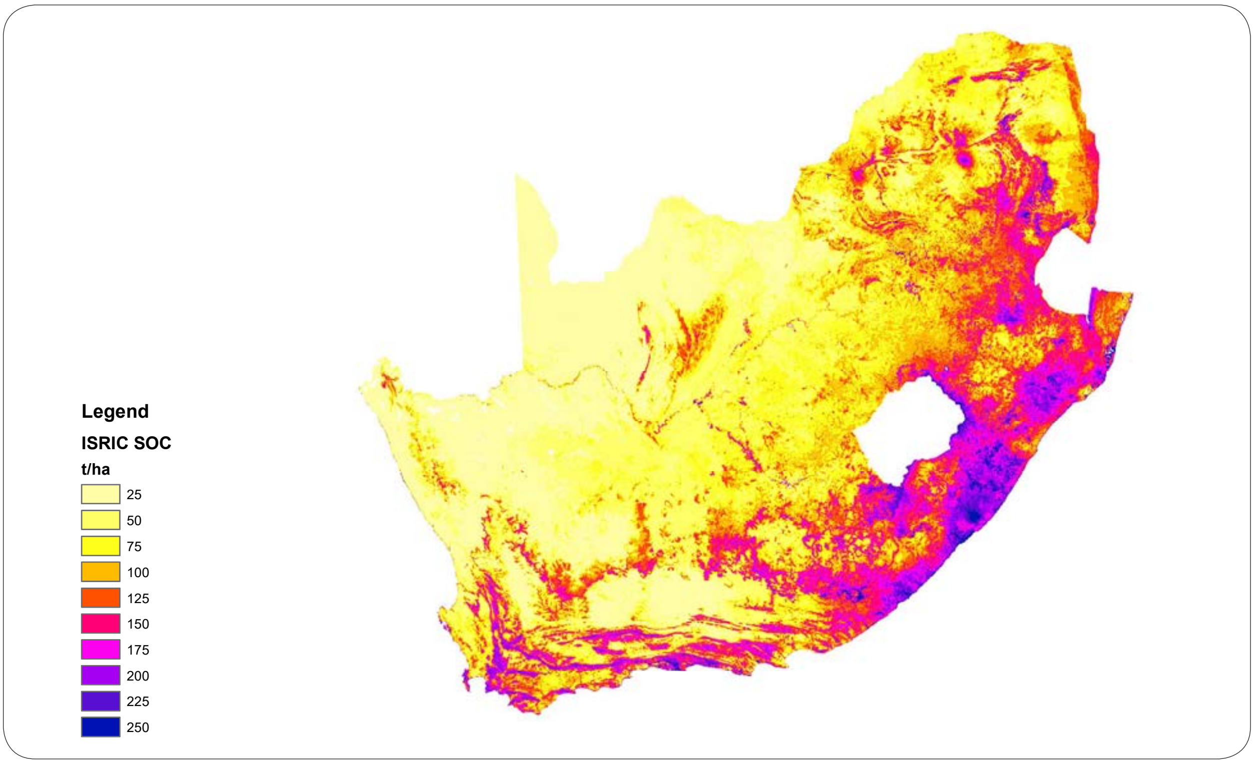


Figure 4.15: Topsoil (to 30cm) carbon from the ISRIC data.

Table 8: Estimates of total carbon loss compared to a natural reference, per land use and per district by 2018 in Tg.

Province	Commercial Agriculture	Pivot Agriculture	Subsistence Agriculture	Bare degraded	Fallow	Other
Alfred Nzo	0.045	0.006	0.423	0.046	0.273	0.000
Amajuba	0.089	0.010	0.027	0.010	0.082	0.000
Amathole	0.083	0.002	0.368	0.022	0.370	0.003
Bojanala	0.156	0.026	0.071	0.021	0.214	0.003
Buffalo City	0.044	0.000	0.051	0.004	0.036	0.003
Cacadu	0.308	0.059	0.003	0.148	0.098	0.035
Cape Winelands	0.121	0.003	0.000	0.234	0.020	0.006
Capricorn	0.035	0.023	0.149	0.029	0.182	0.002
Central Karoo	0.007	0.001	0.000	0.155	0.008	0.000
Chris Hani	0.132	0.013	0.301	0.126	0.145	0.000
City of Cape Town	0.037	0.000	0.000	0.009	0.006	0.001
City of Johannesburg	0.008	0.001	0.000	0.003	0.017	0.000
City of Tshwane	0.109	0.006	0.001	0.009	0.056	0.001
Dr Kenneth Kaunda	0.519	0.006	0.000	0.002	0.145	0.000
Dr Ruth Segomotsi Mompati	0.354	0.014	0.013	0.007	0.162	0.000
Eden	0.288	0.027	0.000	0.147	0.048	0.001
Ehlanzeni	0.060	0.005	0.054	0.048	0.116	0.169
Ekurhuleni	0.041	0.002	0.004	0.002	0.021	0.000
eThekwini	0.001	0.000	0.015	0.003	0.055	0.044
Fezile Dabi	1.045	0.013	0.000	0.009	0.081	0.000
Frances Baard	0.019	0.038	0.000	0.004	0.010	0.004
Gert Sibande	1.356	0.031	0.039	0.030	0.434	0.001
Harry Gwala	0.185	0.048	0.162	0.013	0.156	0.016
iLembe	0.000	0.000	0.070	0.004	0.028	0.208
Joe Gqabi	0.187	0.018	0.108	0.268	0.076	0.000
John Taolo Gaetsewe	0.003	0.000	0.000	0.010	0.013	0.000
Lejweleputswa	1.270	0.028	0.000	0.016	0.123	0.000
Mangaung	0.224	0.003	0.037	0.024	0.028	0.000

Province	Commercial Agriculture	Pivot Agriculture	Subsistence Agriculture	Bare degraded	Fallow	Other
Mopani	0.031	0.003	0.058	0.016	0.107	0.035
Namakwa	0.049	0.000	0.001	0.535	0.038	0.002
Nelson Mandela Bay	0.018	0.001	0.000	0.003	0.010	0.000
Ngaka Modiri Molema	0.513	0.007	0.071	0.009	0.147	0.000
Nkangala	0.592	0.022	0.022	0.022	0.244	0.001
O.R.Tambo	0.001	0.000	0.490	0.028	0.368	0.006
Overberg	0.401	0.003	0.000	0.055	0.015	0.009
Pixley ka Seme	0.023	0.044	0.000	0.100	0.042	0.002
Sedibeng	0.185	0.007	0.000	0.003	0.038	0.000
Sekhukhune	0.051	0.025	0.157	0.087	0.089	0.009
Thabo Mofutsanyane	1.808	0.025	0.002	0.104	0.224	0.001
Ugu	0.003	0.000	0.130	0.010	0.227	0.198
Umgungundlovu	0.138	0.032	0.041	0.007	0.100	0.207
Umkhanyakude	0.002	0.000	0.194	0.022	0.095	0.072
Umzinyathi	0.056	0.009	0.122	0.043	0.135	0.020
Uthukela	0.104	0.040	0.103	0.035	0.113	0.001
Uthungulu	0.002	0.000	0.169	0.020	0.123	0.209
Vhembe	0.022	0.008	0.059	0.016	0.101	0.019
Waterberg	0.504	0.052	0.051	0.040	0.328	0.002
West Coast	0.383	0.000	0.000	0.081	0.018	0.002
West Rand	0.116	0.005	0.000	0.004	0.045	0.001
Xhariep	0.285	0.012	0.000	0.061	0.065	0.001
Z F Mgcawu	0.002	0.001	0.000	0.079	0.006	0.026
Zululand	0.066	0.007	0.205	0.043	0.215	0.048
Total	12.083	0.686	3.774	2.826	5.896	25.264

4.6. The herb (and crop) above ground carbon pool

The above ground herbaceous layer was model as in the NTCSA 2014 as no additional data were available that would allow radical improvements to these calculations, i.e.

AGBherb = 0.5*0.45*a*(MAP-c)*(1-TCF/0.65) for TCF<0.65;

AGBherb=0 if TCF>0.65

Constant a is often referred to as the 'Rain Use Efficiency', and c is the amount of rain needed to have production in a year.

Constants a and c are both related to the topsoil sand content.

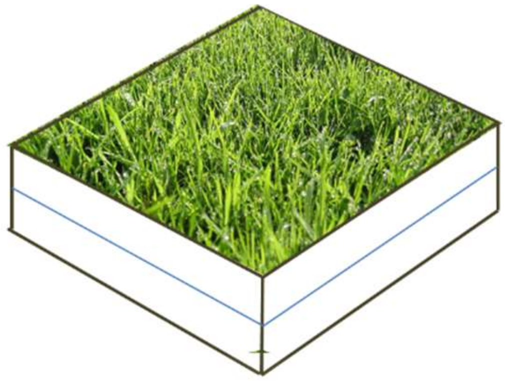
a=-0.0357*Sand+3.33857; a=0.1 if Sand%>92; a=1.1 if Sand%<64

c=328-142/a

TCF = tree cover fraction

The above ground herb layer is a very small fraction of total terrestrial organic carbon stocks. It also varies greatly between seasons depending on that season's actual rainfall, as well as the time since the last fire (particularly in the Fynbos). No attempt will be made to assess the actual herb biomass within a single growing season, rather the approach will be to model a mean herbaceous layer based on mean long term rainfall (Figure 4.8).

For crop fields the above ground herbaceous biomass was based on crop grown and the approximate biomass of the crop based on harvest factors (Table 9). Since no location specific data is available on crops grown, nor on local crop yields, the assessment is based on the most up-to-date agricultural senses data which is 2002 (with partial updates in 2007). Note, a new agricultural census is currently underway, and data from this is scheduled to become available mid-2020.



A value is assigned per crop type, by municipality for crop biomass.

SOCcultivated= 0.5*SOC0-30 + SOC30-100

TBcrop = (AGBcrop,max + BGBcrop)*0.5* crop duration/365)+TBmin

Where: TBcrop is the total of above and below ground biomass. TBmin is the year-round residue mass and AGBmax is the at harvest aboveground biomass, including yield components. Crop duration is the average period between planting and harvest for that crop, in days.

TBmin was calculated as a proportion of above ground residue, plus a proportion of below ground residue (as per Table 9).

BGBcrop is estimated as 0.2 AGBcrop , except for root crops, where BGBcrop is the root DM yield.

AGBcrop is calculated as AGB = Y * Mf / HI where Y is the yield per municipality.

A proportional approach per LU based on NLC data was used as per the SOC analysis. Results from the herb layer are given in Table 5, 6 and 6 and Figures 4.8 and 4.16. In addition all outputs at the 1km resolution, all input files needed to generate the results as well as the code and modelling interface are available as downloadable files from the Carbon Sinks Atlas at https://ccis.environment.gov.za/carbon-sinks/#/.

Table 9: The following values for agricultural crops were used to determine carbon stocks.

Crop category	Harvest index[1] (HI)	Moisture factor[2] (Mf)	Below ground fraction (BGf)	Carbon fraction (Cf)	Crop duration months (CDf)	Crop duration months (CDf)
Summer grain	0.5	0.87	0.2	0.42	8	0.5
Winter grain	0.4	0.89	0.2	0.42	6	0.5
Oilseed	0.39	0.85	0.2	0.42	8	0.5
Legume	0.85	0.85	0.2	0.42	8	0.5
Fodder crops	1	0.5	0.2	0.42	12	0.6
Sugar cane	1	0.28	0.2	0.42	12	0.6
Vegetable crops	0.5	0.2	0.2	0.42	10	0.5
Tree crops	Na	Na	0.4	0.42	12	0.7
Grape vines	na	na	0.4	0.42	12	0.7
subsistence				0.42		0.5

1 The harvest index is the proportion of grain (crop) to the total above ground dry biomass

2 This factor converts the yield to oven-dried yield. AGBcrop is calculated as AGB = Y * Mf / HI where Y is the yield per municipality.

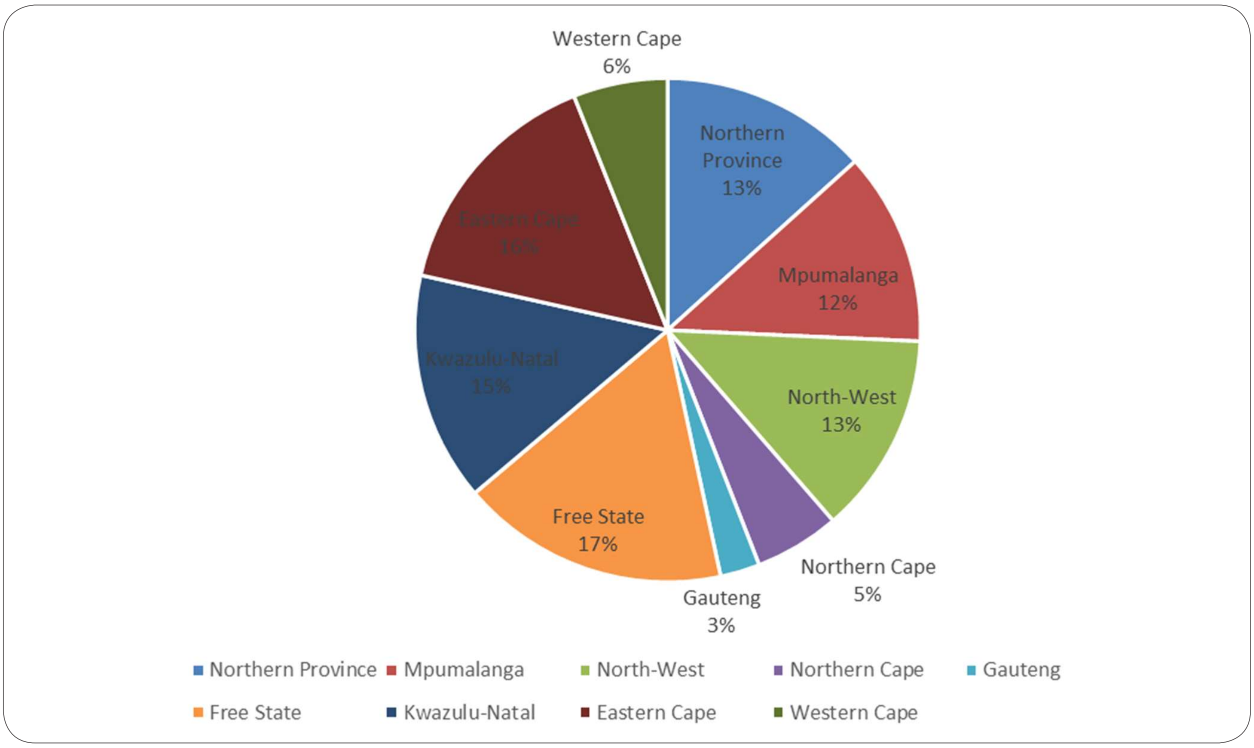
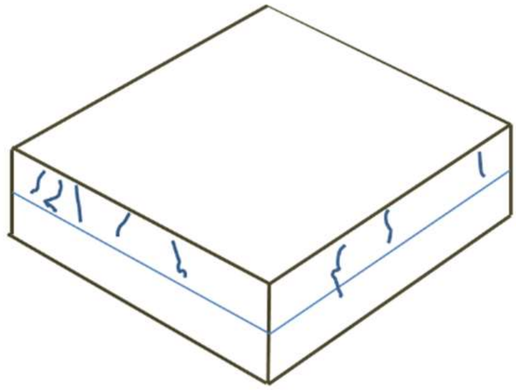


Figure 4.16: Split of AGH by province based on 2014 NLC data.

4.7. The herb (and crop) below ground carbon pool



BGBherb= AGBherb in all biomes (i.e a root:shoot ratio of 1). Some studies in moist grasslands (e.g. O' Connor 2009) have root:shoot ratios for grasses as high as 8. This is likely because the roots measured are probably not alive, but previous season's dead roots, slowly decaying (i.e. they are actually a form of belowground litter). These will not be counted as roots in order to avoid double counting, since they are typically inadvertently included in the soil organic carbon estimate – fine roots are not separated from the mineral soil before drying and crushing it. For crops the BGBherb was 0.2.

Values for 2014, as split by province, are shown in Figure 4.17. Full results are available as downloadable files from the Carbon Sinks Atlas at https://ccis.environment.gov.za/carbon-sinks/#/.

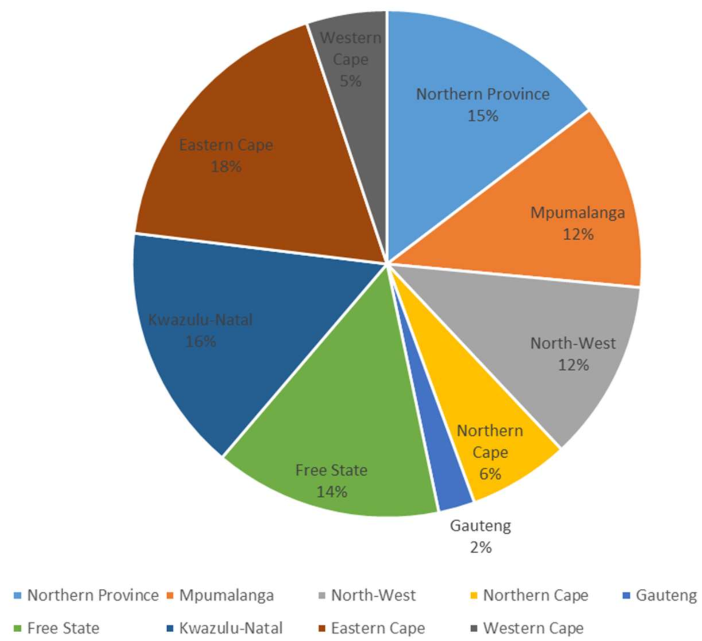


Figure 4.17: The below ground carbon pool split by province.

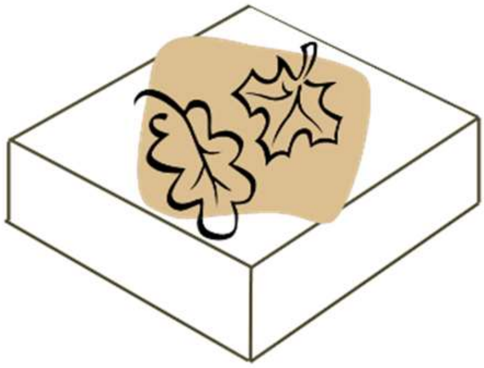
4.8. The litter carbon pool

AGL consists of downed wood, leaves and dung on the soil surface. It is generally a relatively small number, included for completeness. AGL is calculated per biome (or sub-biome, where the biome covers a wide climate range) based on a simple model including litter fall and decay rates as a function of rainfall and validated against the fuel load datasets. In addition an estimate of deadwood has been added to the litter estimates. The deadwood is calculated as 10% of standing woody biomass for non-communal areas and 2% of standing biomass in communal areas (with the assumption that fuelwood harvesting is reducing deadwood in communal areas). Full results are available as downloadable files from the Carbon Sinks Atlas at https://ccis.environment.gov.za/carbon-sinks/#/.

AGL = 90 + 22 for grasslands (from Powell (2009), old lands)

AGL = 121 + 49 gC/m^2 for savannas (from Shea *et al.* 1996)

AGL= 900 + 50 for forests (Weider and Wright 1995)



AGL= 254 + 52 for thickets (based on Powell 2009, assuming the Thicket landscape is 50% degraded)

AGL = 50 + 10 for karoo

AGL= 1500 + 150 for fynbos (van Wilgen *et al.* 1990)

AGL= 0 for desert

Values for litter split by province are shown in Figure 4.18. Full results are available as downloadable files from the Carbon Sinks Atlas at https://ccis.environment.gov.za/carbon-sinks/#/.

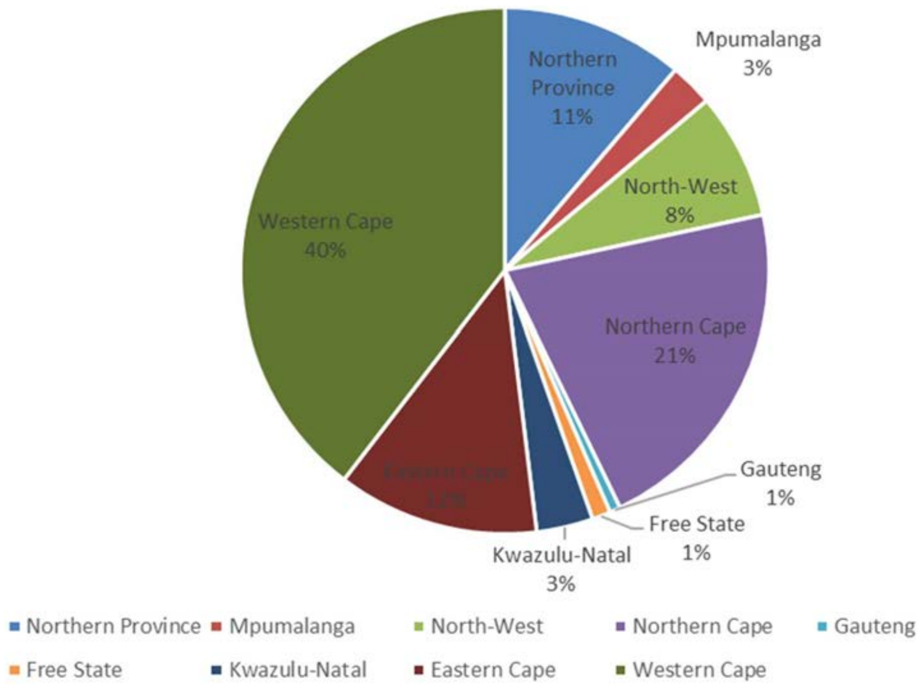


Figure 4.18: The litter carbon pool split by province.

UPDATE THE CARBON SINKS ATLAS WITH NEWLY AVAILABLE SOIL ORGANIC CARBON (SOC) INFORMATION AND DATASETS

Objectives and deliverables

To ascertain if it is possible to improve the soil organic carbon component of the Carbon Sinks Atlas through analysis of available new data sources and the ability of the Carbon Sinks Atlas to include them. New datasets from studies commissioned by DEA and other institutions will be assessed and incorporated. Further, recommendations will be made on how this can be potentially improved, into the future, including discussions on potential frameworks for soil monitoring.

Deliverable – A report on the extent to which the Carbon Sinks Atlas is able to support modelling of SOC and updated SOC maps including maps of the reductions of SOC due to land transformation.

5.1. Analysis of existing soil carbon products

An assessment was undertaken on available soil organic products for South Africa (see Appendix 5). Based on this, two products were considered for analysis in the current study, the ISRIC SoilGrids250m: Global Gridded Soil Information (Hengl *et al.* no date) (hereafter referred to as the ISRIC data) (Figure 5.1) and the Schulze and Schütte 2018, soils rich in organic carbon product (hereafter referred to as the Schultze data) (Figure 5.2). A detailed analysis is presented in Appendix 5. As pointed out in Appendix 5, these two reports use fundamentally different approaches to extrapolating soil pit and profile data to create a national product. The ISRIC uses a raster based statistical approach using machine learning. Schulze uses a polygon based approach based on the South African land type data. Both approaches used digital terrain models as a key covariate to determine terrain position.

Both datasets had to be re-projected to the BSU coordinate system. In the case if the ISRIC data, it was re-sampled from the 250m grid to the 1 km^2 BSU grid. In the case of the Schulze data, large extents of the country had missing values (Figure 5.3). This data was filled using data from Desmid (pers com 2019). However, the Desmid data did not split the profile into topsoil and subsoil, so this was done based on the mean split ratio of the entire dataset (1:1.7). The Schulze data was rasterised to 50m x 50m using the BSU coordinate system, then resampled to the 1km^2 BSU using mean values from the 50m x 50m grid.

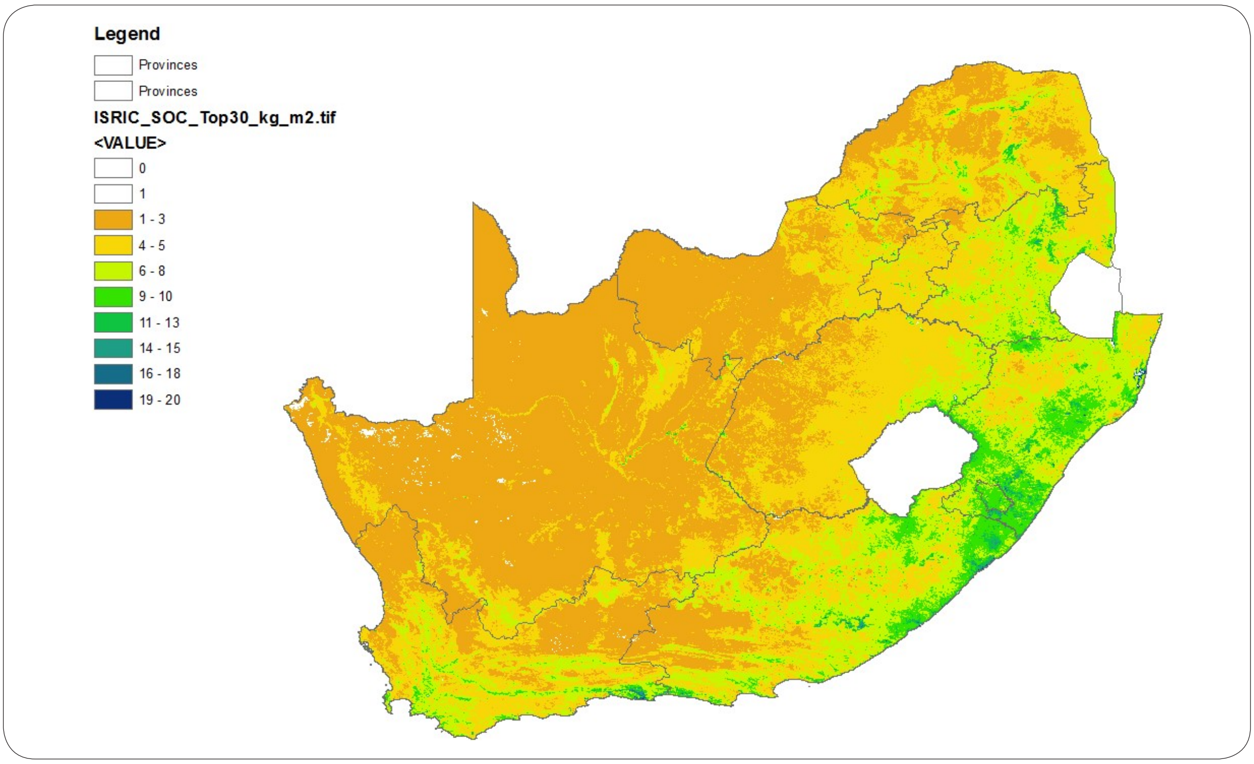


Figure 5.1: Soil organic carbon (SOC) from the top 30cm using ISRIC data. Data in original 250m x 250m raster format.

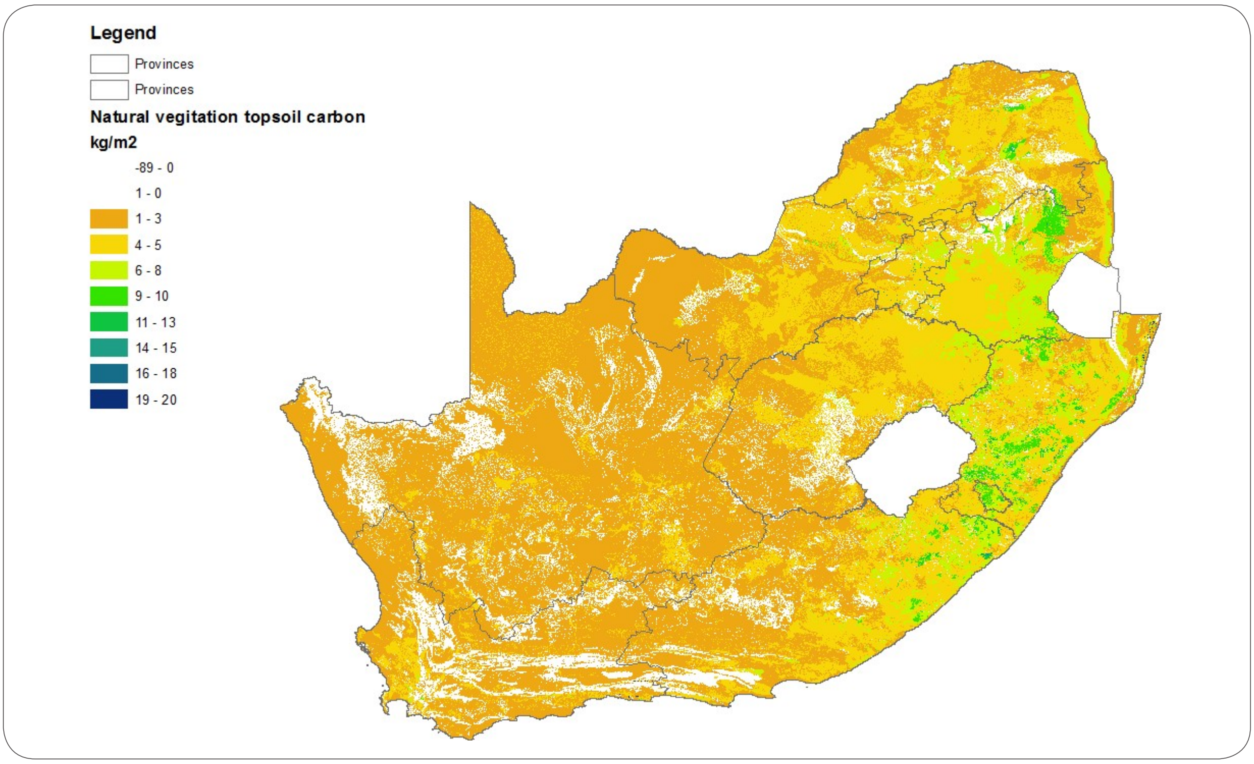


Figure 5.2: Soil organic carbon (SOC) from the top 30cm using Schulze and Schütte data. Data in original vector format.

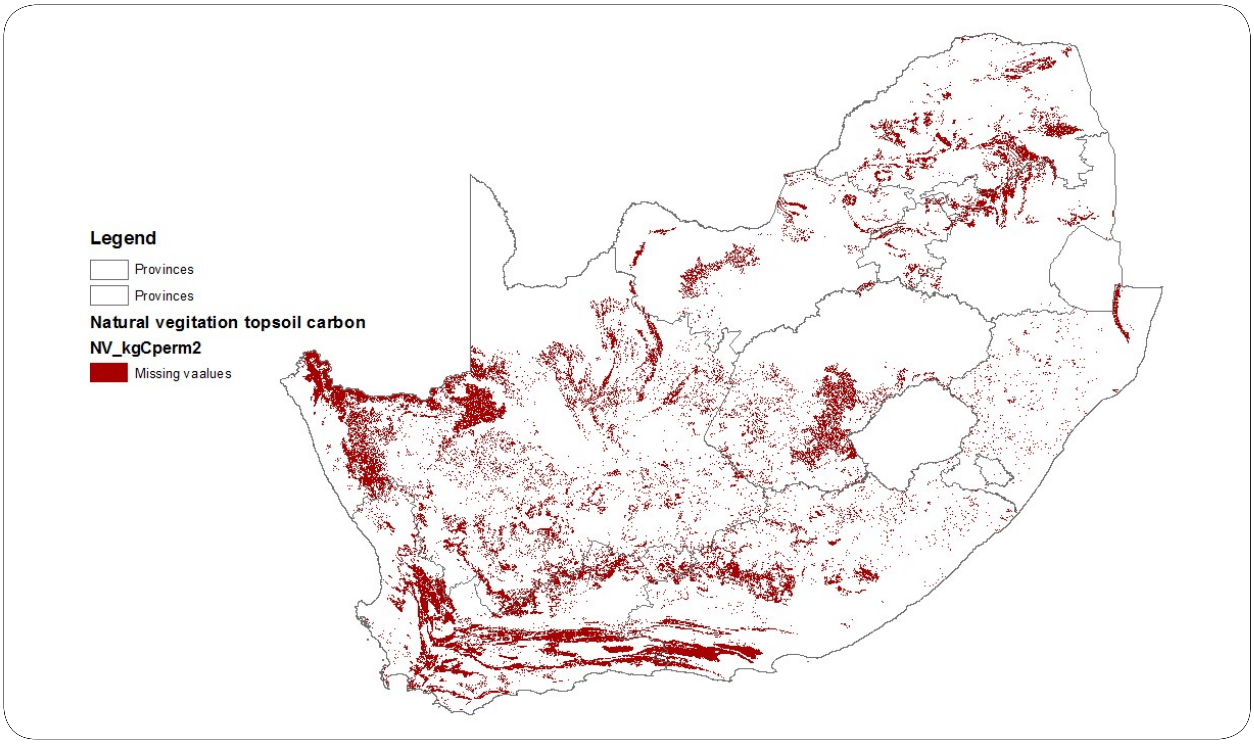


Figure 5.1: Soil organic carbon (SOC) from the top 30cm using ISRIC data. Data in original 250m x 250m raster format.

5.2. Approach to SOC change due to land use activities

The key approach used to estimate SOC loss is based on the IPCC methodology, i.e. a loss (or gain) is assumed based on the type of land use being applied. Extensive effort has been applied to ascertain the best South African specific carbon change factors. This is summarised in Appendix 4. Section 7 on baselines gives greater detail on total and rates of SOC loss.

The approach is based on the country being divided into land units of a specific resolution (1km X 1km as used currently). For each land unit, the proportion of land in each land cover class is calculated based on national land cover maps. Each land use is multiplied by its land use change factor to determine the remaining soil carbon.

A step function is applied, i.e. it is assumed all SOC is lost instantly at the time of observed land transformation. This is clearly a poor assumption as the carbon may be lost (or gained) over a 20 year or longer period. This approach has been taken for three primary reasons.

1. Keeping track of individual parcels of land (which are currently at 30m resolution) over multiple time periods is extremely complex and has huge data processing and storage requirements, which would add orders of magnitude more complexity, storage and processing requirements. Further, this would introduce huge amounts of noise in the data due to data misclassification.

2. The actual contribution of the change to SOC stocks in South Africa is in fact quite limited, and it would introduce huge modelling complexity to account for only limited change.

3. Very limited data is available on rates of SOC change.

Key considerations for major land cover classes of concern are discussed below

Croplands

The conventional ploughing and turnover over of soils leads to the release of sequestered carbon into the atmosphere. The general "rule of thumb" based on global meta-analysis and reviews by the IPCC (2006) is that conventional ploughing leads to the release of 50% of the SOC pool in the top 30cm of soil. This source of carbon emissions can, to a certain extent, be reversed through the adoption of the principles of conservation agriculture (CA), that is, minimal soil disturbance (no tillage), maintaining organic cover year round, and planting a variety of commercial and cover crops.

Estimating both the initial release of soil carbon and potential carbon sequestration following the adoption of CA are dependent on understanding a number of factors. To understand the magnitude of the initial carbon release from conventional crop agriculture, data is required on soil type, soil depth, ploughing method and potential additional of organic inputs, as well as the state of the soil at the time of conversion. To estimate the potential impact of converting from conventional agriculture to CA, an understanding of the soil type, soil depth, tillage type, crop types and planting and management regimes is required. Whereas the general crop planted in each field is known in limited areas, for example, the Western Cape, there is no national scale understanding of the type of crop planted in each field as well as planting and tillage regimes. It is therefore neither possible to estimate the current impact of CA on SOC in South Africa, nor to track it over time, especially in a spatially explicit manner. Whereas the model could be expanded in future to include these processes, the principle limiting factor is available input data, especially records that are updated on a regular basis to allow the impact of CA to be tracked over time.

Rangelands

Due to their relative extent, the majority of South Africa' terrestrial carbon stock is located below ground in the form of SOC in open grassland and savanna ecosystems (NTCSA 2014). In a similar manner to croplands, the ISRIC dataset provides a robust estimate of carbon stocks in an intact, non-disturbed state.

In terms of understanding the impact of disturbance on SOC in rangelands, the Mararakanye and Le Roux (2011) map of gully erosion shows areas where it can be safely assumed that the whole top soil layer and associated SOC have been removed. **The NLC products also identify areas of extreme degradation as given by erosion and bare land classes**. It is, however, known that extensive degradation of natural vegetation takes place that is not mapped by the land cover products. Attempting to map this land degradation in South Africa has proved challenging and at present there is no available product to show the extent of this degradation. Aboveground biomass and primary production estimates using satellite based remote sensing have found that impacts from rainfall variability mask impacts from land degradation (Wessels *et al.* 2009). Von Maltitz *et al.* (2018) has shown that the global indicators for land production as recommended by the UNCCD for monitoring land degradation neutrality (LDN) do not pick up rangeland degradation in the South African context. Certain proxies have been proposed as indicators of changes in soil carbon, for example, basal cover, but these remain to be tested and mapped at a significant scale. Currently there is extremely limited data available on the soil carbon changes related to degradation within the savanna and grasslands, though there is evidence that management practices can result in substantive changes. Kotze *et al.* (2020) for instance suggest that 5.2 t/ha of organic C can be lost in rangeland with poor range condition compared to rangeland in good range condition. Conventional wisdom is that reduced vegetation cover will, over time, result in reduced soil carbon, but the magnitude of this change is poorly researched (Ussiri and Lal 2020). Further, as stated above, we currently have no ability to reliably map the change in vegetation status. Bush encroachment, considered by many to be a form of land degradation (e.g. Turpie *et al.* 2017) is likely to increase soil carbon (Barger *et al.* 2011, Li *et al.* 2016).

In addition to mapping changes in soil carbon, greater knowledge is required for each of the drivers of SOC and how they interact, for example, grazing and fire. Whereas intense overgrazing in dry periods can impact basal cover and soil carbon over time, changes in grazing intensity within a typical commercial management range, has little impact on soil carbon over time. Further research is required on the relationship between SOC and grazing and fire regimes in a South African context to understand potential additional measures that will deliver a real climate change mitigation benefit.

Lastly, the avoided degradation of grasslands has been suggested as a potential mitigation activity within the country. In a similar manner to "traditional REDD+" focussed on forests, halting and reducing the degradation of rangelands is at least 10 times more efficient than allowing them to be degraded and then implementing restoration measures thereafter (IPBES 2018). However, significant research is required to develop baseline scenarios and reference levels, before such projects can be realised. The GEF funded National Grassland Biodiversity Program initiated multisector interest in conserving the grassland biome, and this has been supported through Working for Ecosystems, Working for Water, Working on Fires and other expanded public works programmes (EPWP).

Urban areas

The IPCC 2019 guidance on National GHG Inventories provides a range of estimates of changes in SOC following conversion to settlements. Whereas it is assumed that 20% of SOC is released from areas under hard surfaces (e.g. paved, roads, buildings), is also assumed that there is a 14%-17% increase in areas converted to lawns, parks and so forth. As data on the exact ratio of hard surfaces to gardens, parks and golf courses is not known in South African urban areas, it has been conservatively assumed that it is approximately a 50/50 relationship and that the net impact of urban areas on SOC is zero. However, this is an area that requires future research.

USEFULNESS AND GAPS

Objectives and deliverables

The NTCSA 2014 and Atlas 2017 had, as one of their objectives, the improvement of national carbon stocks accounting in the land use sector. The task will consider the degree to which the Carbon Sinks Atlas is able to capture changes in carbon stocks, as well as gaps in our knowledge of carbon stock dynamics required to effectively understand changes due to anthropogenic impacts. Both national as well as local accounting needs will be considered.

Deliverable – A chapter on the usefulness of the Carbon Sinks Atlas including gaps in the Carbon Sinks dynamics of different land uses and data and information that need to be collected to close these gaps.

6.1. Moving to tier 3 approach

Although the current national reporting to the UNFCCC from the AFOLU sector is based to a large extent on the carbon sinks assessment results, it still uses as its bases the IPCC Tier 2 methodologies. The IPCC default methodologies, however, are not well suited to the South African situation, one of the original justifications for the NTCSA 2014. As explained above, the IPCC split of the landscape into grasslands versus forests is not appropriate to South Africa where much of our vegetation is either a natural transition between these two classes (the vast Savannas) or does not fit well into either (Karoo, Fynbos, Thicket). The current assessment improves on land carbon stock changes from anthropogenic land management impacts. It provides what can in effect be considered as a Tier 3 approach to computing wall to wall carbon stocks. It also allows for computation of change in carbon stocks based on land cover change.

6.2. Impacts of change in land cover products

The initial NTCSA 2014 came out before the 2014 national land cover product became available. Also a retrospectively produced 1990 product was produced post the 2014 NTCSA. The 2014 product used a mosaic of a number of land cover products which it referred to as SANBI 2009 to drive the land cover change. This product merged multiple land cover products that spanned at least a 5 year period.

The NTCSA 2020 has access to three national land cover products and computes data for each of these allowing for change analysis over time. This provides easy comparisons for the 19990 to 2014 period as these two products were designed to be comparable, using land cover classes.

The 2018 land cover product, which should set the methodology for the next few years, uses a very different methodology and class definition from the 2014 NLC. The NTCSA 2020has in effect selected classes that form the lowest common denominator between these two products (see Table 10). This provides relatively comparable fields for most land cover classes, however, the inclusion of a fallow class in the 2018 data has no comparable class in previous land cover products. The base resolution also changes from 30m to 20m between the NLC 2014 and earlier products and the 2018 and future products. Change detection between pre-2018 land cover products and post 2018 land cover products are therefore problematic. Dealing with the new fallow class that is only available from 2018 onwards, can, to an extent, be reduced by setting fallow land to being natural vegetation, but this is a poor assumption and will have the likely effect of over-estimating natural vegetation soils carbon stocks.

Table 10: The 17 land cover classes used in NTCSA2020 and how they relate to the 1990/2014 and 2018 NLC classes. Full descriptions of the classes are available NLC reports.

Class 2014	Class 2018	Class used in NTCSA 2020
1 – 2	14 – 21	Water
3	22 23 73	Wetlands
4	1	Indigenous forest
10 – 12	40	Commercial agriculture no irrigation / dryland
5 – 9	2 – 4 8 – 13 24	Natural vegetation
	42 – 46	Fallow
22	35	Pineapple
13 – 15	38 – 39	Pivot agriculture and other irrigated
16 – 18	32	Orchards
19 – 21	33	Viticulture
23 – 25	41	Subsistence agriculture
26 – 27	34	Sugarcane irrigated
28 – 31	36 – 37	Sugarcane dry
32 – 34	5 – 7	Plantation forests
35 – 39	68 – 72	Mines
40 – 41	25 – 31	Bare
42 – 72	47 – 67	Build up classes

6.3. Improved above ground tree biomass

Substantive improvements have been made to the above ground tree estimates. The NTCSA 2014 used simplistic estimations of tree cover based on satellite based estimates of tree height and tree cover. Both the products used had limitations. Tree height with used the NASA (JPL) proved to be very unreliable in mountainous regions. The MODIS MOD44b canopy cover is poor at estimating canopy cover near the base of its range, an important tree cover for South Africa.

The current product uses multiple ground trothing and LiDAR verification datasets. It is assumed to be a significant improvement on previous data but still has a number of potential concerns:

- It is not calibrated for all biomes, especially fynbos;
- It saturates over 120 t/ha;
- It still tends to over-estimate tree height (and hence biomass) for hilly regions;
- It is not suited to urban areas where urban infrastructure interferes with height measurements.

Given the above constraints, the above approach is not well suited to either indigenous forest biomass estimates, or mature plantation forestry.

A possible future solution for plantation forestry may be a mixed approach using calibrated approaches for early years during forestry rotation, coupled with extrapolations once the method saturates may be a relatively easy method to estimate detailed forestry wood stocks. However, as an industry, the forestry sector is relatively stable, and further, it only contributes marginally to the overall national carbon budget. Changes to the carbon budget come predominantly from increased areas of forestry, rather than from the marginal changes caused by changes in management practices.

Bush encroachment, the increasing density of some woody species within savannas, as well as the invasion of woody species into grasslands, should be relatively well accommodated in the current methodology.

6.4. Soil organic carbon

The NTCSA 2014 used a pre-released version of the AfSIS soil carbon product. Updating this product has been taken over by ISRIC and has been improved in terms of algorithms used, calibration dataset and spatial resolution. An alternative product based on the South African ARC soils profile data, land types data and terrain profiles were also used. The substantive differences between the two products highlight the high variance in soil carbon estimates.

The inclusion of soil carbon from transformed land in the ISRIC calibration data, without stratifying based on land use is seen as a potentially serious consideration for the way in which we have used the data, i.e. we make the assumption that the ISRIC data represents natural vegetation soil carbon, whilst some of the calibration data is in effect from transformed land. The Schulze data does not suffer this constraint as they have stratified the data based on it being natural or transformed. Unfortunately the transformed land is not further broken down into transformation categories meaning we cannot directly use this data for computing soil carbon loss due to transformation.

The ARC, in conjunction with FAO, has begun experimenting on a South African specific product computed in a similar manner to the ISRIC product. Unfortunately this is currently only available for the A horizon. We would strongly motivate that in future a South African specific product be developed which can include all relevant ARC and other data sources, as well as using South African specific co-variables. We understand that ISRIC may well be prepared to share their modelling algorithms and would suggest the ARC would be the best to facilitate this.

Ongoing databases of natural vegetation SOC (with associated variables such as soil depth, texture and gravel fraction) should be collected and added to a national database of soil profiles. This will allow for periodic re-running of the extrapolation models, which will allow for incremental improvements.

6.5. Land use induced changes in SOC

Interest in soil organic carbon change as a consequence of land use has received considerable scientific attention since the release of the NTCSA 2014. We moved from using single national estimates of soil organic carbon loss, to a biome and rainfall linked lookup tables based on the best available knowledge. This represents a substantive improvement but should be periodically reviewed as new data becomes available.

There is also recent interest in the use of alternative land management practices such as no-till agriculture as a mechanism to increase soil carbon stocks. These techniques have gained a rapid and widespread acceptance in the agricultural sector due to their economic benefits. We have built into the model the ability to modify carbon changes based on changes in land management practices. However, until specific practice can be located at specific locations, it is impossible to implement this change. Further monitoring of results coming out from long term alternate farming practice trails is needed to better understand these potential benefits to the soil carbon.

6.6. Agricultural crop data

The NTCSA 2014 used 2002 and 2007 agricultural census statistics to develop municipal level crop data. Currently StatsSA is updating the agricultural data and a new set of agricultural statistics are expected in 2020, which could be used to update this data. Although these updates are welcome, and may make important differences at the local level, it is, however, important to emphasise that this will have very limited impact on overall national carbon stocks.

6.7. The modelling interface

The modelling interface has been completely re-developed. What is now available is in effect, a totally customizable modelling platform in which the NTCSA 2020 was run. All input variables and even the nature of the equations can be easily changed, providing the same raster based logic is used.

Running the model for a new land cover product requires two steps. In the first step the NLC needs to be converted to m^2 of each land cover class per BLU grid cell. This data needs to be as individual layers, one per land use. This is a simple, though computer intensive process. Secondly this new data is copied into the input folder of the model and the model is re-run.

Re-running the model for a new SOC product is likewise quick and easy one the SOC product is in the model input format. If a new SOC product is used, it is important that the model is re-run for all time periods. It is important to update the data based on 1990, 2014, 2018 and any future land cover products. Similarly any other aspect of the model could be changed or updated.

6.8. Climate change induced changes

The current assessment makes no attempt to model changes to baseline carbon stock stated as a consequence of global change impacts. This is not of relevance to the above ground woody component as this is directly measured. However it may have an influence on herbaceous stocks where aspects such as CO_2 fertilizer effects may change the biomass expected at any given rainfall (the current driver of the model). Rainfall itself could also be changing and differ from the long-term data being used to drive the model.

A combination of changes in above ground biomass, e.g. from bush encroachment as well as soil respiration rates due to climate change impacts (hotter, and changed rainfall) may overtime change the soil carbon stocks.

A combination of modelling (e.g. using Century) and long term experimental monitoring data is needed to better understand these potential climate induced changes.

UPDATED BASELINE

Objectives and deliverables

To consider the updated baseline for the AFOLU sector, including scenarios and non-landcover change emissions.

7.1. Background

The agriculture, forestry and other land use (AFOLU) sector is an important carbon stock for South Africa. An initial attempt at an AFOLU baseline was undertaken in 2016 (DEA 2016, Stevens *et al.* 2016).

This was based on the South African 2010 National Greenhouse Gas (GHG) Inventory and included the following agricultural components:

- Livestock enteric fermentation (CH_4),
- Livestock manure management (CH_4 and N_2O),
- Liming (CO_2),
- Urea application (CO_2),
- Direct N_2O emissions from managed soils,
- Indirect N_2O emissions from managed soils,
- Indirect N_2O emissions from manure management.

In addition it included emissions from the following sectors:

- Forest land,
- Cropland,
- Grasslands,
- Wetlands Settlements,
- Other land
- Emissions from biomass burning.

Data for the agricultural components is not available spatially, and is mostly computed from national statistics on livestock numbers and fertilizer sales. As such, the NTCSA 2020 can provide no additional insights into these emissions. In practice much of this data is even less available than in 2010 as the industry data is no longer freely available, and there is no recent census data to update livestock trends. These constraints are discussed in the 2014 National GHG Inventory Report. Updated agricultural statistics are due for 2020 and once these statistics becomes available it may assist in updating some of the data.

The NTCSA date can make a number of improvements to the sector calculations. However, much of the NTCSA 2020 data used different vegetation classifications from those used by DEA 2016 and Stevenson *et al.* (2016), which follow the recommendation of the IPCC and IPCC reporting classes.

The choice of biomes as opposed to the IPCC land cover classes was based on a number of sound ecological considerations. Experience in previous IPCC national reports (DEA 2010 and DEA 2014) have found that the IPCC land classes are poorly aligned to the reality of vegetation biomass as found in South Africa. Further, South African land cover maps struggle to consistently map changes in these classes. The following is a summary of the key constraints to the use of the IPCC land cover classifications in the South African context.

1. In savanna and woodland systems there is a natural gradient in woodiness, i.e. grasslands gradually become more woody over long environmental gradients to a point where until a point at which they reach a man-made threshold of tree cover (e.g. 5% or 10%) at which point they get classified as woodland or forest. From an ecological perspective, there is no clear functional difference if there is a 4% or 16% tree cover. However, there is an ecological change in that the grass layer disappears and true closed canopy forest developed (the South African indigenous forest class). The FAO and IPCC classification systems define a tree cover of 10% and being the distinction between grassland and forest. A large number of South African savanna systems have tree densities near this threshold and can move backword and forward across this threshold due to

slight increases or decreases in tree density. From a practical perspective, mapping these changes are even more challenging with NLC products having a very low accuracy mapping this divide (Thompson *et al*. 2014). In practice vegetation that is almost identical can move backward and forward across this divide between mapping periods giving a false indication of change, despite limited or any change on the ground.

2. South Africa has a number of vegetation types that simply do not fit into the category of being either Grassland or Forest. For instance, much of the Fynbos does not meet the requirements to be classed as forest, but lacks a graminoid component, so cannot be considered to have the characteristics of Grassland. The same is true for Karoo vegetation which has low bushes but little grass. The Karoo vegetation is sometimes grouped (for IPCC reporting) into the "other" category due to its low cover, but clearly is not what is intended in the "other land use" category.

3. Vegetation within biomes is well understood, and within a biome the vegetation behaves in a relatively uniform manner in relation to carbon pools. Ecological functions such as impacts of fire regimes, are often linked to biomes.

4. The concept of biomes is well accepted within South Africa, whilst the Eurocentric IPCC classes are not used except when the country is forced to do so for national reporting purposes.

5. Many grasslands are natural grasslands. They are not transformed forest, nor would they naturally revert to forest if left to natural succession (see Bond *et al*. .2019).

Two solutions are proposed on how to report on South African carbon pools for international purposes.

1. Use a mask of FAO forest classes to extract zonal data from the NTCSA results.

2. Report on changes within South African biomes rather than IPCC classes.

Both approaches could be easily implemented within the NTCSA 2020, but would require consensus from stakeholders on the proposed methods, and if option 1 is selected, consensus would have to be sought on the spatial boundaries between forest and grassland classes.

7.2. A wall-to-wall approach

A distinguishing factor of the NTCSA 2020 as opposed to IPCC tier 1 and Tier 2 approach is that it uses what can be termed a wall-to-wall approach in computing organic carbon pools. It uses observations coupled with models to determine location specific biomass and soil organic carbon stocks. This is done for each and every 1km^2 Land Unit (LU) in the country.

This also differs from IPCC methodologies, where mean values are used for different land cover classes. Also, since above ground woody biomass is directly computed, there is no need to determine harvesting rates to consider loss of biomass (note, this is not fully true for plantation forest and high density indigenous forest where currently measurements saturate above 120 t/ha).

7.3. Baseline land cover change and SOC

Land cover is the key driver of change in the NTCSA 2020. Understanding the details of land cover change is critical for understanding changes in SOC (Table 11 to 13).

Summary data at the national level can hide substantive changes at the local level. For this reason summary district and local municipal statistics are given below and in Appendix 6.

Table 11: Change in land area between 1990 and 2018 based on the 1990 and 2018 NLC data. Viticulture, sugarcane and pineapple data is excluded for space reasons. (-) is loss of land from the land use, a positive number being gain in land (in km^2).

	Water	Wetlands	Indigenous	Natural Vegetation	Commercial Agriculture	Pivot Agriculture	Orchards	Subsistence Agriculture	Plantation Forest	Mines	Bare degraded	Built-up	Fallow
Alfred Nzo	36	-97	50	-1014	-93	36	0	41	61	0	66	23	891
Amajuba	12	63	13	-723	-121	63	0	40	114	-5	23	90	432
Amathole	38	-72	-153	-1135	-30	14	-12	51	54	-3	3	36	1262
Bojanala	24	-83	-6	-1659	-563	242	0	-96	45	73	72	276	1674
Buffalo City	8	-12	-33	-130	18	1	-9	14	6	-1	8	38	127
Cacadu	40	-188	153	8915	-533	493	-17	-3	-27	- 5	-9530	87	562
Cape Winelands	-4	-150	0	-1941	-62	102	60	0	-70	1	1600	89	543
Capricorn	3	-48	-37	-1931	-395	267	-33	113	6	-26	135	339	1591
Central Karoo	-10	-72	0	6250	-62	48	3	0	2	2	-6355	69	128
Chris Hani	37	-201	45	-1029	-243	284	-19	76	54	-5	129	103	768
City of Cape Town	6	-22	-1	-157	2	11	3	0	-30	5	35	35	124
City of Johannesburg	3	-1	0	-181	-73	7	0	1	-37	7	23	159	89
City of Tshwane	11	-14	0	-706	-95	56	5	0	-27	-11	77	310	395
Dr Kenneth Kaunda	-5	-177	0	-728	-616	168	0	0	40	-17	16	99	1220
Dr Ruth Segomotsi Mompati	12	-109	0	-1293	-1425	237	-3	-47	34	-70	126	154	2379
Eden	16	-198	22	-950	-453	430	8	0	-177	2	698	100	508
Ehlanzeni	44	61	119	-925	-232	52	140	-112	-534	0	313	290	567
Ekurhuleni	11	1	0	-136	-150	18	1	6	-33	-8	17	146	127

	Water	Wetlands	Indigenous	Natural Vegetation	Commercial Agriculture	Pivot Agriculture	Orchards	Subsistence Agriculture	Plantation Forest	Mines	Bare degraded	Built-up	Fallow
eThekwini	2	-1	51	-282	-4	1	-1	25	-15	3	8	19	188
Fezile Dabi	43	-461	0	-218	-385	178	1	0	78	20	50	84	610
Frances Baard	11	-80	0	-46	-296	317	26	2	2	-60	-14	48	90
Gert Sibande	77	437	22	-3050	-562	201	3	-64	653	5	111	204	1917
Harry Gwala	30	-8	68	-953	-204	250	2	100	249	1	0	-22	478
iLembe	-4	2	9	-128	-8	0	1	103	-52	1	6	-74	83
Joe Gqabi	43	-324	8	-1736	-285	283	-7	12	256	-2	1282	62	406
John Taolo Gaetsewe	11	-44	0	-482	-20	0	0	-3	1	22	195	114	195
Lejweleputswa	-272	-393	0	-427	-1315	766	3	0	105	-15	164	103	1280
Mangaung	-7	-103	-2	-418	-274	135	0	104	34	-3	234	65	234
Mopani	-4	-64	-67	-903	-75	11	11	-109	-53	-17	148	209	897
Namakwa	-377	-149	0	-5344	-51	15	5	-1	4	44	4751	218	853
Nelson Mandela	12	-4	1	-55	-22	7	-2	0	-2	-18	7	30	45
Ngaka Modiri	1	-271	0	-1104	-759	195	0	-52	80	-43	6	187	1757
Nkangala	67	183	13	-1896	-706	185	2	30	154	176	135	197	1456
O.R.Tambo	42	-51	87	-1300	-1	1	0	41	9	0	34	60	1079
Overberg	-23	-83	14	-577	-73	110	-9	1	-81	2	370	58	305
Pixley ka Seme	-36	-475	0	7919	-119	283	1	3	0	-27	-8130	150	432
Sedibeng	10	-73	0	-160	-129	51	-1	0	-18	-2	24	85	214
Sekhukhune	33	-80	0	-1849	-249	140	14	357	-2	30	615	409	573
Thabo Mofuts	72	-493	-54	-1465	-300	282	2	3	110	-10	546	158	1147
Ugu	13	-2	70	-716	-6	2	29	133	-20	1	11	-144	593
Umgungundlo	22	9	46	-586	-186	184	0	43	7	2	-13	55	333
Umkhanyaku de	-92	77	164	-584	-74	5	-16	43	-29	7	132	-96	390
Umzinyathi	14	6	2	-955	-85	65	1	37	46	-1	137	103	643
Uthukela	30	30	-3	-972	-147	232	0	150	27	0	52	23	579
Uthungulu	-6	22	33	-426	-21	2	-2	-29	-72	18	44	-131	365
Vhembe	36	-37	-69	-620	-75	78	12	- 376	-2	-12	10	216	755

	Water	Wetlands	Indigenous	Natural Vegetation	Commercial Agriculture	Pivot Agriculture	Orchards	Subsistence Agriculture	Plantation Forest	Mines	Bare degraded	Built-up	Fallow
Waterberg	45	-92	0	-1739	-1847	425	-18	54	14	-21	272	240	2663
West Coast	-15	-109	0	-1911	-307	394	-291	-9	-3	18	928	83	1276
West Rand	3	-52	0	-148	-241	63	4	1	12	-7	26	43	297
Xhariep	-66	-653	-2	-452	-460	469	5	0	79	-4	417	72	594
Z F Mgcawu	-308	-96	0	-600	5	8	7	0	-1	13	590	180	60
Zululand	-4	37	16	- 1515	-87	34	3	31	340	-4	157	21	929

Table 12: Proportional change in land area (as % of total area) between 1990 and 2018 based on the 1990 and 2018 NLC data. Viticulture, sugarcane and pineapple data is excluded for space reasons. (-) is loss of land from the land use, a positive number being gain in land.

	Water	Wetlands	Indigenous	Natural Vegetation	Commercial Agriculture	Pivot Agriculture	Orchards	Subsistence Agriculture	Plantation Forest	Mines	Bare degraded	Built-up	Fallow
Alfred Nzo	0.3	-0.9	0.5	-9.5	-0.9	0.3	0.0	0.4	0.6	0.0	0.6	0.2	8.3
Amajuba	0.2	0.9	0.2	-10.2	-1.7	0.9	0.0	0.6	1.6	-0.1	0.3	1.3	6.1
Amathole	0.2	-0.3	-0.7	-5.4	-0.1	0.1	-0.1	0.2	0.3	0.0	0.0	0.2	6.0
Bojanala	0.1	-0.5	0.0	-9.0	-3.1	1.3	0.0	-0.5	0.2	0.4	0.4	1.5	9.1
Buffalo City	0.3	-0.4	-1.2	-4.7	0.6	0.0	-0.3	0.5	0.2	0.0	0.3	1.4	4.6
Cacadu	0.1	-0.3	0.3	15.3	-0.9	0.8	0.0	0.0	0.0	0.0	-16.4	0.1	1.0
Cape Winelands	0.0	-0.7	0.0	-9.0	-0.3	0.5	0.3	0.0	-0.3	0.0	7.5	0.4	2.5
Capricorn	0.0	-0.2	-0.2	-8.9	-1.8	1.2	-0.2	0.5	0.0	-0.1	0.6	1.6	7.3
Central Karoo	0.0	-0.2	0.0	16.1	-0.2	0.1	0.0	0.0	0.0	0.0	-16.4	0.2	0.3
Chris Hani	0.1	-0.6	0.1	-2.8	-0.7	0.8	-0.1	0.2	0.1	0.0	0.4	0.3	2.1
City of Cape Town	0.3	-0.9	0.0	-6.4	0.1	0.5	0.1	0.0	-1.2	0.2	1.4	1.4	5.1
City of Johannesburg	0.2	0.0	0.0	-11.0	-4.4	0.4	0.0	0.1	-2.2	0.4	1.4	9.7	5.4

	Water	Wetlands	Indigenous	Natural Vegetation	Commercial Agriculture	Pivot Agriculture	Orchards	Subsistence Agriculture	Plantation Forest	Mines	Bare degraded	Built-up	Fallow
City of Tshwane	0.2	-0.2	0.0	-11.2	-1.5	0.9	0.1	0.0	-0.4	-0.2	1.2	4.9	6.3
Dr Kenneth Kaunda	0.0	-1.2	0.0	-5.0	-4.2	1.1	0.0	0.0	0.3	-0.1	0.1	0.7	8.3
Dr Ruth Segomotsi Mompati	0.0	-0.2	0.0	-3.0	-3.3	0.5	0.0	-0.1	0.1	-0.2	0.3	0.4	5.4
Eden	0.1	-0.8	0.1	-4.1	-1.9	1.8	0.0	0.0	-0.8	0.0	3.0	0.4	2.2
Ehlanzeni	0.2	0.2	0.4	-3.3	-0.8	0.2	0.5	-0.4	-1.9	0.0	1.1	1.0	2.0
Ekurhuleni	0.5	0.1	0.0	-6.8	-7.6	0.9	0.1	0.3	-1.7	-0.4	0.9	7.3	6.4
eThekwini	0.1	0.0	2.0	-11.0	-0.2	0.0	0.0	1.0	-0.6	0.1	0.3	0.7	7.3
Fezile Dabi	0.2	-2.2	0.0	-1.1	-1.9	0.9	0.0	0.0	0.4	0.1	0.2	0.4	3.0
Frances Baard	0.1	-0.6	0.0	-0.4	-2.3	2.5	0.2	0.0	0.0	-0.5	-0.1	0.4	0.7
Gert Sibande	0.2	1.4	0.1	-9.6	-1.8	0.6	0.0	-0.2	2.1	0.0	0.3	0.6	6.0
Harry Gwala	0.3	-0.1	0.7	-9.2	-2.0	2.4	0.0	1.0	2.4	0.0	0.0	-0.2	4.6
iLembe	-0.1	0.1	0.3	-3.9	-0.2	0.0	0.0	3.1	-1.6	0.0	0.2	-2.3	2.5
Joe Gqabi	0.2	-1.3	0.0	-6.8	-1.1	1.1	0.0	0.0	1.0	0.0	5.0	0.2	1.6
John Taolo Gaetsewe	0.0	-0.2	0.0	-1.8	-0.1	0.0	0.0	0.0	0.0	0.1	0.7	0.4	0.7
Lejweleputswa	-0.8	-1.2	0.0	-1.3	-4.1	2.4	0.0	0.0	0.3	0.0	0.5	0.3	4.0
Mangaung	-0.1	-1.0	0.0	-4.2	-2.8	1.4	0.0	1.1	0.3	0.0	2.4	0.7	2.4
Mopani	0.0	-0.3	-0.3	-4.5	-0.4	0.1	0.1	-0.5	-0.3	-0.1	0.7	1.0	4.5
Namakwa	-0.3	-0.1	0.0	-4.2	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.2	0.7
Nelson Mandela	0.6	-0.2	0.0	-2.8	-1.1	0.3	-0.1	0.0	-0.1	-0.9	0.4	1.5	2.3
Ngaka Modiri	0.0	-1.0	0.0	-3.9	-2.7	0.7	0.0	-0.2	0.3	-0.2	0.0	0.7	6.3
Nkangala	0.4	1.1	0.1	-11.3	-4.2	1.1	0.0	0.2	0.9	1.0	0.8	1.2	8.7
O.R.Tambo	0.3	-0.4	0.7	-10.7	0.0	0.0	0.0	0.3	0.1	0.0	0.3	0.5	8.9
Overberg	-0.2	-0.7	0.1	-4.7	-0.6	0.9	-0.1	0.0	-0.7	0.0	3.0	0.5	2.5

	Water	Wetlands	Indigenous	Natural Vegetation	Commercial Agriculture	Pivot Agriculture	Orchards	Subsistence Agriculture	Plantation Forest	Mines	Bare degraded	Built-up	Fallow
Pixley ka Seme	0.0	-0.5	0.0	7.7	-0.1	0.3	0.0	0.0	0.0	00	-7.9	0.1	0.4
Sedibeng	0.3	-1.8	0.0	-3.9	-3.1	1.2	0.0	0.0	-0.4	-0.1	0.6	2.0	5.2
Sekhukhune	0.2	-0.6	0.0	-13.7	-1.8	1.0	0.1	2.6	0.0	0.2	4.5	3.0	4.2
Thabo Mofuts	0.2	-1.5	-0.2	-4.5	-0.9	0.9	0.0	0.0	0.3	0.0	1.7	0.5	3.5
Ugu	0.3	0.0	1.5	-14.9	-0.1	0.0	0.6	2.8	-0.4	0.0	0.2	-3.0	12.4
Umgungundlo	0.2	0.1	0.5	-6.1	-1.9	1.9	0.0	0.4	0.1	0.0	-0.1	0.6	3.5
Umkhanyaku de	-0.7	0.6	1.3	-4.5	-0.6	0.0	-0.1	0.3	-0.2	0.1	1.0	-0.7	3.0
Umzinyathi	0.2	0.1	0.0	-11.0	-1.0	0.8	0.0	0.4	0.5	0.0	1.6	1.2	7.4
Uthukela	0.3	0.3	0.0	-8.7	-1.3	2.1	0.0	1.3	0.2	0.0	0.5	0.2	5.2
Uthungulu	-0.1	0.3	0.4	-5.2	-0.3	0.0	0.0	-0.4	-0.9	0.2	0.5	-1.6	4.4
Vhembe	0.1	-0.1	-0.3	-2.4	-0.3	0.3	0.0	-1.5	0.0	0.0	0.0	0.8	3.0
Waterberg	0.1	-0.2	0.0	-3.9	-4.1	0.9	0.0	0.1	0.0	0.0	0.6	0.5	5.9
West Coast	0.0	-0.4	0.0	-6.1	-1.0	1.3	-0.9	0.0	0.0	0.1	3.0	0.3	4.1
West Rand	0.1	-1.3	0.0	-3.6	-5.9	1.5	0.1	0.0	0.3	-0.2	0.6	1.0	7.2
Xhariep	-0.2	-1.9	0.0	-1.3	-1.3	1.4	0.0	0.0	0.2	0.0	1.2	0.2	1.7
Z F Mgcawu	-0.3	-0.1	0.0	-0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.2	0.1
Zululand	0.0	0.2	0.1	-10.2	-0.6	0.2	0.0	0.2	2.3	0.0	1.1	0.1	6.3

Table 12: Estimates of total carbon loss due to land cover change in 2018 based on 2018 NLC data, by district.

	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Pineapple	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Bare degraded	Fallow
Alfred Nzo	0.045	0.006	0.000	0.000	0.000	0.423	0.000	0.000	0.046	0.273
Amajuba	0.089	0.010	0.000	0.000	0.000	0.027	0.000	0.000	0.010	0.082
Amathole	0.083	0.002	0.002	0.000	0.000	0.368	0.000	0.000	0.022	0.370
Bojanala	0.156	0.026	0.003	0.000	0.000	0.071	0.000	0.000	0.021	0.214
Buffalo City	0.044	0.000	0.000	0.000	0.002	0.051	0.000	0.000	0.004	0.036
Cacadu	0.308	0.059	0.021	0.000	0.013	0.003	0.000	0.000	0.148	0.098
Cape Winelands	0.121	0.003	0.002	0.004	0.000	0.000	0.000	0.000	0.234	0.020
Capricorn	0.035	0.023	0.002	0.000	0.000	0.149	0.000	0.000	0.029	0.182
Central Karoo	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.155	0.008
Chris Hani	0.132	0.013	0.000	0.000	0.000	0.301	0.000	0.000	0.126	0.145
City of Cape Town	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.006
City of Johannesburg	0.008	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.017
City of Tshwane	0.109	0.006	0.001	0.000	0.000	0.001	0.000	0.000	0.009	0.056
Dr Kenneth Kaunda	0.519	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.145
Dr Ruth Segomotsi Mompati	0.354	0.014	0.000	0.000	0.000	0.013	0.000	0.000	0.007	0.162
Eden	0.288	0.027	0.001	0.001	0.000	0.000	0.000	0.000	0.147	0.048
Ehlanzeni	0.060	0.005	0.053	0.000	0.000	0.054	0.000	0.116	0.048	0.116
Ekurhuleni	0.041	0.002	0.000	0.000	0.000	0.004	0.000	0.000	0.002	0.021
eThekwini	0.001	0.000	0.000	0.000	0.000	0.015	0.000	0.044	0.003	0.055
Fezile Dabi	1.045	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.081
Frances Baard	0.019	0.038	0.004	0.000	0.000	0.000	0.000	0.000	0.004	0.010
Gert Sibande	1.356	0.031	0.001	0.000	0.000	0.039	0.000	0.000	0.030	0.434
Harry Gwala	0.185	0.048	0.001	0.000	0.000	0.162	0.000	0.015	0.013	0.156
iLembe	0.000	0.000	0.001	0.000	0.000	0.070	0.000	0.207	0.004	0.028
Joe Gqabi	0.187	0.018	0.000	0.000	0.000	0.108	0.000	0.000	0.268	0.076

	Commercial Agriculture	Pivot Agriculture	Orchards	Subsistence Agriculture	Plantation Forest	Mines			Bare degraded	Fallow
John Taolo Gaetsewe	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.013
Lejweleputswa	1.270	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.123
Mangaung	0.224	0.003	0.000	0.000	0.000	0.037	0.000	0.000	0.024	0.028
Mopani	0.031	0.003	0.035	0.000	0.000	0.058	0.000	0.000	0.016	0.107
Namakwa	0.049	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.535	0.038
Nelson Mandela	0.018	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.010
Ngaka Modiri	0.513	0.007	0.000	0.000	0.000	0.071	0.000	0.000	0.009	0.147
Nkangala	0.592	0.022	0.001	0.000	0.000	0.022	0.000	0.000	0.022	0.244
O.R.Tambo	0.001	0.000	0.006	0.000	0.000	0.490	0.000	0.000	0.028	0.368
Overberg	0.401	0.003	0.009	0.000	0.000	0.000	0.000	0.000	0.055	0.015
Pixley ka Seme	0.023	0.044	0.002	0.001	0.000	0.000	0.000	0.000	0.100	0.042
Sedibeng	0.185	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.038
Sekhukhune	0.051	0.025	0.009	0.000	0.000	0.157	0.000	0.000	0.087	0.089
Thabo Mofuts	1.808	0.025	0.001	0.000	0.000	0.002	0.000	0.000	0.104	0.224
Ugu	0.003	0.000	0.011	0.000	0.000	0.130	0.000	0.187	0.010	0.227
Umgungundlo	0.138	0.032	0.003	0.000	0.000	0.041	0.000	0.204	0.007	0.100
Umkhanyaku de	0.002	0.000	0.001	0.000	0.007	0.194	0.000	0.064	0.022	0.095
Umzinyathi	0.056	0.009	0.001	0.000	0.000	0.122	0.000	0.019	0.043	0.135
Uthukela	0.104	0.040	0.001	0.000	0.000	0.103	0.000	0.000	0.035	0.113
Uthungulu	0.002	0.000	0.005	0.000	0.000	0.169	0.000	0.204	0.020	0.123
Vhembe	0.022	0.008	0.019	0.000	0.000	0.059	0.000	0.000	0.016	0.101
Waterberg	0.504	0.052	0.002	0.000	0.000	0.051	0.000	0.000	0.040	0.328
West Coast	0.383	0.000	-0.001	0.003	0.000	0.000	0.000	0.000	0.081	0.018
West Rand	0.116	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.004	0.045
Xhariep	0.285	0.012	0.001	0.000	0.000	0.000	0.000	0.000	0.061	0.065
Z F Mgcawu	0.002	0.001	0.001	0.025	0.000	0.000	0.000	0.000	0.079	0.006
Zululand	0.066	0.007	0.002	0.000	0.000	0.205	0.000	0.046	0.043	0.215

7.4. Consideration of baseline years

National Land Cover data is available for three periods, 1990, 2014 and 2018. As such any of these could be considered a baseline year against which to monitor change.

Ideally the methodology, spatial resolution and accuracy of all datasets should remain constant over time, but unfortunately this is not the case. The 1990 and 2014 datasets are relatively comparable, and use the same classification classes. NLC 2018 used improved satellite images, a new methodology and a completely revised set of land cover classes. The NLC 2018 methodology is likely to remain the approved methodology for the foreseeable future. NLC 2018 classes can be relatively well aligned with the NLC 1990 and 2014 classes by finding a "lowest common denominator". Though not a perfect fit, the classes as given in Table 14 are reasonably close in most respects except that NLC 2018 has a new class called "fallow". This new class is very useful for a SOC accounting purpose, but it must be borne in mind that it is not possible to compute changes in this class. (This will obviously change once NLC products for future periods become available).

Tree cover is currently for 2015 or 2018, which makes it well aligned for a 2014 or 2018 baseline year.

Table 14: The 17 land cover classes used in NTCSA2020 and how they relate to the 1990/2014 and 2018 NLC classes. Full descriptions of the classes are available NLC reports.

Class 2014	Class 2018	Class used in NTCSA 2020
1 – 2	14 – 21	Water
3	22 23 73	Wetlands
4	1	Indigenous forest
10 – 12	40	Commercial agriculture no irrigation / dryland
5 – 9	2 – 4 8 – 13 24	Natural vegetation
	42 – 46	Fallow
22	35	Pineapple
13 – 15	38 – 39	Pivot agriculture and other irrigated
16 – 18	32	Orchards
19 – 21	33	Viticulture
23 – 25	41	Subsistence agriculture
26 – 27	34	Sugarcane irrigated
28 – 31	36 – 37	Sugarcane dry
32 – 34	5 – 7	Plantation forests
35 – 39	68 – 72	Mines
40 – 41	25 – 31	Bare
42 – 72	47 – 67	Build up classes

Given the lack of historical data, it is not possible to generate a 1990 tree cover product. A high variance in the current tree cover products makes between year comparisons ill-advisable.

7.5. Spatially available data

Currently there is no spatially explicit data for AFOLU values for the following information

- Livestock enteric fermentation (CH_4),
- Livestock manure management (CH_4 and N_2O),
- Liming (CO_2),
- Urea application (CO_2),
- Direct N_2O emissions from managed soils,
- Indirect N_2O emissions from managed soils,
- Indirect N_2O emissions from manure management.

This makes estimates of spatially explicit emissions impossible for sectors other than the land cover sectors.

7.6. Developing baseline SOC trends based on 1990 to 2018 land cover data

Three national land cover products NLC 1990, 2014 and 2018 were used to interrogate trends in historic SOC changes and to extrapolate these changes into the medium future at 10 year intervals until the year 2050.

Changes in soil organic carbon are based on anticipated changes from a natural vegetation baseline and modelled against the best available data on soil carbon loss from land cover change (see appendix 4).

Three methods were used to generate linear extrapolation of future trends.

1. Using a linear extrapolation of the change observed between 1990 and 2014. For each land unit (1km x 1km) the total SOC for the reference period, 1990, 2014 and 2018 was calculated as per equation 2.25. SOC values were summed per biome (or province or district). Change over the 1990 to 2014 period was calculated as annual change as per equation 2.25. Values were extrapolated to 2030, 2040 and 2050 by multiplying the time period since 1990 by the annual change and adding this to the 1990 value. The results in a linear extrapolation of the 1990 to 2014 value.

   Note: *The 1990 to 2014 land cover data was used for this calculation as it was based on identical classes and it therefore creates a good baseline period against which to calculate trends. The NLC 2018 data used slightly different classes and this would introduce some errors due to these class differences.*

   The NLC 2018 data is shown on the diagrams below with both the fallow class being used in the calculations, as well as with the fallow class set to the same SOC values as the natural vegetation (which makes it reasonably comparable with the 1990 and 2014 datasets).

EQUATION 2.25
ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} \left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \right)$$

(Note: T is used in place of D in this equation if T is $\geq$ 20 years, see note below)

Where:

2. A similar approach was used as above, but the extrapolation was based on the mean value between the 2014 and 2018 (with fallow results). The mean between these two values was chosen as it is likely that many of the fallow fields existed before 1990.

3. A similar approach was used as above, but the extrapolation was based on the mean value between the 2014 and 2018 (without fallow results i.e. fallow is regarded as fully restored to natural). The mean between these two values was chosen as it is likely that many of the fallow fields existed before 1990.

Results using all three methods are given in Figure 7.1. This figure has been annotated to better assist in understanding the different baseline projections and how they relate to available data.

Interpreting the baseline calculation graphs

- The reference value (SOCREF) is the SOC that would be expected under the natural vegetation. When used over the entire country, it represents the hypothetical SOC that would be expected if the entire area was natural vegetation. It does not relate to a specific period in the past, but for simplicity has been set to 1900 in the graphs. The slope of the line from 1900 to 1990 must, therefore not be treated as a rate of change.
- The 1990 to 2014 (blue line) is the actual data from 1990 to 2014, which is extrapolated to 2050.
- The yellow line is the extrapolation of the 1990 to a value that is the mean between the 2014 and 2018 data (with fallow land being included in the 2018 data).
- The red dot is the value from the 2018 data if fallow land is included.
- The blue dot is the 2018 value when fallow land is excluded, i.e. fallow land is assumed to have the same carbon as natural vegetation (the reference value).

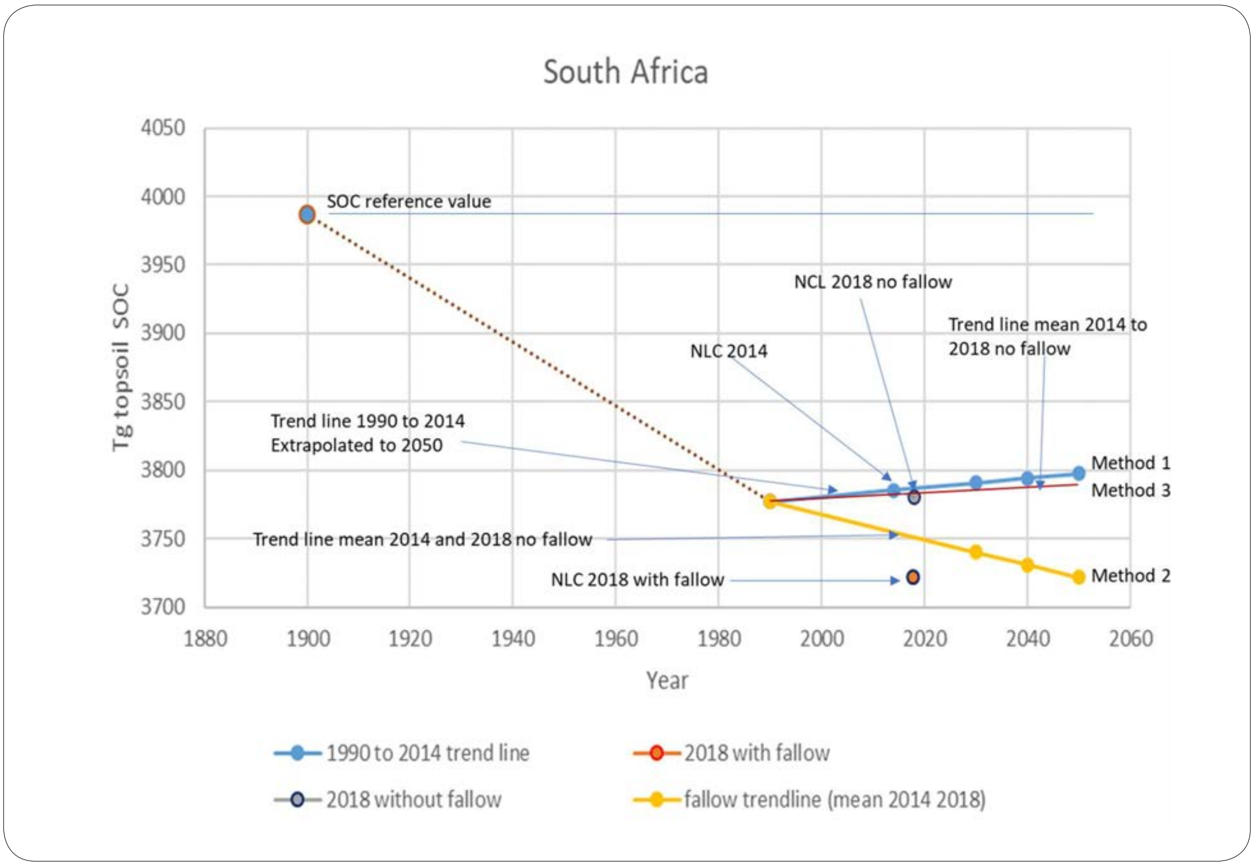


Figure 7.1: National SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on three extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included). Method 3: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

Graphs of SOC changes and baseline extrapolations for individual biomes are given in Figures 7.2 to 7.10 and districts Figure 7.11 to 7.19 using both method 1 and 2. Method 3 results are not shown as in most cases they are remarkably similar to Method 1. Data for districts are given in Tables 15 using Methods 1 and 3.

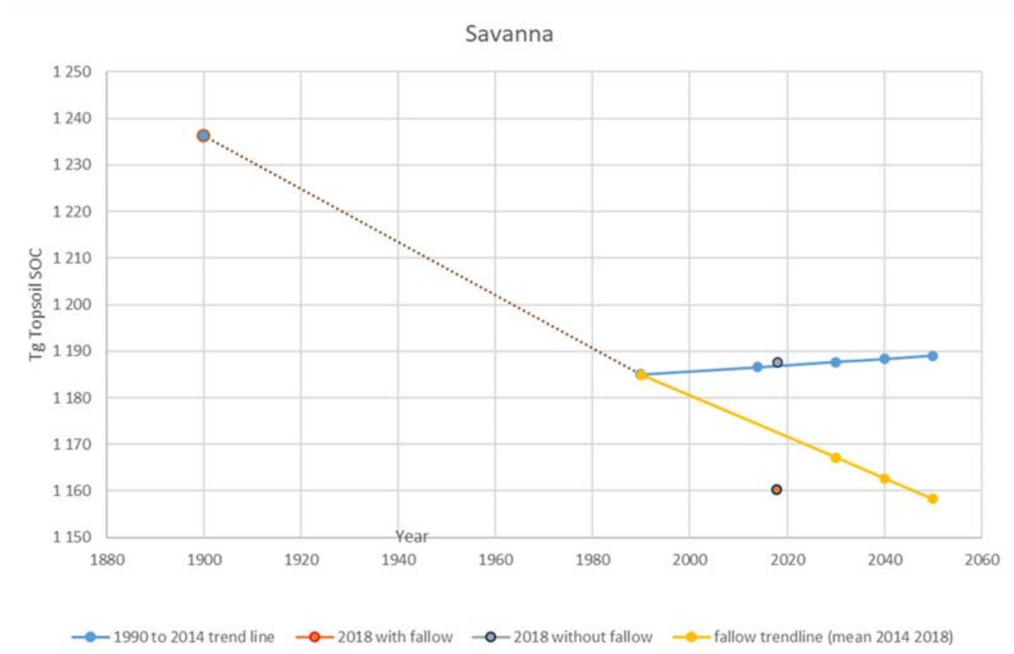


Figure 7.2: Savanna SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

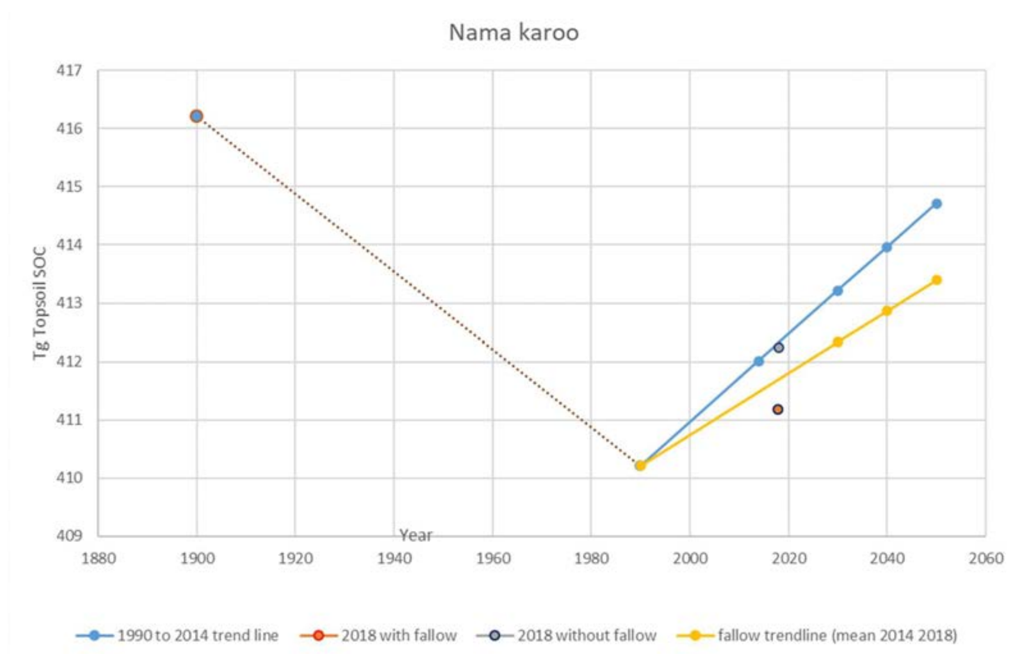


Figure 7.3: Nama Karoo SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included). Note concerns re barren ground discussed below.

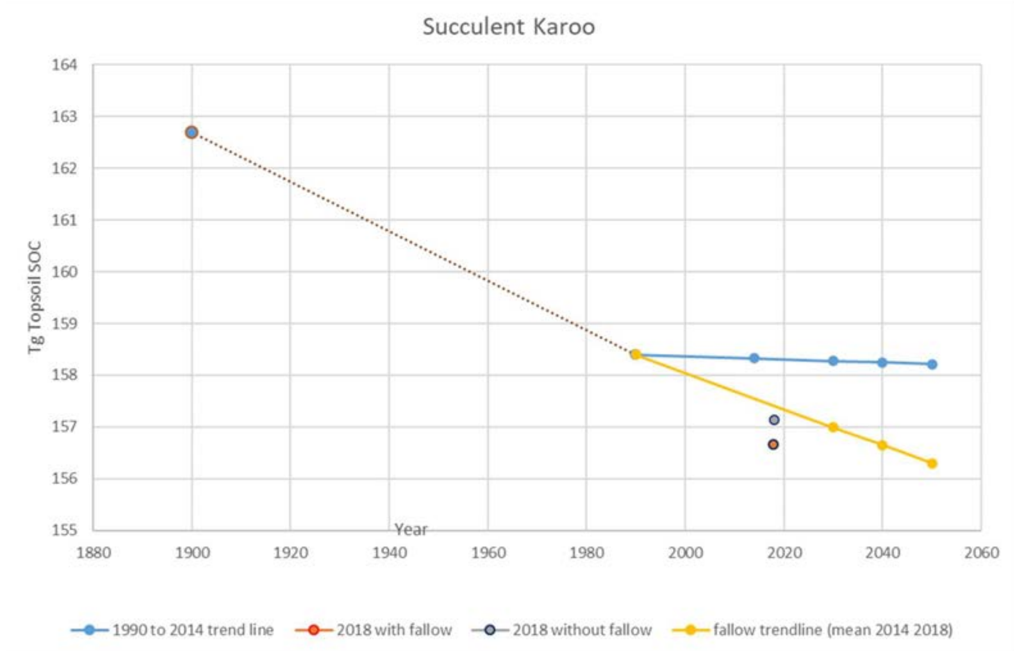


Figure 7.4: Succulent Karoo SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

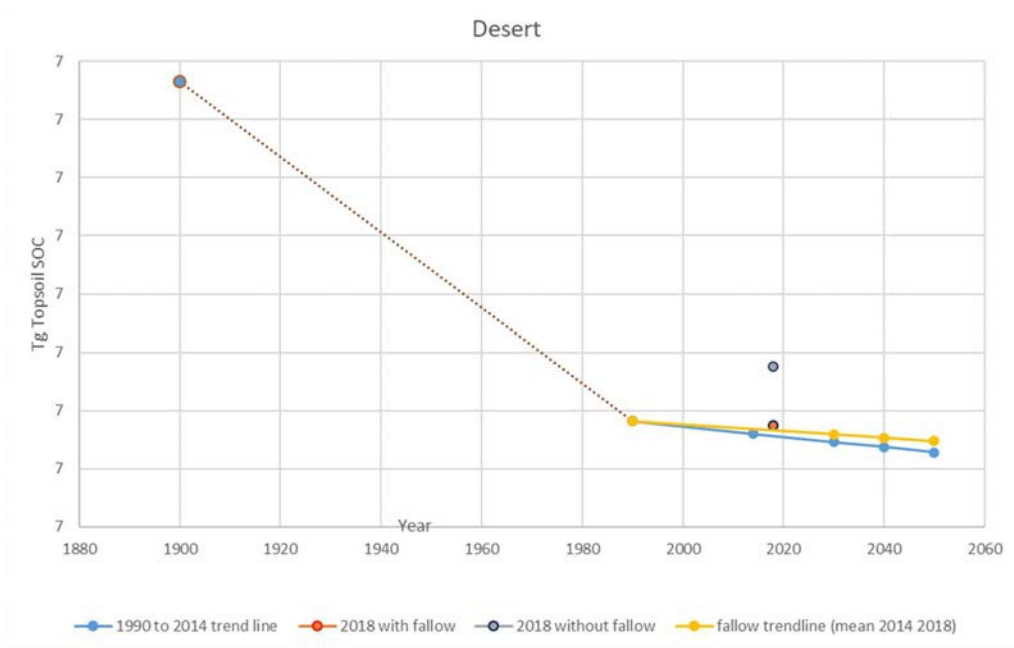


Figure 7.5: Desert SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

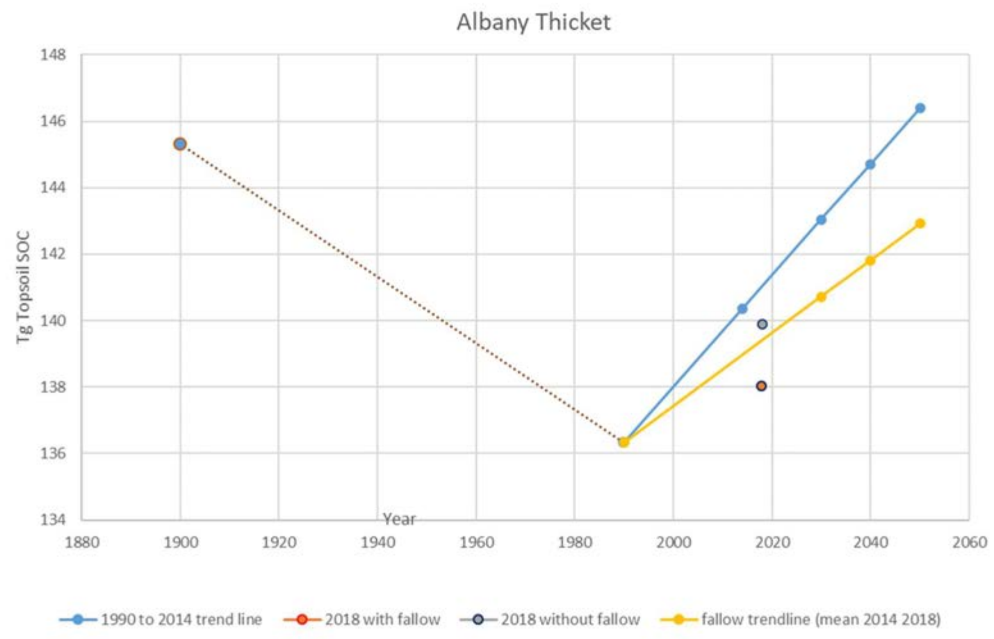


Figure 7.6: Albany Thicket SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included). Note concerns re barren ground discussed below.

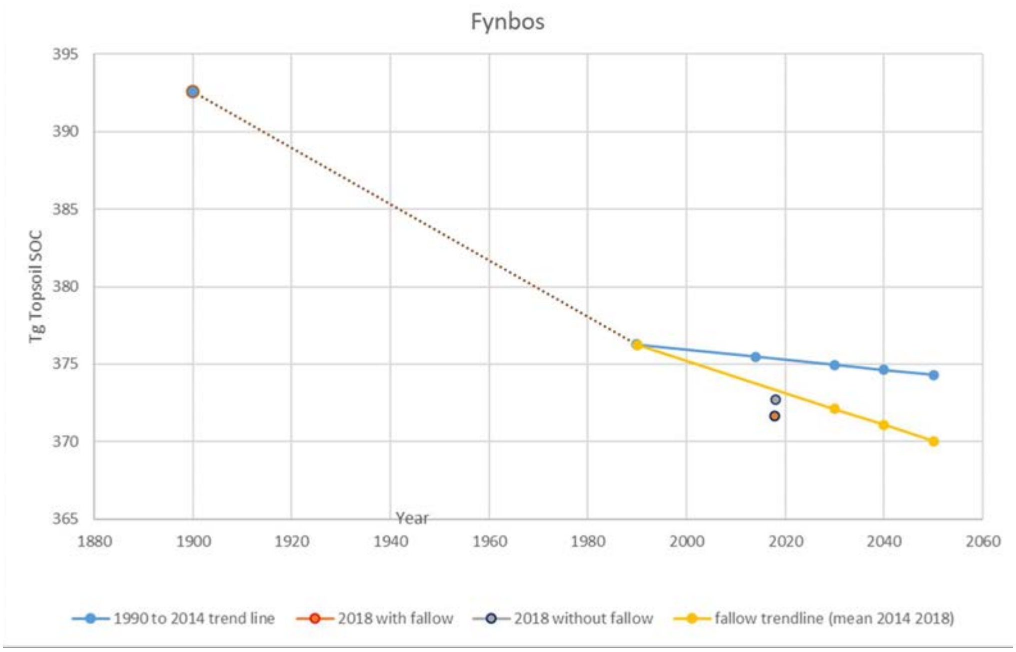


Figure 7.7: Fynbos SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

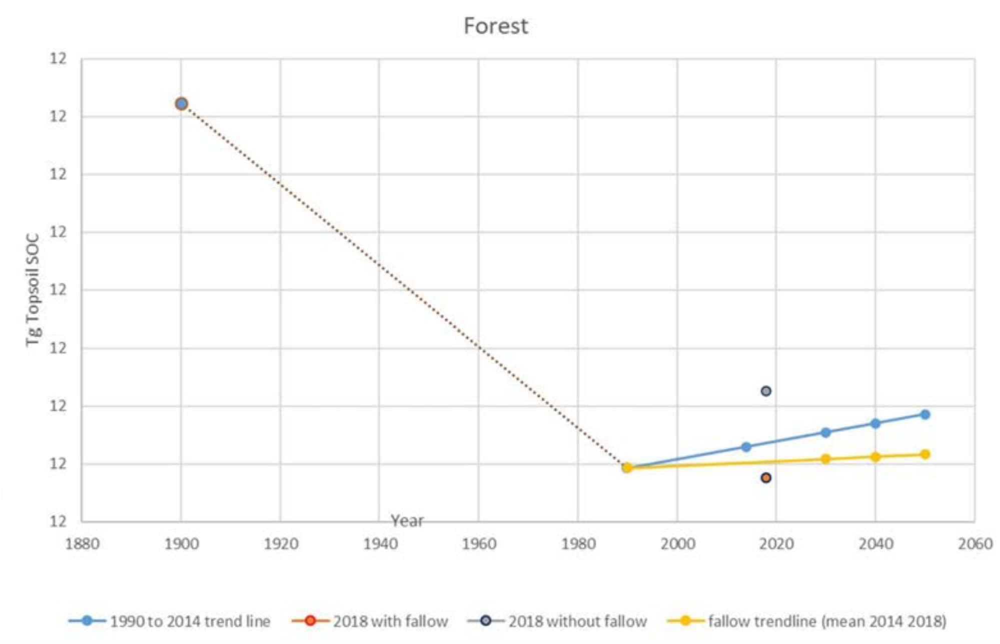


Figure 7.8: Forest SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1:Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

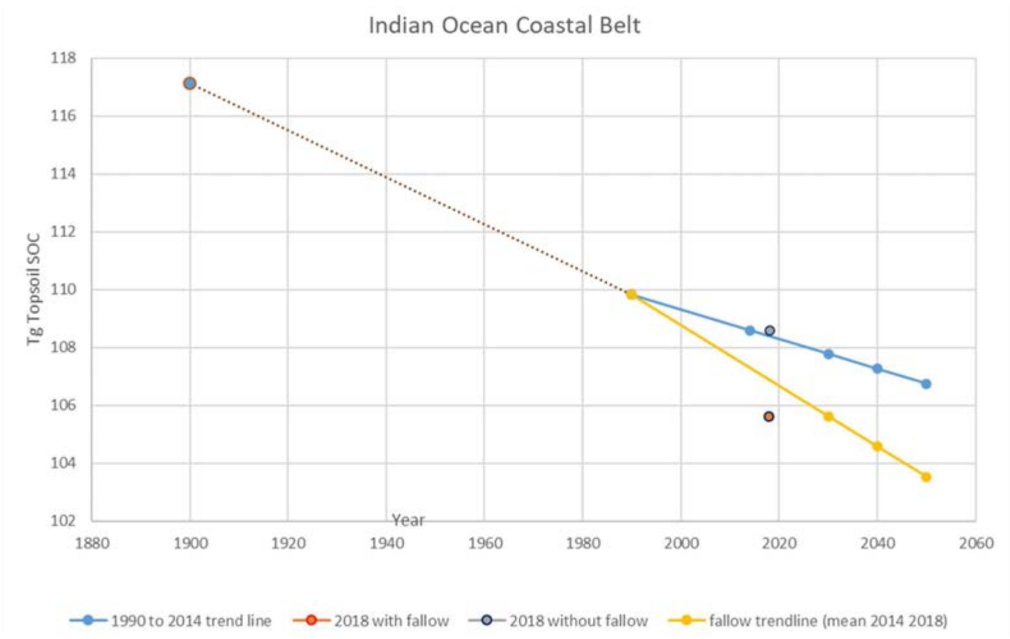


Figure 7.9: Indian Ocean Coastal Belt SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

Figure 7.10: Grassland SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

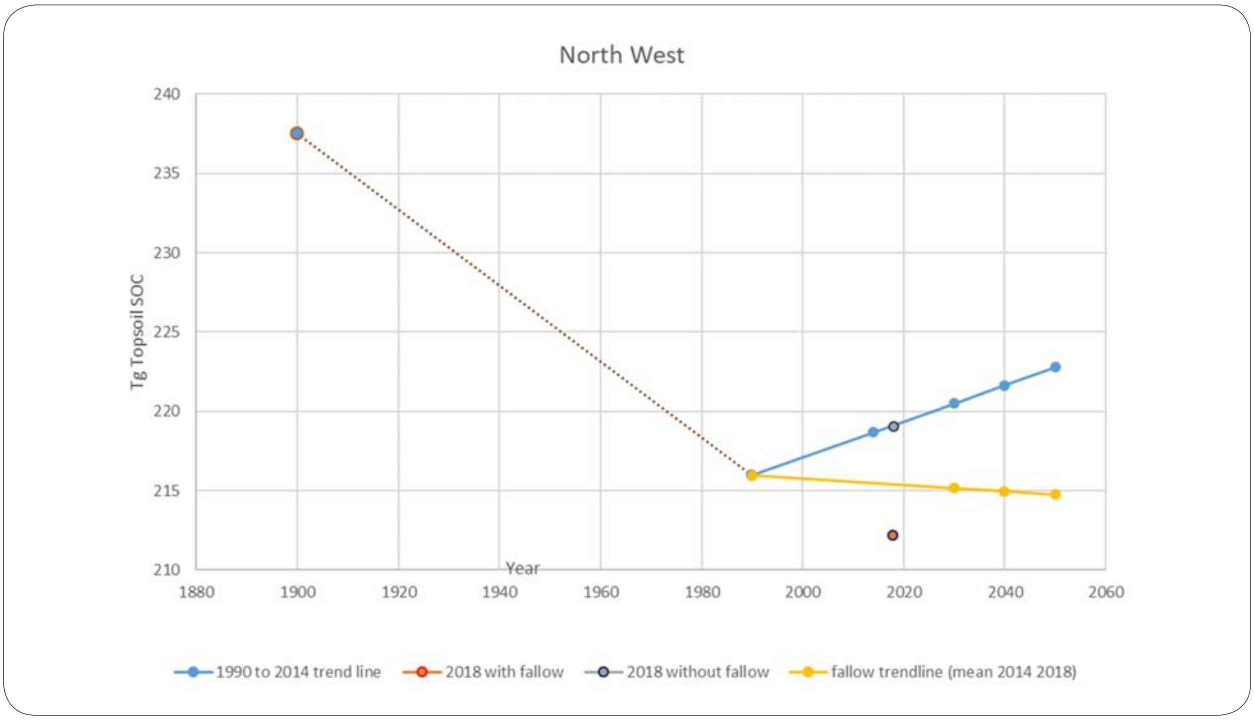


Figure 7.11: North West province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

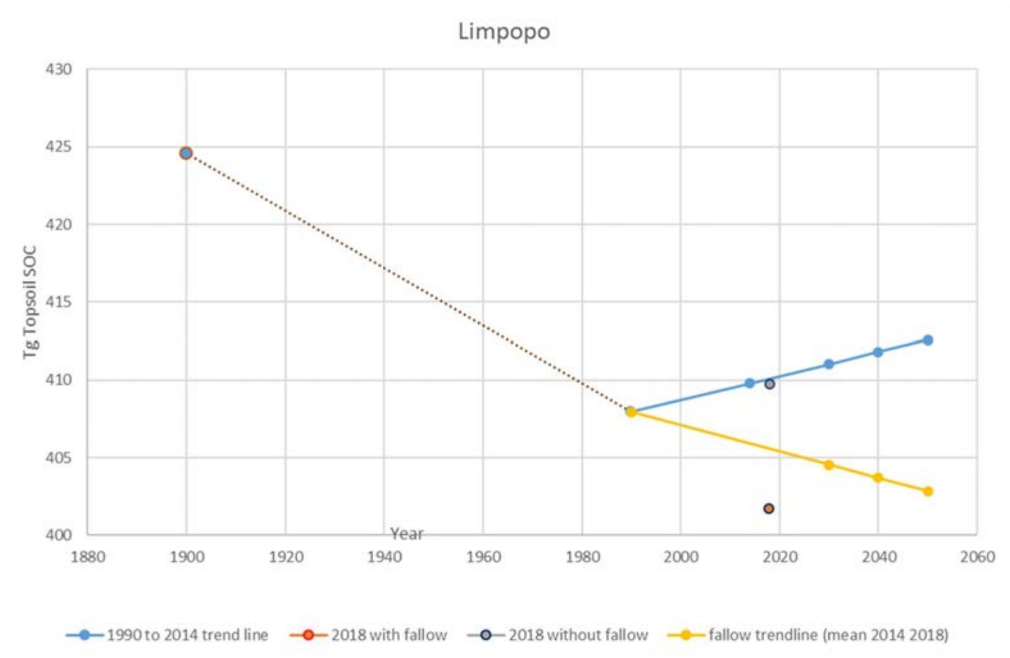


Figure 7.12: Limpopo province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

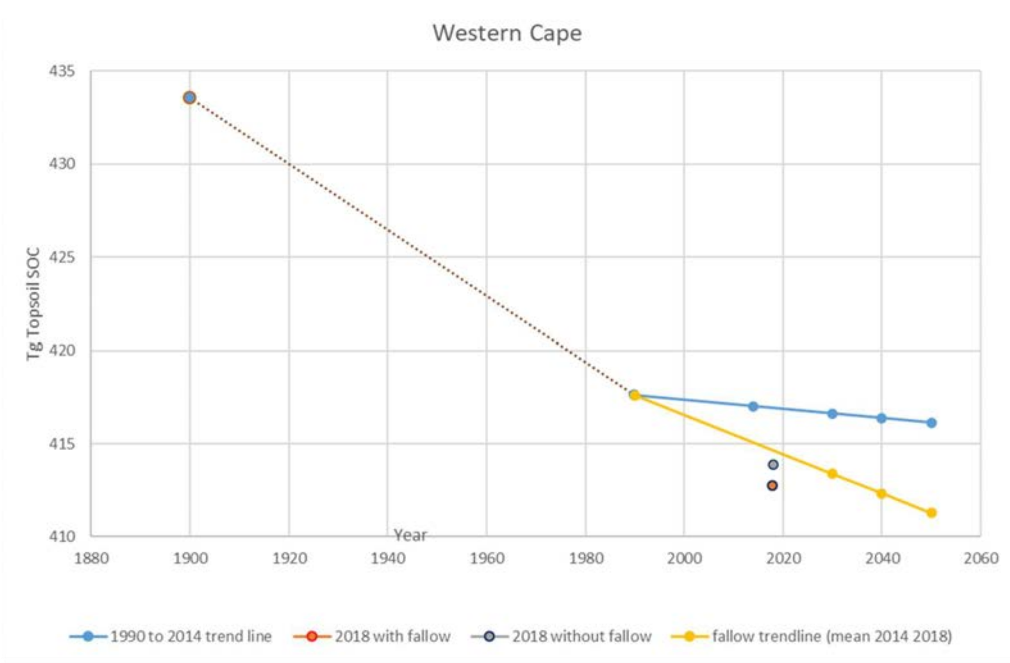


Figure 7.13: Limpopo province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

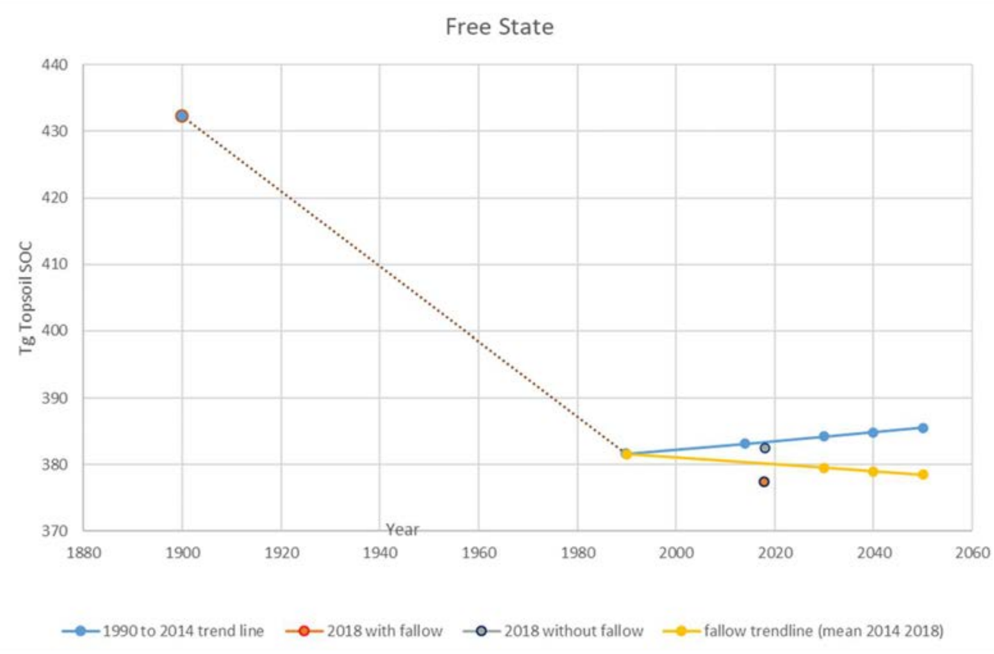


Figure 7.14: Free State province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

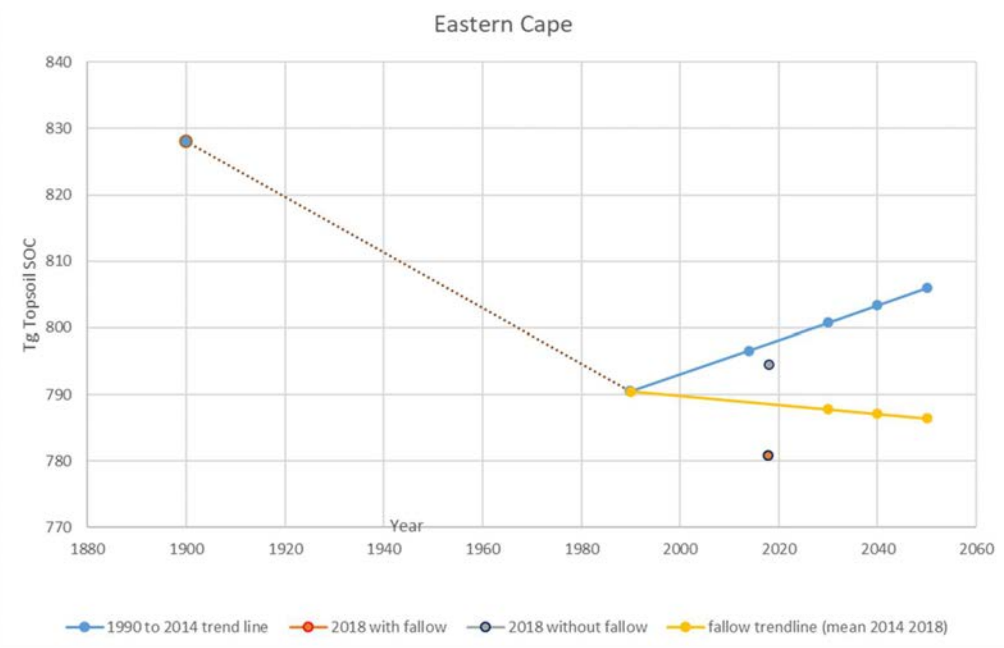


Figure 7.15: Eastern Cape province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

Figure 7.16: KwaZulu Natal province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

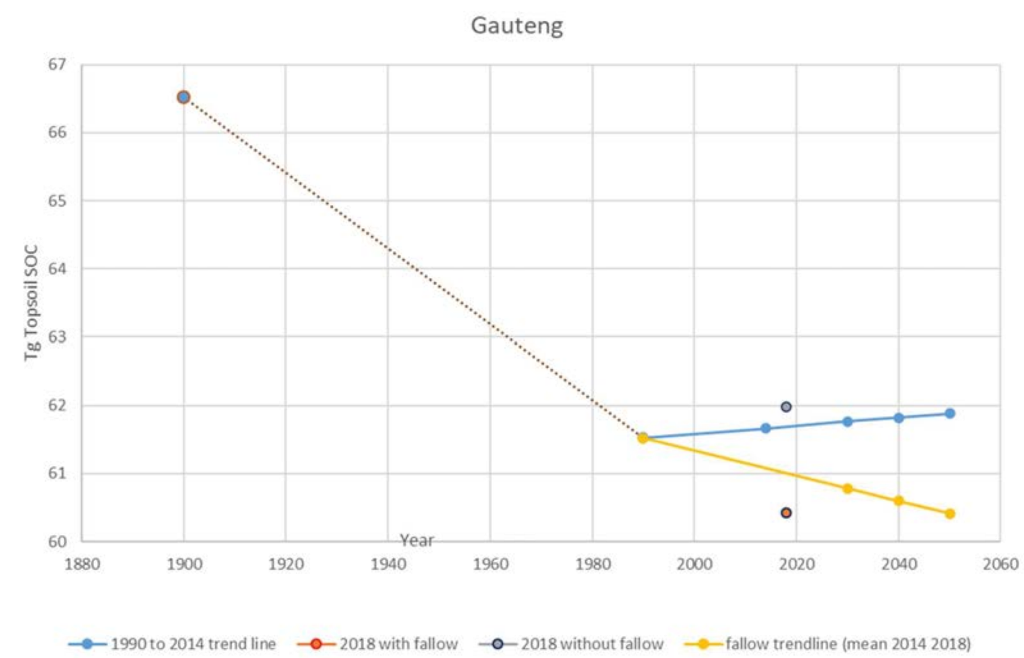


Figure 7.17: Gauteng province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

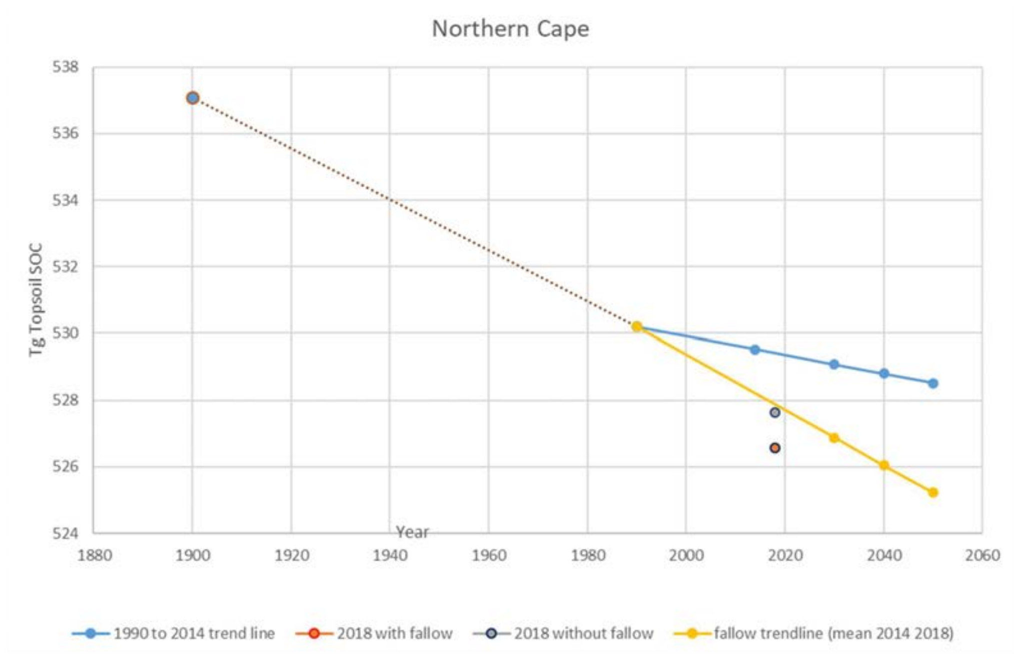


Figure 7.18: Northern Cape province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

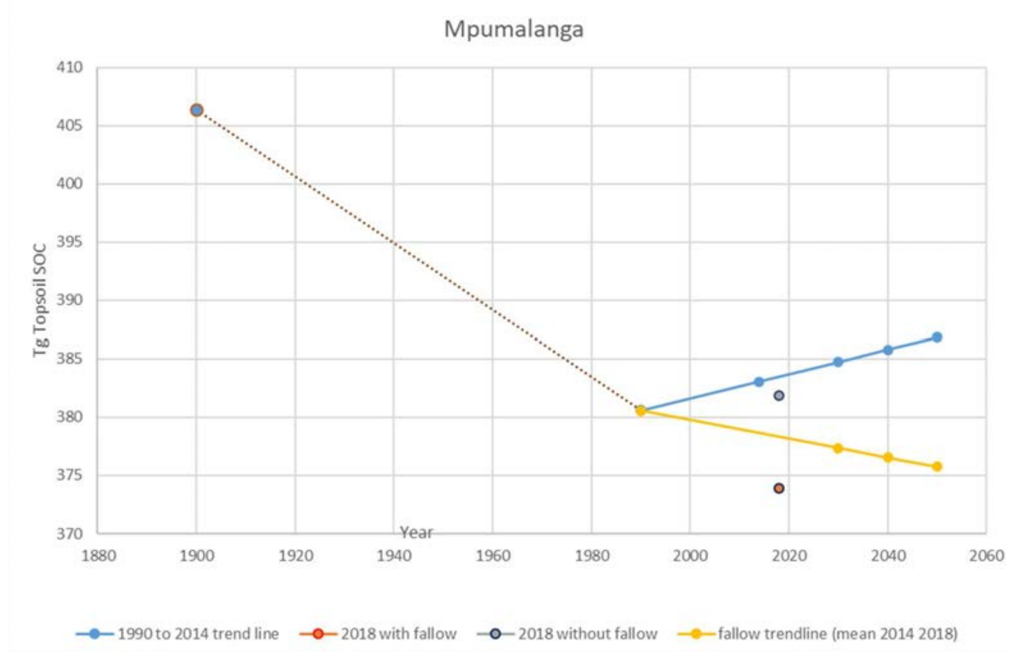


Figure 7.19: Mpumalanga province SOC loss between the reference value, 1990, 2014 and 2018 as well as linear projections to 2050 based on two extrapolation methods. Method 1: Linear extrapolation of the 1990 to 2014 data. Method 2: Linear extrapolation of the 1990 to the mean between the 2014 and 2018 data (with fallow land soil carbon loss included).

Table 15: Extrapolations of district level I SOC until 2050 based on either the 1990 to 2014 period (Method 1) , or based on the 1990 to the mean between the 2014 and 2018 (no fallow) data (Method 3). The annual rate of gain/loss for method 3 is given in the final column.

	Trends extrapolated from 1990 to 2014 NLC data Tg C						**Trends extrapolated from 1990 to the mean of 2014 to 2018 (no fallow) NLC data (the mean is given as the year 2016)**			**Rate Tg C/ year**
Fezile Dabi	68.1	57.0	57.3	57.4	57.6	57.7	57.3	57.5	57.8	12.0
Uthukela	64.2	61.7	61.2	60.9	60.7	60.5	61.3	61.1	60.8	-15.2
Umgungundlovu	73.1	68.8	68.3	67.9	67.7	67.4	68.5	68.4	68.2	-11.1
Mangaung	30.4	27.5	27.7	27.7	27.8	27.8	27.6	27.6	27.6	1.5
Johannesburg	7.1	6.9	7.0	7.0	7.1	7.1	7.0	7.0	7.1	3.5
City of Tshwane	23.4	22.1	22.0	21.9	21.9	21.9	22.1	22.0	22.0	-1.9
Nelson Mandela	9.5	9.2	9.3	9.3	9.3	9.3	9.3	9.3	9.3	1.6
Eden	112.6	108.6	108.6	108.6	108.5	108.5	108.3	108.1	107.8	-13.8
Dr Ruth Segomotsi	69.5	64.8	65.7	66.3	66.7	67.1	65.7	66.1	66.8	34.2
Sedibeng	17.6	15.5	15.5	15.5	15.5	15.5	15.6	15.6	15.6	1.7
Dr Kenneth Kau	44.8	38.8	39.4	39.8	40.1	40.4	39.5	39.9	40.4	27.0
Alfred Nzo	74.2	69.1	68.9	68.9	68.8	68.8	69.0	68.9	68.9	-3.5
Harry Gwala	84.8	80.7	79.7	79.1	78.7	78.2	80.2	79.9	79.5	-20.5
Sekhukhune	58.1	55.7	55.6	55.6	55.6	55.6	55.2	55.0	54.7	-16.5
John Taolo Gae	30.9	30.8	30.7	30.7	30.7	30.7	30.7	30.7	30.7	-2.3
Central Karoo	85.1	83.8	83.9	84.0	84.1	84.1	83.7	83.6	83.6	-3.9
West Rand	16.2	14.7	14.8	14.9	15.0	15.0	14.9	15.0	15.1	6.5
Pixley ka Seme	209.6	208.2	208.3	208.4	208.4	208.5	208.1	208.1	208.0	-3.5
Namakwa	179.2	175.5	174.5	173.9	173.5	173.1	173.9	173.1	171.8	-60.7
Frances Baard	31.1	30.1	30.4	30.6	30.8	30.9	30.5	30.6	30.9	13.0
Z F Mgcawu	86.3	85.6	85.5	85.5	85.4	85.4	85.3	85.2	85.0	-8.6
eThekwini	15.8	15.3	15.2	15.1	15.1	15.1	15.2	15.1	15.1	-3.2
Ekurhuleni	8.1	7.5	7.6	7.7	7.7	7.8	7.6	7.7	7.8	5.0
Amajuba	38.8	37.4	37.2	37.1	37.1	37.0	37.3	37.3	37.3	-2.4
Umzinyathi	50.1	47.7	47.3	47.1	46.9	46.8	47.5	47.3	47.2	-9.3
Umkhanyakude	74.4	71.8	70.8	70.1	69.7	69.3	71.2	70.8	70.3	-24.4
Zululand	87.7	84.2	83.5	83.0	82.8	82.5	83.7	83.5	83.2	-17.0
iLembe	24.3	22.0	21.6	21.4	21.2	21.1	21.6	21.3	21.0	-16.2
Uthungulu	63.2	59.6	59.2	58.9	58.7	58.5	59.2	58.9	58.6	-17.8
Gert Sibande	181.6	166.3	167.8	168.9	169.5	170.2	167.4	168.1	169.0	45.9
Overberg	63.3	59.0	58.8	58.7	58.6	58.5	58.7	58.6	58.3	-10.9

	Trends extrapolated from 1990 to 2014 NLC data Tg C						Trends extrapolated from 1990 to the mean of 2014 to 2018 (no fallow) NLC data (the mean is given as the year 2016)			Rate Tg C/ year
Ehlanzeni	146.1	143.0	143.1	143.1	143.1	143.2	142.9	142.9	142.8	-2.3
Nkangala	78.6	71.3	72.2	72.8	73.1	73.5	72.1	72.5	73.1	28.8
Vhembe	84.7	82.9	83.4	83.7	84.0	84.2	83.4	83.7	84.1	21.5
Mopani	69.0	67.5	67.6	67.6	67.6	67.7	67.6	67.6	67.7	2.7
Waterberg	147.5	139.2	140.2	140.8	141.2	141.6	140.6	141.4	142.4	54.2
Capricorn	65.3	62.7	63.0	63.2	63.4	63.5	63.0	63.1	63.2	8.4
Ngaka Modiri Mo	56.2	49.5	50.1	50.6	50.8	51.1	50.2	50.5	51.0	25.1
Bojanala	61.1	57.6	58.2	58.5	58.7	58.9	58.2	58.5	59.0	22.8
City of Cape Town	11.1	10.7	10.8	10.8	10.8	10.8	10.7	10.7	10.7	-0.5
Buffalo City	19.2	18.3	18.3	18.4	18.4	18.4	18.3	18.3	18.3	0.7
Cacadu	208.5	196.8	202.7	206.7	209.2	211.7	202.9	206.1	210.8	233.5
West Coast	77.7	73.5	73.6	73.7	73.7	73.8	73.3	73.2	73.1	-5.9

Discussion of baseline values

Different biomes, provinces and districts differ substantively in the rate of SOC changes between 1990 and the 2014/2018 period. In most instances there is an increase in SOC, when the 2018 fallow data is not included. In general, although there are exceptions, the 2018 data with fallow land excluded (i.e. treated as natural vegetation), plots close to the extrapolated 1990 to 2014 line, though in most situations is a slightly lower value. When fallow is included the total SOC loss is substantively greater, but as is discussed below, it is currently impossible to understand the rates of change.

The use of 1990 to 2014 or 1990 to the mean of 2014 to 2018 (no fallow) (as in the modelled 2016 value), provides very similar results in most circumstances (as demonstrated using Method 3). This value might be the most appropriate baseline to use, as it includes the most up-to-date dataset (2018) and is also based on two recent datasets, rather than one. This potentially also reduces noise from factors such as floods or droughts.

The use of the Method 2 data (the mean between 2014 and 2018 with fallow), or simply the 1990 to 2018 (with fallow) trendline is not an advisable dataset to use. Much of the fallow may have occurred before 1990, and since we currently do not know the amount of fallow before 1990 versus after 1990, it is impossible to accurately give a value for SOC in 1990. Changing the 1990 value will, however, radically change the slope of the baseline. Although inclusion of the fallow class is recommended for a better estimate of total SOC loss, unless estimates can be made of the fallow extent in 1990 it is impossible to accurately calculate rates of change[3].

3 The South African National Biodiversity Institute (SANBI) has an initiative to attempt to map agricultural field extents from old 1:50 000 maps. This could aid in understanding the extent of fallow when compared to more recent cropland location. It may also be possible to add this fallow classification using satellite imagery, to older (i.e. the 1990) NLC product. Both these options are beyond the scope of this project.

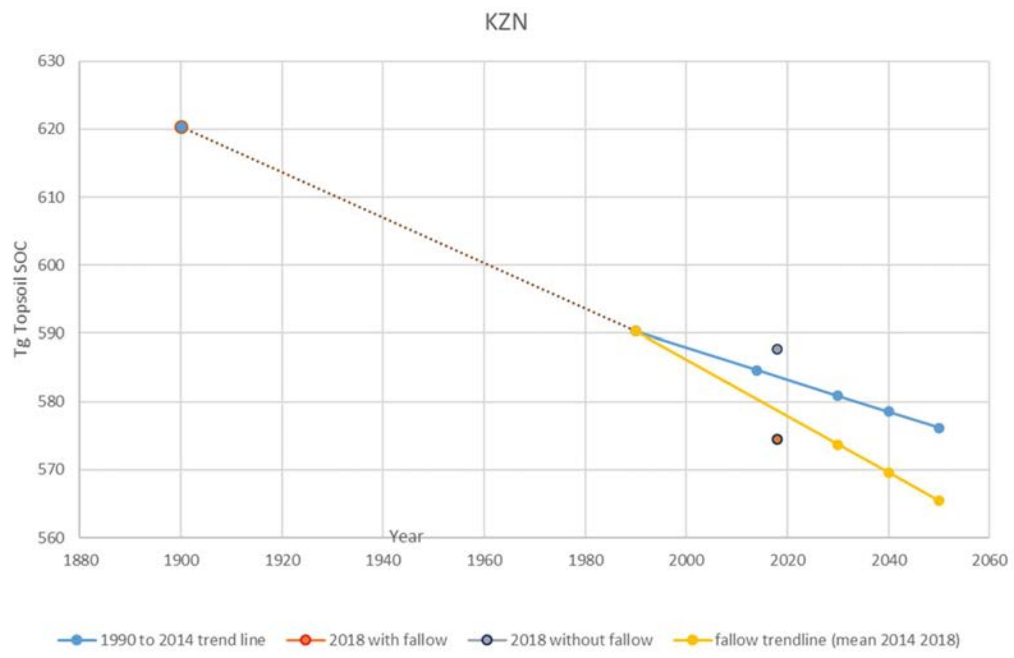


Figure 7.20: An illustration of the effect of inclusion of drought induced bare ground on the 1990 SOC loss. When the bare ground class was switched off (red line) the steep rates of SOC increase disappeared.

In comparing data from the Western Cape (from provincial data) as opposed to the Fynbos (biome data) there is a substantial difference between the 2014 and 2018 results. It appears that for some reason the 2014 results give an overly optimistic view of SOC increases that are not supported by the 2018 data.

The Albany Thicket data has a disproportionately high rate of apparent SOC accumulation, and this, appears to be as a result of drought conditions in the 1990 period that resulted in a high proportion of the land being mapped in the 1990 NLC as barren. If this barren class is excluded (See Figure 7.20) then there is a huge reduction in the loss in SOC as observed in 1990. However, this difference is reduced in both 2014 and 2018 (with no fallow). Extrapolation of this new baseline, where bare ground is excluded, has a greatly reduced but still positive slope.

A number of uncertainties impact on the baseline values. These key issues are summarised below:

- The 1990 data had extensive areas of bare ground (especially in the Eastern Cape, and to a lesser extent the Western Cape. These areas of bare ground are largely reduced in later land cover products. This may indicate a reduction in degradation but is more likely due to drought conditions at the time that the 1990 imagery was acquired. South Africa was known to have suffered a severe drought in the early 1990's. The impact of this on the data is that the 1990 period could have had unnaturally high bare ground (and hence low soil SOC). This therefore could give a false sense that land management caused reduced bare ground.

  Given the long-time interval between the 1990 and 2014 data (24 years) versus the 4 years between the 2014 and 2018 data, any factors leading to abnormal 1990 data will have a strong "fulcrum" effect, radically changing the perceived rate of change as indicated by the slope of the line (this illustrated in Figure 7.20).

These drought effects on the 1990 data may likely also have had an impact on Nama Karoo data, but appear to not have had as profound an influence on other biomes or regions.

- Urban expansion has been given the same carbon value as natural vegetation. This was a pragmatic decision based on IPCC guidelines and the fact that there are no detailed studies to support alternative data in South Africa. Although it is very likely that middle and high income suburbia have increased carbon, it is also quite likely that low income areas with low vegetation cover might have lost SOC. It is also probable that some areas of urban expansion took place on agricultural or degraded land with already reduced SOC stocks which would not have recovered.
- As discussed above, inclusion of the fallow class, though important for understanding the true carbon dynamics, cannot be used for trend analysis. If fallow is ignored, i.e. treated as natural, it implies that carbon stocks from abandoned fields has reverted back to the pre-disturbance level (i.e. there has been full recovery. In truth this is unlikely, and is probably the main reason for the perceived gains in carbon stocks over much of the country.

TECHNICAL BACKSTOPPING OF WORKSHOPS

Objectives and deliverables

The objective of this task to provide a technical backstopping to consultative workshops that will be conducted by DEA staff. In addition material will be prepared (PowerPoint slides) to assist the DEA in communicating information relating to the atlas and its use.

Deliverable – PowerPoint presentations and/or other input material.

PowerPoints, tables and datasheets developed in consultation with DEFF.

INTELLECTUAL PROPERTY AND OTHER CONSIDERATIONS AND CONSIDERATIONS

All data generated from this project are in the public domain and made available to DEFF, municipalities or any other interested parties. This includes all outputs from the modelling process.

The model for generating the outputs will be made available on a royalty free license use basis and also placed in the public domain. Input data used as model inputs will remain the property of the data providers who generated the data. Where possible, and through agreement with the data provider, this will be made publicly available. Alternatively information will be provided as to where this data can be accessed.

Note: *all data used to derive the model outputs will be publicly available. However, in some instances the use of the data does not permit a third party to distribute the information and those wishing to use it will need to access it from the original source.*

REFERENCES

Bond, W.J. Stevens, N. Midgley, G.F. Lehmann C.E. (2019). The trouble with trees: afforestation plans for Africa. Trends Ecol. Evol. (Amst.) (2019), 10.1016/j.tree..08.003.

Chang, C.C. and Lin, C.J. (2001). Libsvm: A library for support vector machines [eb/ol].

DEA. (2015). The South African National Terrestrial Carbon Sink Assessment. Pretoria, South Africa.
What we refer to as NTCSA 2014.

Friedman, J., Hastie, T., and Tibshirani, R. (2001). *The elements of statistical learning*, volume 1.
Springer series in statistics New York.

Guevara, M. *et al.* (2018). No silver bullet for digital soil mapping: Country-specic soil organic carbon estimates across latin america. SOIL Discussions, 2018:1{20}. doi: 10.5194/soil-2017-40. URL
https://www.soil-discuss. net/soil-2017-40/.

Hengl, T., de Jesus, M.J, Heuvelink, G.B. M., Ruiperez Gonzalez, M Kilibarda, M., Blagotic, A., Shangguan, W., Wright, M.N., Geng,X., *et al.* (2017). SoilGrids250m: Global gridded soil information based on machine learning. 12(2):1{40,. doi: 10.1371/journal.pone.0169748. URL https://doi.org/10.1371/journal.pone.0169748.

Hengl, T., de Jesus, J. M., MacMillan, R. A., Batjes, N. H., Heuvelink, G. B., Ribeiro, E., Samuel-Rosa, A., Kempen, B., Leenaars, J. G., Walsh, M. G., *et al.* (2014). Soilgrids1km—global soil information based on automated mapping. *PLoS One*, 9(8):e105992.

Hengl, T., Heuvelink, G. B., Kempen, B., Leenaars, J.G., Walsh, M. G., Shepherd, K. D., Sila, A., MacMillan, R. A., de Jesus, J. M., Tamene, L., *et al.* (2015a). Mapping soil properties of Africa at 250 m resolution: random forests significantly improve current predictions. *PloS one*, 10(6):e0125814.

Henry, M. Valentini, R. and. Bernoux. M. (2009). Soil carbon stocks in ecoregions of Africa. Biogeosciences Discussions, 6:797{823,. doi: 10.5194/bgd-6-797-2009. URL
https://www.biogeosciences-discuss.net/6/797/2009/.

IPCC. (2006). IPCC Guidelines for National Greenhouse Gas Inventories; Vol.4 Agriculture, Forestry and Other Land-Use; Prepared by the National Greenhouse Gas Inventories Programme. (S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.). Kanagawa: IGES, Japan, http://www.ipcc-nggip.iges.or.jp.

IPCC. (2019). Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. (E. Calvo Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, N. S., … S. Federici, Eds.) (Vol. 4). Switzerland: Intergovernmental Panel on Climate Change. Retrieved from
https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

IPCC. (2019). Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. (P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H. O. Portner, D. C. Roberts, … J. Malley, Eds.). Intergovernmental Panel on Climate Change

Jacquier, D. and Seaton, S. (2010). Spline tool for estimating soil attributes at standard depths. CSIRO, Land and Water, Australia, 4 p.

Leenaars J.G.B., van Oostrum, A.J.M. and Ruiperez Gonzalez, M. (2014). Africa Soil Profiles Database, Version 1.2. A compilation of georeferenced and standardised legacy soil profile data for Sub- Saharan Africa (with dataset). ISRIC Report 2014/01. Africa Soil Information Service (AfSIS) project and ISRIC - World Soil Information, Wageningen, the Netherlands. 162 pp.; 16 fig.; 10 tab.;

Mararakanye, N. and Le Roux, J. J. (2011). Manually Digitizing of Gully Erosion in South Africa Using High Resolution: SPOT 5 Satellite Imagery at 1:10 000 scale. Pretoria

Mucina, L., Rutherford, M.C., (2006). The Vegetation of SA, Lesotho and Swazland. Strelitzia, Pretoria.

NTCSA (2020). This report and its additional components such as the summary for policy makers and the web based atlas.

NTCSA 2014. DEA. (2015). The South African National Terrestrial Carbon Sink Assessment. Pretoria, South Africa.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos,A., Cournapeau, D., Brucher, M., Perrot, M., and Duchesnay, E. (2011). Scikitlearn: Machine learning in Python. *Journal of Machine Learning Research*,12:2825–2830.

Poeplau C., Vos, C. and Don. A. (2017). Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content. SOIL, 3(1):61{66,.doi: 10.5194/soil-3-61-2017. URL https://www.soil-journal.net/3/61/2017/.

Schulze, R (2007). South African Atlas of climatology and agrohydrology. Water Research Commission. Pretoria. RSA. WRC report 1489/1/06

Schulze, R and Schütte, R. (2018) identification and mapping of soils rich in organic carbon in south africa as a climate change mitigation option. Contributing also as an Input to the Electronic National Carbon Sinks Atlas Developed by DEA. GIZ Contract No: 83258289. Schulze and Associates. May 2018.

Stevens, N. Erasmus, B.F.N., Archibald, S., Bond, W.J. (2016). Woody Encroachment over 70 Years in South African Savannahs: Overgrazing, Global Change or Extinction Aftershock? Philos. Trans. R. Soc. B Biol. Sci., 371, 20150437.

Thompson. M. (2014). 2013-2014 South African National Land-Cover Dataset. Data user report and metadata. GEOTERRAIMAGE. Pretoria.

Vapnik, V. (2013). *The nature of statistical learning theory*. Springer science & business media.

Von Maltitz, G.P., Gambizo, J., Kellner, K., Rambau, T., Lindeque, L. and Kgope, B. (2019). Experiences from the South African land degradation neutrality target setting process. Environmental Science and Policy. Volume 101, November 2019, Pages 54-62. IPBES 2018

Walsh, M.G., Ahamed, S., Hartemink, A.E., Huising, J., Okoth, P., and Palm, C.A. (2009). A new information system for managing sub-saharan Africa's soil: Why and how?,.

Wessels, K.J., Prince, S.D., Malherbe, J., Small, J., Frost, P.E., VanZyl, D., (2007). Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in SA. J. Arid Environ. 68, 271–297. https://doi.org/10.1016/J.JARIDENV.2006.05.015

Yigini, Y., Olmedo, G.F., Viatkin, K., Baritz, R. and R Vargas, R.R. (editors). (2017) Soil Organic Carbon Mapping Cookbook. FAO, 2nd edition, 220pp. URL http://www.fao.org/3/a-bs901e.pdf.

THE SAEON - DEA COLLABORATIVE AGREEMENT

SAEON is engaged with DEA in the following collaboration projects:

1. Development of SANEIM (South African National Environmental Information Management) platform in collaboration with various directorates and agencies within DEA.
    a. Outcome: Integrated metadata for DEA in respect of all environmental data and digital objects.
    b. Funding: Each party provides own funding.

2. Establishment and operation of a platform for Invasive Alien Plants assessment, for use by DEA, SAEON, and the ARC to refine estimates of IAPs, and potentially bush encroachment and firewood availability.
    a. Outcome: Updated species distributions for Invasive Alien Plants and Bush Encroachment.
    b. Funding: DEA contracts SAEON to support ARC hardware and software.

3. Provision of human resources to manage the Marine Information Management System (MIMS) and South African Data Centre for Oceanography (SADCO) in collaboration with DEA Oceans and Coasts, and provision of infrastructure, data, and technical guidance to OCIMS.
    a. Outcome: Operational systems (MIMS, SADCO) integrated with OCIMS.
    b. Funding: DEA contracts SAEON.

4. Collaboration with SANBI to publish SANBI data via SARVA, and development of common technical infrastructure where appropriate.
    a. Outcome: Synchronised metadata.
    b. Funding: Each party provides own funding.

5. Development of the National Climate Change Response Information System (NCCRIS) which integrates data from SARVA, BioEnergy Atlas, National Climate Change Response Database, Carbon Sinks Atlas, GHG Emissions Reporting, and many more to provide a comprehensive record and view of our national response.
    a. Outcome: Operational system (NCCRIS) integrated with various systems.
    b. Funding: DEA contracts SAEON.

CARBON SINKS QGIS PLUGIN MANUAL

This is appended as a separate PDF QGIS-plugin-user-manual-quick-start.pdf. This is also available as a download from the web based carbon sinks atlas https://ccis.environment.gov.za/carbon-sinks/#/.

USING THE QGIS PLUGIN TO COMPUTE NATIONAL TERRESTRIAL CARBON STOCKS

This section gives step by step instructions on how to run the QGIS plug in in order to re-analyse the NTCSA. This could be done when a new NLC dataset becomes available or if there are improvements to any existing datasets.

The QGIS plugin as described in Appendix 2 provides a highly customisable and simple to run interface for computing the carbon stocks of the NTCSA.

Data preparation

Core to use of the modelling framework is preparing all the data required into identical datasets in terms of resolution and projection. We have used the Department of Environment Forestry and Fisheries (DEFF) data grid as our standard coordinate and projection system, though in truth, alternative systems can be used providing all data uses the same layout.

For the NTCSA a 1km^2 grid was used, this means each grid cell is 100 ha. Since the data is computed in t/ha results need to be multiplied by 100 to get the total mass per grid cell.

Although the modelling framework can be set to find data from any directory and with any name, we have found that by using a set of short and constant names for data layers, and keeping all data in a single input directory, is the simplest way to populate and run the model. If alternate data is needed, e.g. to run the model using a different year's land cover, then it simple to just replace the old data with new data and re-run the model. This means the model can be re-run for a new set of land cover data in a very short time, once the data has been processed to the correct format (which takes quite a long computational time).

The following datasets with the suggested short names are required to run the model. If alternative names are used for the datasets then these will need to be changed in the model using the following process:

- Select the directory where the data is to be found, refresh the data and add the desired coverages.
- Click on the layer in the model that needs to be changed.
- Click on "add layer".
- Click again on the layer in the model that needs to be changed and select the new layer.

NB *– This 3 step process is needed to ensure that each new layer is loaded and active.*

Table A3.1: Summary of input data required to run the model.

Description and units	Unit	Source	File name used in model
Proportion of each LU covered by each land cover as per Table 2. This is an individual file per land cover type.	m^2	NLC 1990 NLC 2014 NLC 2018 etc.	NLC_1990_ClassA_Water_m^2_km^2.tif NLC_1990_ClassB_Wetlands_m^2_km^2.tif NLC_1990_ClassC_IndigenousForest_m^2_km^2.tif NLC_1990_ClassD_NaturalVegetation_m^2_km^2.tif NLC_1990_ClassE_CommercialAgriculture_m^2_km^2.tif NLC_1990_ClassF_PivotAgriculture_m^2_km^2.tif NLC_1990_ClassG_Orchards_m^2_km^2.tif NLC_1990_ClassH_Viticulture_m^2_km^2.tif NLC_1990_ClassI_Pineapple_m^2_km^2.tif NLC_1990_ClassJ_SubsistenceAgriculture_m^2_km^2.tif NLC_1990_ClassK_SugarcaneIrrigated_m^2_km^2.tif NLC_1990_ClassL_SugarcaneDry_m^2_km^2.tif NLC_1990_ClassM_PlantationForest_m^2_km^2.tif NLC_1990_ClassN_Mines_m^2_km^2.tif NLC_1990_ClassO_Bare_m^2_km^2.tif NLC_1990_ClassP_Built-up_m^2_km^2.tif NLC_1990_ClassQ_Fallow_m^2_km^2.tif NLC_2014_ClassA_Water_m^2_km^2.tif NLC_2014_ClassB_Wetlands_m^2_km^2.tif NLC_2014_ClassC_IndigenousForest_m^2_km^2.tif NLC_2014_ClassD_NaturalVegetation_m^2_km^2.tif NLC_2014_ClassE_CommercialAgriculture_m^2_km^2.tif NLC_2014_ClassF_PivotAgriculture_m^2_km^2.tif NLC_2014_ClassG_Orchards_m^2_km^2.tif NLC_2014_ClassH_Viticulture_m^2_km^2.tif NLC_2014_ClassI_Pineapple_m^2_km^2.tif NLC_2014_ClassJ_SubsistenceAgriculture_m^2_km^2.tif NLC_2014_ClassK_SugarcaneIrrigated_m^2_km^2.tif NLC_2014_ClassL_SugarcaneDry_m^2_km^2.tif NLC_2014_ClassM_PlantationForest_m^2_km^2.tif NLC_2014_ClassN_Mines_m^2_km^2.tif NLC_2014_ClassO_Bare_m^2_km^2.tif NLC_2014_ClassP_Built-up_m^2_km^2.tif NLC_2014_ClassQ_Fallow_m^2_km^2.tif NLC_2018_ClassA_Water_m^2_km^2.tif NLC_2018_ClassB_Wetlands_m^2_km^2.tif NLC_2018_ClassC_IndigenousForest_m^2_km^2.tif NLC_2018_ClassD_NaturalVegetation_m^2_km^2.tif NLC_2018_ClassE_CommercialAgriculture_m^2_km^2.tif NLC_2018_ClassF_PivotAgriculture_m^2_km^2.tif NLC_2018_ClassG_Orchards_m^2_km^2.tif

Description and units	Unit	Source	File name used in model
			NLC_2018_ClassH_Viticulture_m²_km².tif NLC_2018_ClassI_Pineapple_m²_km².tif NLC_2018_ClassJ_SubsistenceAgriculture_m²_km².tif NLC_2018_ClassK_SugarcaneIrrigated_m²_km².tif NLC_2018_ClassL_SugarcaneDry_m²_km².tif NLC_2018_ClassM_PlantationForest_m²_km².tif NLC_2018_ClassN_Mines_m²_km².tif NLC_2018_ClassO_Bare_m²_km².tif NLC_2018_ClassP_Built-up_m²_km².tif NLC_2018_ClassQ_Fallow_m²_km².tif
Land cover factor – this is a factor by which soil carbon is lost (or gained) due to land management practice.	Integer % will be divided by 100 to form proportion in model.	See appendix 4	LC_A_factor LC_B_factor LC_C_factor LC_D_factor LC_E_factor LC_F_factor LC_G_factor LC_H_factor LC_I_factor LC_J_factor LC_K_factor LC_L_factor LC_M_factor LC_N_factor LC_O_factor LC_P_factor LC_Q_factor
Biomes (using vegmap biome codes – note Albany Thicket (code 5) is classified with Nama-Karoo (code 3) in some vegmap products, Azonal was changed to 9 and IOCB to 10.	1 – 10	SANBI 2018 vegmap	BIOME

Description and units	Unit	Source	File name used in model
Mean annual precipitation.	Mm	Schultz 2006	MAP
Proportion of sand in soil.	%	ISRIC	Sand
Tree biomass.	t/ha	CSIR	AGW_tree
Urban area.	I	Computed from NLC above	URBAN
FaPAR	Annual sum		FAPAR
Tree cover fraction TCF.	%		TCF
Herb values for different agricultural crops per municipality. Herb_natural is computed in the model.	t/ha	NTCSA 2014	Herb_irr Herb_DL_sub Herb_DL_com Herb_sug Herb_Natural

Table A3.2: Important variables computed in the model including output layers. Note, biomass is in t/ha biomass NOT t/ha C.

Description and units	Unit	Source	
Above ground woody biomass	t/ha	Tree biomass Urban biomass	AGW
Below ground woody biomass	t/ha	Tree biomass	BGW
Above ground Herbaceous biomass	t/ha	AGH equation Crop biomass	AGH
Below ground herbaceous biomass	t/ha	AGH	BGH
Litter	t/ha	Biome factors	LGL
SOC	tC/ha	ISRIC and Schulze data	SOC
Urban area (areas with greater than 60 % from NLC_P (where NLC_P is the urban class)	I	Computed from NLC above	Urban

Table A3.3: NLC classes from the 1990, 2014 and 2018 NLC used to create the classes used by the NTCSA2020.

NTCSA 2020 class	Class 1990	Class 2014	Class 2018	Name Class for NTCSA 2020	Use
A	1, 2	1, 2	14-21	Water	Mask out water bodies.
B	3	3	22 23 73	Wetlands	Treated as natural vegetation.
C	4	4	1	Indigenous forest	Treated as natural vegetation.
D	5-9	5-9	3 4 8-13 24	Natural vegetation	This is considered baseline for all carbon pools.
E	10-12	10-12	40	Commercial agriculture no irrigation / dryland	Correct for soil carbon loss. Herb layer estimates.
F	13-15	13-15	38 39	Pivot agriculture and other irrigated	Correct for soil carbon loss. Herb layer estimates.
G	16-18	16-18	32	Orchards	Correct for soil carbon loss. Herb layer estimates.
H	19-21	19-21	33	Viticulture	Correct for soil carbon loss. Herb layer estimates.
I	22	22	35	Pineapple	Correct for soil carbon loss. Herb layer estimates.
J	23-25	23-25	41	Subsistence agriculture	Correct for soil carbon loss. Herb layer estimates.
K	26-27	26-27	34	Sugarcane irrigated	Correct for soil carbon loss. Herb layer estimates.
L	28-31	28-31	36 37	Sugarcane dry	Correct for soil carbon loss. Herb layer estimates.
M	32-34	32-34	5-7	Plantation forests	Mask out of plantations. Plantation AGW calculations.
N	35-39	35-39	68-72	Mines	Corrections for mine area.
O	41-40	41-40	25-31	Bare	Corrections for bare areas. For the Karroo no correction is made as the natural vegetation misclassifies as bare.
P	42-72	42-72	47-67	Build-up classes	Corrections for build-up areas.
Q			42-46	Fallow	Considered as natural veg for vegetation, but as carbon loss to soils.

Data units

Data can be entered as any unit e.g. t/ha, kg/m^2, g/m^2 etc.

It is however important to ensure that all data is converted to a common format before doing the final summation of results. This typically involves multiplying the final result by a constant such as 0.001.

Note, data is computed as values per unit area (e.g. per m^2, ha or km^2). These values are not the same as the size of the land units (raster resolution i.e. 1km^2 in the current example). It is therefore important to multiply the value by the area of the LU if calculating total carbon. In the current example carbon is represented as t/ha and the LU is 1km^2. Therefore to calculate the carbon per LU requires multiplying by 100.

Order of calculations

All sub-components must be computed first before calculating total carbon.

The full mode

The logic and pseudocode for the entire model is given in the table below. Individual components and how they can be coded into the model interface are provided in later sections.

Table A3.4: Pseudocode for the carbon stock calculations.

Pseudocode	Comments	Notes of units
Above ground woody (ABW)		
AGW = if URBAN = 0 then WOODYt_km else FAPAR x 5000 / 100	URBAN mask (0/1) AGW_tree FAPAR	/100 to convert g/m^2 to tonnes / ha
Below ground woody (BGW)		
BGW = AGW*		
For MAP>800 BGW=0.25AGW 300< MAP<800 BGBwoody=(- 0.0035MAP+3.05)*AGW MAP<300 BGBwoody=2.0*AGBwoody	BGW is based on AGW but changes with rainfall	t/ha
Above ground biomass herb		
For non-agricultural vegetation		
a=-0.0376*sand%+3.442; a=0.1 if Sand%>92; a=1.1 if Sand%<64	Formula for a and C. these are precalculated and need not be calculated each time unless formula is changed.	
c=328-142/a		
AGH_Natural = 0.5*0.45*a*(MAPc)*(1-TCF/0.65) for TCF<0.65; AGBherb=0 if TCF>0.65	Computes natural vegetation above ground herb	Computed as g/m^2 X 100 to give t/ha

Pseudocode	Comments	Notes of units
If agricultural		
This is computed per municipal area and stored in a number of layers per agricultural class		
AGH_LCA = NLC_A / 1000 000 x 0	Water = 0 AGH	g/m^2
AGH_LCB = NLC_B / 1000 000 x Herb_ Natural	wetlands	g/m^2
AGH_LCC = NLC_C / 1000 000 x Herb_Natural	Indigenous forest	g/m^2
AGH_LCD = NLC_D / 1000 000 x Herb_Natural	Natural Veg	g/m^2
AGH_LCE = NLC_E / 1000 000 x Herb_DL_Com	Commercial dryland	g/m^2
AGH_LCF = NLC_F / 1000 000 x Herb_DL_Irr	Pivot	g/m^2
AGH_LCG = NLC_G / 1000 000 x 0	Orchard	g/m^2
AGH_LCH = NLC_H / 1000 000 x 0	Viticulture	g/m^2
AGH_LCI = NLC_I/ 1000 000 x Herb_DL_Irr	Pineapple	g/m^2
AGH_LCJ = NLC_J / 1000 000 x Herb_DL_Sub	Sub Agric	g/m^2
AGH_LCK = NLC_K / 1000 000 x Herb_Sug	Irrigated sugar	g/m^2
AGH_LCL = NLC_L / 1000 000 x Herb_Sug	Dryland sugar	g/m^2
AGH_LCM = NLC_M / 1000 000 x 0	Plantation	g/m^2
AGH_LCN= NLC_N/ 1000 000 x 0	Mines	g/m^2
AGH_LCO = NLC_O / 1000 000 x 0	Bare	g/m^2
AGH_LCP= NLC_P/ 1000 000 x 0	Build-up – note, a generic value for all Build-up vegetation is computed for AGW	g/m^2
AGH_LCQ = NLC_Q / 1000 000 x Herb_ Natural	Fallow – this is given the same value as natural vegetation	g/m^2
Sum (AGH_LCA to AGH_LCQ)		g/m^2
Below ground herb		
BGH=AGH for natural vegetation	Use same code as for AGH with the additional multiplier for crops	
BGH+ AGHX0.2 for crops		

Pseudocode	Comments	Notes of units
	Litter	
AGL = 90 + 22 for grasslands		g/m^2
AGL = 121 + 49 gC/m^2 for savannas		g/m^2
AGL= 900 + 50 for forests		g/m^2
AGL= 254 +52 for thickets		g/m^2
AGL = 50 + 10 for karoo		g/m^2
AGL= 1500 + 150 for fynbos		g/m^2
AGL= 0 for desert		g/m^2
	Soil carbon	
LCA = LC_A_factor x LC_management_factor x SOC30 X NLC_A x 0.0000001 To LCA = LC_Q_factor x LC_management_factor x SOC30 X NLC_Q x 0.0000001	Where: LC_X_factor is a multiplier for soil loss in land cover X LC_management_factor is a multiplier for management impacts SOC30 is topsoil carbon in kg/m^2 NLC_X is the area of land in m^2 of land cover X	t (in effect per km^2) Note factors have been multiplied by 10 to make integer t
Total soil carbon = (LCA+LCB+LCC … LCQ) X 0.01+ SOC30_100		LC is total t carbon per LC class i.e. div 100 to get per mean per ha
	Total organic carbon	
TEOC = SOC + (AGBwoody + BGBwoody + DW + AGBherb +BGBherb + AGL)*0.42	Note, soil is in tC/ha whilst the rest is in t Biomass / ha, hence the multiplier of 0.42.	Total terrestrial carbon

Above and below ground woody biomass

This used two sets of data, one for urban areas and one for rural areas. Urban areas are calculated based FaPAR whilst rural areas used the CSIR generated tree cover product.

Notes on developing and running the code in the QGIS modelling interface

Consult the QGIS plugin manual: QGIS-plugin-user-manual-quick-start.pdf. This is also available as a download from the web based carbon sinks atlas https://ccis.environment.gov.za/carbon-sinks/#/ for overall description of how to run the plugin.

Make sure you are logged onto the correct sub-directory and ensure all required input files are in the input directory. Ensure that REFRESH has been "clicked" and Add All has been "clicked" so that all files are loaded and available to the model.

The model code is given below and can be simply cut-and-pasted into the model builder.

The model needs to be run separately for each time period being investigated. Use search and replace (in word or excel or notepad) to change the date of input files. I.e. replace all 1990 with 2014 (or 2018)

If importing files from excel "click" clean-up expression to make the code more easily readable.

Note ";" is used to denote comments. Each line of code or a comment must end with ";" to let the model builder know it is a new line.

Note an input data layer needs to be within inverted commas e.g. "LC_management_factor"*"ISRIC_SOC_Top30_kg_m²" This is not required for the name for a new layer (i.e. the name before the =) but can be included. Strictly names should be of the format "name@1" or "name@2" to indicate the band, but since all layers used only have on band, not including the @1 has no impact.

The full model code as run is given below.

```
;# CODEFOR SOIL CARBON;
"LCA"=("LC_A_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassA_Water_m²_km²"*0.000001;Water ;
"LCB"=("LC_B_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassB_Wetlands_m²_km²"*0.000001;Wetland;
"LCC"=("LC_C_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassC_Indi genousForest_m²_km²"*0.000001;Ind Forest;
"LCD"=("LC_D_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassD_NaturalVegetation_m²_km²"*0.000001;Natural;
"LCE"=("LC_E_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassE_CommercialAgriculture_m²_km²"*0.000001;Com Dryland Agric;
"LCF"=("LC_F_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassF_PivotAgriculture_m²_km²"*0.000001;Pivot irrigation;
"LCG"=("LC_G_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassG_Orchards_m²_km²"*0.000001;Orchards;
"LCH"=("LC_H_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassH_Viticulture_m²_km²"*0.000001;Viticulture;
"LCI"=("LC_I_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassI_Pineapple_m²_km²"*0.000001;Pineapple;
"LCJ"=("LC_J_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassJ_SubsistenceAgriculture_m²_km²"*0.000001;Sub dryland agriculture;
"LCK"=("LC_K_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassK_SugarcaneIrrigated_m²_km²"*0.000001;Sugar Irrigated;
"LCL"=("LC_L_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassL_SugarcaneDry_m²_km²"*0.000001;Sugar Dry;
"LCM"=("LC_M_factor"*0.01)*("LC_management_factor"*"ISRIC_SOC_Top30_kg_m²")*"NLC_2018_ClassM_PlantationForest_m²_km²"*0.000001;Plantation forests;
```

```
“LCN”=(“LC_N_factor”*0.01)*(“LC_management_factor”*”ISRIC_SOC_Top30_kg_m^2”)*”NLC_2018_ClassN_Mines_m^2_km^2”*0.000001;Mines;

“LCO”=(“LC_O_factor”*0.01)*(“LC_management_factor”*”ISRIC_SOC_Top30_kg_m^2”)*”NLC_2018_ClassO_Bare_m^2_km^2”*0.000001;Bare;

“LCP”=(“LC_P_factor”*0.01)*(“LC_management_factor”*”ISRIC_SOC_Top30_kg_m^2”)*”NLC_2018_ClassP_Built-up_m^2_km^2”*0.000001;Build up;

“LCQ”=(“LC_Q_factor”*0.01)*(“LC_management_factor”*”ISRIC_SOC_Top30_kg_m^2”)*”NLC_2018_ClassQ_Fallow_m^2_km^2”*0.000001;Fallow for 2018 onwards;

“2018TOTAL_TOP30_ISRIC”=(“LCA”+”LCB”+”LCC”+”LCD”+”LCE”+”LCF”+”LCG”+”LCH”+”LCI”+”LCJ”+”LCK”+”LCL”+”LCM”+”LCN”+”LCO”+”LCP”+”LCQ”)*10;;

“2018TOTAL_SOC_ISRIC”=(“ISRIC_SOC_Sub100_kg_m2”*10)+(“2018TOTAL_TOP30_ISRIC”);;

;ADDITIONAL CODE to split soil carbon between natural and transformed landscapes - this requires calculating proportion of subsoil as well as topsoil. This section is not needed for the base model.;;

“LSubA”=(“LC_A_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassA_Water_m^2_km^2”*0.000001; Water ;

“LSubB”=(“LC_B_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassB_Wetlands_m^2_km^2”*0.000001;Wetland;

“LSubC”=(“LC_C_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassC_IndigeonusForest_m^2_km^2”*0.000001;Ind Forest;

“LSubD”=(“LC_D_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassD_NaturalVegetation_m^2_km^2”*0.000001;Natural;

“LSubE”=(“LC_E_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassE_CommercialAgriculture_m^2_km^2”*0.000001;Com Dryland Agric;

“LSubF”=(“LC_F_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassF_PivotAgriculture_m^2_km^2”*0.000001;Pivot irrigation;

“LSubG”=(“LC_G_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassG_Orchards_m^2_km^2”*0.000001;Orchards;

“LSubH”=(“LC_H_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassH_Viticulture_m^2_km^2”*0.000001;Viticulture;

“LSubI”=(“LC_I_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassI_Pineapple_m^2_km^2”*0.000001;Pineapple;

“LSubJ”=(“LC_J_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassJ_SubsistenceAgriculture_m^2_km^2”*0.000001;Sub dryland agriculture;

“LSubK”=(“LC_K_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassK_SugarcaneIrrigated_m^2_km^2”*0.000001;Sugar Irrigated;

“LSubL”=(“LC_L_factor”*0.01)*”ISRIC_SOC_Sub100_kg_m^2”*”NLC_2018_ClassL_SugarcaneDry_m^2_km^2”*0.000001;Sugar Dry;
```

"LSubM"=("LC_M_factor"*0.01)*"ISRIC_SOC_Sub100_kg_m^{2}"*"NLC_2018_ClassM_PlantationForest_m^{2}_km^{2}"*0.000001;Plantation forests;

"LSubN"=("LC_N_factor"*0.01)*"ISRIC_SOC_Sub100_kg_m^{2}"*"NLC_2018_ClassN_Mines_m^{2}_km^{2}"*0.000001;Mines;

"LSubO"=("LC_O_factor"*0.01)*"ISRIC_SOC_Sub100_kg_m^{2}"*"NLC_2018_ClassO_Bare_m^{2}_km^{2}"*0.000001;Bare;

"LSubP"=("LC_P_factor"*0.01)*"ISRIC_SOC_Sub100_kg_m^{2}"*"NLC_2018_ClassP_Builtup_m^{2}_km^{2}"*0.000001;Build up;

"LSubQ"=("LSubQ"=("LC_Q_factor"*0.01)*"ISRIC_SOC_Sub100_kg_m^{2}"*"NLC_2018_ClassQ_Fallow_m^{2}_km^{2}"*0.000001;Fallow for 2018 onwards;

"cropland_soil

_2018"="LSubE"+"LSubF"+"LSubG"+"LSubH"+"LSubI"+"LSubJ"+"LSubK"+"LSubL"+"LCE"+"LCF"+"LCG"+"L-CH"+"LCI"+"LCJ"+"LCK"+"LCL";sums subsoil + topsoil agriculture;

"plantaiton_soil_2018"="LSubM"+"LCM";sums subsoil + topsoil plantations;

"urban_soil_2018"="LSubN"+"LSubP"+"LCN"+"LCP";sums urban soil; "natural_soil_2018"="LSubA"+"LSub-B"+"LSubC"+"LSubD"+"LSubO"+"LSubQ"+"LCA"+"LCB"+"LCC"+"LCD"+"LCO"+"LCQ";sums natural soils ;

CODE FOR ABOV GROUND HERB MATURAL ;;

"AGH_Nat_total"=(0.5*0.45*"a_AGH"*("MAP"-"c_AGH")*"TCF_equ")/100;;

"AGH_low"=(("AGH_Nat_total" < 0.01))*0.01 + (("AGH_Nat_total">=0.01))*"AGH_Nat_total";Cleans negative values and sets to 0.01;

"AGH_Natural"=((("TFC">65))*0+(("TFC"<=65))*"AGH_low");sets herb to zero if under 65% canopy;

CODE FOR ABOVE GROUND HERB;;

"AGH_LCA"="NLC_2018_ClassA_Water_m^{2}_km^{2}"/1000000*0;Water assume 0;

"AGH_LCB"="NLC_2018_ClassB_Wetlands_m^{2}_km^{2}"/1000000*"AGH_Natural";Wetland assume natural;

"AGH_LCC"="NLC_2018_ClassC_IndigenousForest_m^{2}_km^{2}"/1000000*"AGH_Natural";Ind Forest assume natural;

"AGH_LCD"="NLC_2018_ClassD_NaturalVegetation_m^{2}_km^{2}"/1000000*"AGH_Natural";Natural;

"AGH_LCE"="NLC_2018_ClassE_CommercialAgriculture_m^{2}_km^{2}"/1000000*"Herb_DL_Com";Com Dryland Agric;

"AGH_LCF"="NLC_2018_ClassF_PivotAgriculture_m^{2}_km^{2}"/1000000*"Herb_Irr";Pivot irrigation;

"AGH_LCG"="NLC_2018_ClassG_Orchards_m^{2}_km^{2}"/1000000*0;Orchards;

"AGH_LCH"="NLC_2018_ClassH_Viticulture_m^{2}_km^{2}"/1000000*0;Viticulture;

"AGH_LCI"="NLC_2018_ClassI_Pineapple_m^{2}_km^{2}"/1000000*"Herb_Irr";Pineapple;

"AGH_LCJ"="NLC_2018_ClassJ_SubsistenceAgriculture_m^{2}_km^{2}"/1000000*"Herb_DL_Sub";Sub dryland agriculture;

"AGH_LCK"="NLC_2018_ClassK_SugarcaneIrrigated_m^{2}_km^{2}"/1000000*"Herb_Sug";Sugar Irrigated;

"AGH_LCL"="NLC_2018_ClassL_SugarcaneDry_m^2_km^2"/1000000*"Herb_Sug";Sugar Dry;

"AGH_LCM"="NLC_2018_ClassM_PlantationForest_m^2_km^2"/1000000*0;Plantation forests assume zero;

"AGH_LCN"="NLC_2018_ClassN_Mines_m^2_km^2"/1000000*0;Mines assume zero;

"AGH_LCO"=(("Biome" < 4)) * ("NLC_2018_ClassO_Bare_m^2_km^2"/1000000*"AGH_Natural");Bare assume natural in Karoo and desert. Else 0;

"AGH_LCP"="NLC_2018_ClassP_Built-up_m^2_km^2"/1000000*0;Build up - covered in biomass estimate under woody - assume 0 here ;

"AGH_LCQ"="NLC_2018_ClassQ_Fallow_m^2_km^2"/1000000*"AGH_Natural";Fallow for 2018 onwards – assume same as natural;

"AGH"="AGH_LCA"+"AGH_LCB"+"AGH_LCC"+"AGH_LCD"+"AGH_LCE"+"AGH_LCF"+"AGH_LC-G"+"AGH_LCH"+"AGH_LCI"+"AGH_LCJ"+"AGH_LCK"+"AGH_LCL"+"AGH_LCM"+"AGH_LCN"+"AGH_LCO"+"AGH_LCP"+"

AGH_LCQ";;

"2018AGH"="AGH";;

"cropland_herb_2018"=("AGH_LCE"+"AGH_LCF"+"AGH_LCG"+"AGH_LCH"+"AGH_LCI"+"AGH_LC-J")*1.2+"A

GH_LCK"+"AGH_LCL";;

"plantation_herb_2018"=("AGH_LCM")*2;;

"urban_herb_2018"=("AGH_LCN"+"AGH_LCP")*2;;

"natural_herb_2018"=("AGH_LCA"+"AGH_LCB"+"AGH_LCC"+"AGH_LCD"+"AGH_LCO"+"AGH_LCQ")*2;;

;;

BGH + AGH for natural AGH*O.2 for crops;;

"BGH"="AGH_LCA"+"AGH_LCB"+"AGH_LCC"+"AGH_LCD"+("AGH_LCE"*0.2)+("AGH_LCF"*0.2)+"AGH_LCG"

+"AGH_LCH"+("AGH_LCI"*0.2)+("AGH_LCJ"*0.2)+("AGH_LCK"*0.2)+("AGH_LCL"*0.2)+"AGH_LC-M"+"AGH_L

CN"+"AGH_LCO"+"AGH_LCP"+"AGH_LCQ";;

"2018BGH"="BGH";;

"";;

CODE FOR WOODY VEGETATION";;

"AGW_U"=((("Urban"=1))*1)*("FAPAR"/365*5000/100);;

"AGW_R"=(("Urban"<1))*"AGW_Tree";;

"2018AGW"="AGW_U"+"AGW_R";;

"BGW300"=(("MAP" < 300))*"2018AGW";;

"BGWequ"=(-0.0035*"MAP")+3.05;;

```
"BGW300_800"=((((“MAP”>300)) and ((“MAP”<800)))*”BGWequ”)*”2018AGW”;;
"BGW800"=((“MAP” < 800))*”2018AGW”;;
"2018BGW"=”BGW300”+”BGW300_800”+”BGW800”;;
Deadwood”;;
"Deadwood"=((“Communal_areas” =1))*(“2018AGW”*0.02) + ((“Communal_areas”= 0))*(“2018AGW”*0.1);;
“”;;
"AGL_DS"=((“Biome” = 1))*0;desert;
"AGL_SK"=((“Biome” = 2))*50;Succulent Karoo;
"AGL_NK"=((“Biome” = 3))*50;Nama Karoo;
"AGL_FB"=((“Biome” = 4))*1500;fynbos;
"AGL_TH"=((“Biome” = 5))*254;Thicket;
"AGL_GL"=((“Biome” = 6))*90;Grassland;
"AGL_SV"=((“Biome” = 7))*121;savanna;
"AGL_FO"=((“Biome” = 8))*900;forest;
"AGL_IO"=((“Biome” = 16))*1500;IOCB;
"AGL_AZ"=((“Biome” = 11))*50;Azonal;
"2018AGL"=(“AGL_DS”+”AGL_SK”+”AGL_NK”+”AGL_FB”+”AGL_TH”+”AGL_GL”+”AGL_SV”+”AGL_FO”+”AGL_IO”+”AGL_AZ”)*0.01+”Deadwood”;;
CALCULATION OF TOTAL CARBON SOC is just C but biomass needs to be converted to just C hence x 0.42;;
"2018TOTAL_C_ISRIC"=”2018TOTAL_SOC_ISRIC”+(“2018AGW”+”2018BGW”+”2018AGH”+”2018BGH”+”2018AGL”)*0.42;;
```

The QGIS Zonal statistics function is used to extract statistics from the data, for instance using a municipality layer as the zonal layer. Using the batch mode allows for running a single analysis for all output layers.

TIPS AND TRICKS for developing the code and running the model.

The code can be developed (or edited) on a word processor or in Excel rather than in the model builder. This is a lot faster and easier. We found using Excel and spreading the code over multiple cells allowed for the quick generation of repetitive components. The concatenate function was then used to merge the text from individual cells.

Use search and replace to change years in the code when doing different year runs (the outputs also have the year in their name so outputs from multiple runs can be in the same file).

Check for any errors in the created outputs which are indicated either as a red triangle or a data range outside of expected range (normally given as 1.7 to -1.7 e^{308}).

The zonal statistics write the output directly into the attribute table of the zonal layer. It is therefore best to create a duplicate layer of the layer used for the zonal statistics to use for this temporary function. To facilitate this we have included vector layers for biome, province, district municipality and local municipality (labelled with their name followed by "_blank". We then use the "export" "save as" to create a duplicate).

When running zonal statistics in batch mode three results are given per layer (unless one goes through the time consuming process of selecting only some – the layer needed). We have found it easier to create an Excel spreadsheet that automatically sorts the data and orders it into the required format.

This then simply needs a cut and paste of the attribute table in which the zonal statistics are stored.

To do this, right click on the layer, click on open attribute table, right click any cell in the table and select all, click on "copy" select rows to clipboard (the 8th button along from the pencil icon). We run this as a single zonal statistic for all three years in one go.

Notes on converting look up values to coverages - soil carbon loss

A number of look up tables are used to read off data for specific locations. The most complex of these is the one used to calculate expected soil carbon loss as a consequence of land use change.

These lookup coverages do not need changing unless the lookup data is updated. This short note is the method we found most efficient to create this data.

A combination of biomes and rainfall was decided on as the basis for SOC loss (see Appendix 4). Simple code, using the QGIS plugin was used to generate a layer with unique values for each biome by rainfall combination.

In essence it gave each location a code based firstly on the biome and secondly on the rainfall (see Table A4.2, Figure A4.1 in appendix 4).

For each land cover class (i.e. row of Table A4.2) a look up coverage was created replacing the code values with the SOC multipliers from Table A4.1 It was found that the AGCGIS reclassify by ascii tool (within spatial analyst) was the quickest and easiest way to do this. This tool however only works with integer, so all values were multiplied by 100. A simple text file of the form

12 : 44
22 : 80
etc

Is the input file to the ARCGis reclassifying tool? A simple transpose in Excel and a copy and paste into notepad creates the files.

From ARCGis, select the layer, select DATA, EXPORT DATA to create a new layer in TIFF format suited to the QGIS plugin.

IMPROVING SOUTH AFRICA'S TERRESTRIAL SOC LOSS ESTIMATES

Rationale and approach

This brief focusses on two components, firstly, improving our understanding of the manner in which carbon stocks change following a change in land-cover or land management in South Africa, and secondly, the development of a strategy to improve and update the national soil carbon map over time.

Better understanding changes in carbon stocks following land-cover transitions

An important part of improving the AFOLU component of South Africa's national GHG inventory is enhancing our understanding of changes in carbon stocks following changes in land cover and management, and particularly Soil Organic Carbon (SOC) stocks that are not readily measurable through remote sensing techniques. The intention here is to identify a set of South African specific SOC stock transition values for each of the principal land-cover changes that typically occur across the country (essentially an IPCC Tier 3 approach).

In terms of effectiveness and efficiency, the most predominant land cover transitions in terms of spatial area and their impact on carbon stocks at a national scale were identified as focus areas for intense data collection. Land cover transition data was obtained from the National GHG Inventory (1990 - 2018) as well as the National Land Cover 1990, 2014 and 2018 datasets to identify the nationally most important transitions to focus on (Figures A4.2 to A4.4). The following set of transitions from natural vegetation was selected for further focus:

- Pasture
- Dryland commercial crops
- Irrigated crops
- Dryland subsistence crops
- Dryland and irrigated sugar cane
- Fallow lands
- Orchards and vines
- Plantations
- Urban, built
- Mines
- Bare land

The magnitude of the change in carbon stocks is dependent on the pre-existing 'reference' stocks in an indigenous or non-disturbed state, which are principally determined by climate (temperature and rainfall), soil texture, topography and vegetation type (Ellery *et al.* 1991, Wiesmeier *et al*. 2019)[4]. The change in SOC following each transition was therefore evaluated across a range of climatic zones and biomes (Table A4.1, Figure A4.1) in order to provide a better understanding of how changes in SOC following land cover transitions may vary across the country. Ideally, two further determinants of SOC should be included, namely soil texture and topography (slope, aspect, catenal position), but following a review of the limited number of available domestic empirical studies at this time, it was decided only to disaggregate change factors at a biome and climate zone level at this point. Further separation based on soil texture and topography would either require substantial additional field data5 or an extensive modelling-based approach, e.g. using Century or RothC.

4 A full review of decisions around the selection of a suitable SOC reference dataset is given in Appendix 5.

5 For a good set of reference data, a systematic set of representative soil pit data is required from the whole country. This needs to cover all major soil forms, topographies, and climates, with sufficient replication to be statistically meaningful. It should be biased to areas of greatest interest and importance. Further, this data should be re-sampled at intervals of about every 10 to 15 years to capture changes driven by climate change. South Africa is lucky in that it has a very extensive historic set of data, but this data is aging, does not use the most up to date methods, and often does not record gravel and rock fractions.

Table A4.1: The range of considered biomes and climatic zones.

South African Biomes	Climate zones	Annual rainfall
Desert	Desert	0-200 mm
Succulent Karoo	Arid	200-400 mm
Nama Karoo	Semi-arid	400-600 mm
Fynbos	Sub-humid	600-800 mm
Albany Thicket	Humid	800-1000 mm
Grassland	Super-humid	>1000 mm year
Savanna		
Forest		
Azonal e.g. rivers, wetlands.		
Indian Ocean Coastal Belt		

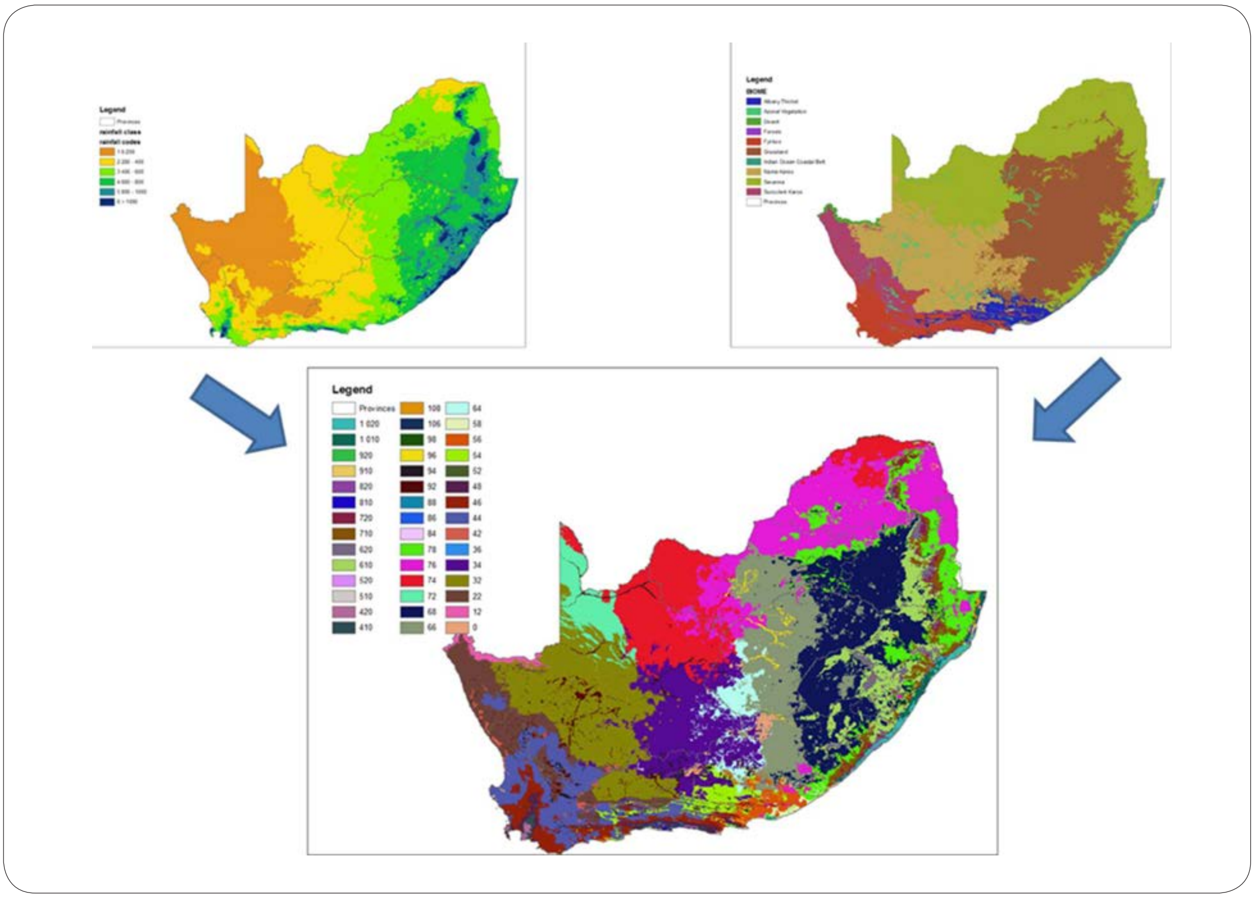


Figure A4.2: The way climatic zones across South Africa (source Lynch 2004 in Schulz 2012) were combined with South African Biomes (source: Mucina and Rutherford 2006) to give biome by rainfall classes. Ledged classes correspond to the classes in Table A4.2 below.

Based on this set of land-cover transitions and primary determinants, the spreadsheet-based data template was compiled. A five-step process was then followed to identify a robust set of SOC change values for each transition, in each biome and climate zone (Table A4.2):

1. A default value of 1 (no change) was assumed across the matrix as a starting value to ensure that there is at least a value on which the model can run.
2. Starting at a broad scale, an IPCC Tier 1 value was then sought from IPCC guidance where available (IPCC 2006, 2013, 2019).
3. Thereafter, more accurate estimates were sought from the initial National Terrestrial Carbon Sink Assessment (NTCSA, DEA 2015) as well as international meta-analysis where possible.
4. A literature review was done of all domestic field studies (IPCC Tier 3) that are available in published journal articles, reports and dissertations.
5. Lastly, a consolidated SOC change estimate was calculated and decided upon for each land-cover change. This is based on available data and expert opinion on the robustness and suitability of domestic and international studies.

Table A4.2: Screen dumps from the Excel spreadsheet of SOC loss factors per biome per rainfall class. Yellow highlights show rainfall by biome combinations that cover a significant portion of the biome (over 20%) or over 1 % of total country land area.

Land cover class	1 Desert	2 Succulent karoo		78186	3 Nama karoo	244208	4 Fynbos		81653			
Code used in model	12	22	24	26	32	34	42	44	46	48	410	420
Rainfall class	0-200	0-200	200-400	400-600	0-200	200-400	0-200	200-400	400-600	600-800	800-1000	>1000
Km 2 per biome per rainfall unit	6225	53789	24202	195	142111	102097	4019	38566	26241	8295	3195	1337
Percentage of biome	100.00	68.80	30.95	0.25	58.19	41.81	4.92	47.23	32.14	10.16	3.91	1.64
Percentage of country	0.49	4.27	1.92	0.02	11.28	8.10	0.32	3.06	2.08	0.66	0.25	0.11
Pasture	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Dryland Commercial Crops	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Irrigated crops	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dryland subsistence crops	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Dryland sugar	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Irrigated sugar	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Fallow Lands	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Orchards and Vines	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Plantations	1	1	1	1	1	1	1	1	1	1	1	1
Urban, built	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Mines	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Bare land	1	1	1	1	1	1	0.4	0.4	0.4	0.4	0.4	0.4

Land cover class	5 Albany thicket		35286				6 Grassland		365632		
Code used in model	52	54	56	58	510	520	64	66	68	610	620
Rainfall class	0-200	200-400	400-600	600-800	800-1000	>1000	200-400	400-600	600-800	800-1000	>1000
Km 2 per biome per rainfall unit	1279	17084	13349	3239	318	17	23878	123799	154546	51685	11724
Percentage of biome	3.62	48.42	37.83	9.18	0.90	0.05	6.53	33.86	42.27	14.14	3.21
Percentage of country	0.10	1.36	1.06	0.26	0.03	0.00	1.89	9.82	12.26	4.10	0.93
Pasture	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Dryland Commercial Crops	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Irrigated crops	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dryland subsistence crops	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Dryland sugar	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Irrigated sugar	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Fallow Lands	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Orchards and Vines	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Plantations	1	1	1	1	1	1	1	1	1	1	1
Urban, built	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Mines	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Bare land	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Land cover class	7 Savanna		406220				8 Forest	4883			
Code used in model	72	74	76	78	710	720	84	86	88	810	820
Rainfall class	0-200	200-400	400-600	600-800	800-1000	>1000	200-400	400-600	600-800	800-1000	>1000
Km 2 per biome per rainfall unit	33793	124617	153746	64064	23752	6248	39	243	1096	1929	1576
Percentage of biome	8.32	30.68	37.85	15.77	5.85	1.54	0.80	4.98	22.45	39.50	32.28
Percentage of country	2.68	9.89	12.20	5.08	1.88	0.50	0.00	0.02	0.09	0.15	0.13
Pasture	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Dryland Commercial Crops	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Irrigated crops	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dryland subsistence crops	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Dryland sugar	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Irrigated sugar	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Fallow Lands	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Orchards and Vines	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Plantations	1	1	1	1	1	1	1	1	1	1	1
Urban, built	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Mines	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Bare land	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Land cover class	11 Azonal	26440					16 Indian OCB			11639
Code used in model	92	94	96	98	910	920	106	108	1010	1020
Rainfall class	0-200	200-400	400-600	600-800	800-1000	>1000	400-600	600-800	800-1000	>1000
Km 2 per biome per rainfall unit	10206	9450	5932	279	272	301	24	633	5691	5291
Percentage of biome	38.60	35.74	22.44	1.06	1.03	1.14	0.21	5.44	48.90	45.46
Percentage of country	0.81	0.75	0.47	0.02	0.02	0.02	0.00	0.05	0.45	0.42
Pasture	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Dryland Commercial Crops	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Irrigated crops	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Dryland subsistence crops	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Dryland sugar	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Irrigated sugar	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Fallow Lands	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Orchards and Vines	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Plantations	1	1	1	1	1	1	1	1	1	1
Urban, built	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Mines	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Bare land	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Further change type specific considerations that were used to determine the biome loss factors are given below.

Pasture

"Pasture" is considered in a separate class to indigenous grassland as it is cultivated to a certain degree through the planting of particular species, the application of fertilizer as well as irrigation. Due to additional water and nitrogen, pastures therefore often have higher SOC than the indigenous grassland which they replace.

The IPCC (2019) default value of 1.14 was adopted as an initial Tier 1 estimate (IPCC 2019, Table 6.2). Thereafter, a limited number of domestic studies were used to identify a Tier 3 estimate of changes in SOC for particular biomes and climate zones (e.g. Mills 2003, Mills *et al.* 2012).

Key References

Mills, A. J. (2003). Reciprocal relationships between vegetation structure and soil properties in selected biomes of South Africa. Stellenbosch University. Retrieved from http://scholar.sun.ac.za/handle/10019.1/53567

Mills, A. J., Birch, S. C., Stephenson, J. D., & Bailey, R. V. (2012). Carbon stocks in fynbos, pastures and vineyards on the Agulhas Plain, South Africa: A preliminary assessment. South African Journal of Plant and Soil, 29(3–4), 191–193. https://doi.org/10.1080/02571862.2012.73063

IPCC. (2019). Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. (E. Calvo Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, N. S., … S. Federici, Eds.) (Vol. 4). Switzerland: Intergovernmental Panel on Climate Change. Retrieved from https://www.ipccnggip.iges.or.jp/public/2019rf/index.html

Dryland Commercial Crops

Within a land cover class or land use type, management practices can have a significant impact on SOC storage, especially in croplands and grasslands (Paustian *et al.* 1997; Conant *et al*. 2001; Ogle *et al*. 2004 and 2005 in Ogle *et al*., 2019a). In croplands, management modifies SOC stocks to different degrees depending on how specific practices affect carbon input and output from the soil system (Paustian *et al*., 1997; Bruce *et al*., 1999; Ogle *et al*., 2005 in Ogle *et al*., 2019b). According to Ogle *et al.* (2019b) the main management practices affecting SOC stocks in croplands are the type of residue management, tillage management, fertilizer management (both mineral fertilizers and organic amendments), choice of crop and intensity of cropping management (e.g. continuous cropping versus cropping rotations with periods of bare fallow), irrigation management, and mixed systems with cropping and pasture or hay in rotating sequences.

A review of SOC levels in Southern African croplands showed that the equilibrium of SOC levels within croplands is disturbed by cultivation as a function of various factors such as tillage, crop removal through grazing or burning, and duration of cultivation. Inferior driving forces for SOC decline due to cultivation are soil structure or aggregation, soil water content and temperature, soil texture, microbial populations and functional diversity, biogeochemical activity, soil mineral composition, soil chemical environment, N fertilizer application or fertilizer management, type of cropping system, management, or type of crop residue (Swanepoel *et al*., 2016).

Cultivation generally causes a decline in SOC with a rapid decline occurring in the first five years of cultivation. On the other hand, systems using little or no soil disturbance combined with high inputs of organic materials (roots, above-ground plant residues, manures) support the accumulation and retention of SOC. Since conservation agriculture combines the three principles of minimum soil disturbance, permanent soil cover with crop residues and mulches, crop rotation and intercropping, it provides many of the management factors that supports increased SOC. Swanepoel *et al.* (2018) systematically reviewed the status of CA research in South Africa. The authors reported that increases in SOC resulted from CA treatments of reduced or no-tillage, soil cover or mulch, and diversified cropping. Reduced or no-till had the greatest effect on increased SOM or SOC compared to other CA treatments. However, in some cases the increases in SOC were small, slow or not significant compared to conventional systems. The effect of conservation agriculture and reduced/no-till on increased SOC stock was found to be dependent of the climatic zone and the method used to calculate SOC stock changes (Meurer *et al*., 2018).

Determining the full potential of conservation agriculture to support increased SOC stocks in croplands requires sufficient information on baseline SOC values under natural vegetation and/or under conventional crop production prior to conservation agriculture implementation, soil bulk density and stone content, crop rotations implemented, actual amounts of aboveground biomass/residue inputs, soil texture, and climatic zone (rainfall and temperature).

Key References

Nel, P. C., Barnard, R. O., Steynberg, R. E., de Beer, J. M., & Groeneveld, H. T. (1996). Trends in maize grain yields in a long-term fertilizer trial. Field Crops Research, 47(1), 53–64. https://doi.org/https://doi.org/10.1016/0378-4290(96)00006-8

Lobe, I., Amelung, W., & Du Preez, C. C. (2001). Losses of carbon and nitrogen with prolonged arable cropping from sandy soils of the South African Highveld. European Journal of Soil Science, 52(1), 93–101. https://doi.org/10.1046/j.1365-2389.2001.t01-1-00362.x

Loke, P. F., Kotzé, E., Du Preez, C. C., & Twigge, L. (2019). Dynamics of soil carbon concentrations and quality induced by agricultural land use in central South Africa. Soil Science Society of America Journal, 83(2), 366–379. https://doi.org/10.2136/sssaj2018.11.0423

Mills, A. J. (2003). Reciprocal relationships between vegetation structure and soil properties in selected biomes of South Africa. Stellenbosch University. Retrieved from http://scholar.sun.ac.za/handle/10019.1/53567

Mills, A. J., Birch, S. J. C., Stanway, R., Huyser, O., Chisholm, R. A., Sirami, C., & Spear, D. (2013). Sequestering carbon and restoring renosterveld through fallowing: a practical conservation approach for the Overberg, Cape Floristic Region, South Africa. Conservation Letters, 6(4), 255–263. https://doi.org/10.1111/conl.12003

Irrigated Crops

Adopting the factor used in the NTCSA (DEA 2015), a default value of 0.8 was assumed for all biomes. Thereafter, two studies were identified (du Preez and Wiltshire 1997, Swanepoel *et al*. 2016), that provide Tier 3 estimates for arid and semi-arid areas within the grassland biome.

Key References

du Preez, C. C., & Wiltshire, G. H. (1997). Changes in the organic matter and nutrient contents of some South African irrigated soils. South African Journal of Plant and Soil, 14(2), 49–53. https://doi.org/10.1080/02571862.1997.10635080

Swanepoel, C. M., van der Laan, M., Weepener, H. L., du Preez, C. C., & Annandale, J. G. (2016). Review and meta-analysis of organic matter in cultivated soils in southern Africa. Nutrient Cycling in Agroecosystems, 104(2), 107–123. https://doi.org/10.1007/s10705-016-9763-4

Dryland subsistence crops

Few studies have focussed on the impact of dryland subsistence crop production on SOC in South Africa. An IPCC Tier 1 default factor of 0.58 for Dryland and Humid areas and 0.48 for Super Humid areas (IPCC 2006, Table 5.5) has therefore been adopted.

Key References

IPCC. (2006). IPCC Guidelines for National Greenhouse Gas Inventories; Vol.4 Agriculture, Forestry and Other Land-Use; Prepared by the National Greenhouse Gas Inventories Programme. (S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.). Kanagawa: IGES, Japan, http://www.ipcc-nggip.iges.or.jp.

Miles, N., Meyer, J. H., & Antwerpen, R. van. (2008). Soil organic matter data: what do they mean? Proceedings of the Annual Congress - South African Sugar Technologists' Association, (February 2017), 324–332. Retrieved from https://pdfs.semanticscholar.org/1f48/a285461ef09b6318dfcd73914f7d620f8bcc.pdf

Dryland and irrigated sugar cane

Within South Africa, sugarcane was often planted in areas that were previously grassland, forest, riparian or wetland areas. The change estimates from local field studies in humid areas are therefore adopted for this climate zone across four biomes (grassland, forest, Indian Ocean Coastal Belt and Azonal. For the remaining dryland sugar areas, a change factor of 0.6 is adopted, as used in the NTCSA (DEA 2015). Irrigated sugar areas are assumed to have higher SOC stocks and therefore a default factor of 1 is assumed.

Key References

Graham, M. H., Haynes, R. J., & Meyer, J. H. (2002). Changes in soil chemistry and aggregate stability induced by fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. European Journal of Soil Science, 53(4), 589–598. https://doi.org/10.1046/j.1365-2389.2002.00472.x

Du Preez, C. C., Van Huyssteen, C. W., & Mnkeni, P. N. S. (2011). Land use and soil organic matter in South Africa 2: A review on the influence of arable crop production. South African Journal of Science, 107(5/6). https://doi.org/10.4102/sajs.v107i5/6.358

Fallow Lands

A number of field studies have been done on changes in SOC in fallow lands in South Africa, however these are concentrated within the sub-tropical thicket and fynbos biomes. A few domestic studies were identified within the grassland, forest and other biomes and therefore the IPCC Tier 1 default change factors have been adopted for the majority of biomes and climate zones (0.58 for Dryland and Humid areas and 0.48 for Super Humid areas, IPCC 2006, Table 5.5).

Key References

Abera, Y., & Belachew, T. (2011). Effects of land use on soil organic carbon and nitrogen in soils of Bale, South Eastern Ethiopia. Tropical and Subtropical Agroecosystems, 14(14), 229–235. Retrieved from http://www.redalyc.org/articulo.oa?id=93915703022

Powell, M. J. (2009). Restoration of degraded subtropical thickets in the Baviaanskloof MegaReserve, South Africa. Master's Thesis, Rhodes University.

Mills, A. J., Birch, S. C., Stephenson, J. D., & Bailey, R. V. (2012). Carbon stocks in fynbos, pastures and vineyards on the Agulhas Plain, South Africa: A preliminary assessment. South African Journal of Plant and Soil, 29(3–4), 191–193. https://doi.org/10.1080/02571862.2012.730636

Mills, A. J., Birch, S. J. C., Stanway, R., Huyser, O., Chisholm, R. A., Sirami, C., & Spear, D. (2013). Sequestering carbon and restoring renosterveld through fallowing: a practical conservation approach for the Overberg, Cape Floristic Region, South Africa. Conservation Letters, 6(4), 255– 263. https://doi.org/10.1111/conl.12003

Walker, S. M., & Desanker, P. V. (2004). The impact of land use on soil carbon in Miombo Woodlands of Malawi. Forest Ecology and Management, 203, 345–360.

Orchards and Vines

The establishment of vineyards and orchards generally have a negligible impact on SOC over time. It is important to note that both are planted, grown, cleared and replanted in cycles, often with the root stump biomass being cleared before replanting. The NTCSA conservatively assumed a change factor of 0.8 which has been adopted in this modelling exercise, except for the biomes and climatic regimes in which Fourie (2012) and Mills *et al.* (2012) did field studies. Within these arid, semi-arid and sub-humid areas of the Fynbos biome, change factors of 1.00, 1.03 and 1.03 have been adopted based on these studies, which are further supported by the recommended IPCC default of 1.00 (IPCC 2006).

Key References

Fourie, J. C. (2012). Soil Management in the Breede River Valley Wine Grape Region, South Africa . 4. Organic Matter and Macro-nutrient Content of a Medium-textured Soil, 33(1), 105–114. Retrieved from https://www.afranjournal.org/index.php/sajev/article/viewFile/1312/527

Mills, A. J., Birch, S. C., Stephenson, J. D., & Bailey, R. V. (2012). Carbon stocks in fynbos, pastures and vineyards on the Agulhas Plain, South Africa: A preliminary assessment. South African Journal of Plant and Soil, 29(3–4), 191–193. https://doi.org/10.1080/02571862.2012.730636

Plantations

The text below is from a draft of the MRV guidance for South African Plantation Industry which has not been finalised or published as yet. It is included as it is considered appropriate to have consistency across the two documents. As such it should not be quoted, and the finalised text should be used instead.

A meta-analysis of the South African data largely supports the main findings in the international data, namely that there is a decrease in soil C stocks following afforestation of grassland with pines and eucalypts (Table A4.3). This decrease commonly ranges between 5 and 20 t C ha-1 (du Toit *et al.* 2016).

There is often an assumption that belowground carbon stocks should increase over time. However, root turnover and the soil respiration lead to the release of carbon into the atmosphere in a similar manner to aboveground processes. Whereas the afforestation of previously degraded and deeply ploughed land may lead to an increase in soil carbon stocks, the establishment of plantations on indigenous grasslands or pasture generally results in a decrease in the soil organic carbon pool.

Table A4.3: Field assessments of the change in soil carbon stocks following the afforestation of grasslands and pasture.

Species	Location	Age	Sampling depth	Change in soil C	Reference
		Years	cm	tC/ha*	
Pine	Swaziland	30	100	-15.5	Morris 1986**
Pine	KwaZulu-Natal	30	20	-9.2	Musto 1992**
Pine	KZN, Mpumalanga	37	20	-4.9	du Toit 1993**
Pine	Cape, Mpumalanga	39	20	-20.6	Nowicki 1998**
Pine	New Zealand	10		-1.3 to -16.0	Kirshbaum *et al.* 2009
Pine	New Zealand	11	100	-6	Parfitt and Ross 2011
Muliple	Across Europe	(mean) 45	30	-24	Poeplau and Don 2013
Acacia	Sudan	15, 24	50	< 2.5	Abaker *et al.* 2016
Euc, Pine	Uruguay	12	30	< -1	Hernandez *et al.* 2016
Euc	Brazil	10-30	45	< -1	Cook *et al.* 2014
Euc	Brazil(110 sites)	20	30	-4.4	Cook *et al.* 2016
Euc, Pine	Congo, Nigeria	10-30	30	-1	Paul *et al.* 2002

* A negative number indicates a reduction in soil carbon.

** Cited in du Toit *et al.* 2016

Key References

Ros Mesa, I. (2015). Stochastic modelling of soil carbon stocks under different land uses: a case study in South Africa. Stellenbosch University.

Settlements

The earlier national land-cover maps (1990, 2004) do not disaggregate urban and mining areas into a finer level, allowing for the separate consideration of, for example, buildings, further capped surfaces, parks and gardens. The 2018 national land-cover does provide this detail and therefore a far more detailed change analysis will be possible in future.

At present, there are no published studies on the impact of a change to a settlement land cover class on SOC in South Africa. An IPCC Tier 1 approach was therefore adopted.

The approach is primarily described in IPCC 2006 (Section 8.3.3.2) and the relevant lookup table (Table 6.2) was updated in the IPCC 2019 Guidance. As the proportion of paved area to turf grass and other land-cover is not known, with some leading to an increase in SOC, and others to a decrease, at this point it is conservatively assumed that net SOC remain approximately the same following a conversion to settlements.

Bare land

Conversion to bare land is a prominent land-cover change transition across the country, however, within the dry biomes (Desert, Succulent Karoo and Nama Karoo), it may be an outcome of the remote sensing approach and not be indicative of a substantial change in carbon stocks on the ground. For these drier biomes, a conservative change factor of 1 is therefore assumed.

In more mesic biomes, an IPCC Tier 1 change factor of 0.7 is assumed as a default (IPCC 2019, Table 6.2). However, in certain biomes, especially the Albany Thicket biome, there have been substantial field surveys (e.g. Lechmere-Oertel *et al.* 2005, Powell 2009, Mills and Cowling 2010, Mchunu 2012), based on which, more specific Tier 3 factors have been identified.

Key References

Lechmere-Oertel, R. G., Kerley, G. I. H., & Cowling, R. M. (2005). Patterns and implications of transformation in semi-arid succulent thicket, South Africa. Journal of Arid Environments, 62(3), 459–474.

Powell, M. J. (2009). Restoration of degraded subtropical thickets in the Baviaanskloof MegaReserve, South Africa. Master Thesis, Rhodes University.

Mills, A. J., & Cowling, R. M. (2010). Below-ground carbon stocks in intact and transformed subtropical thicket landscapes in semi-arid South Africa. Journal of Arid Environments, 74, 93– 100.

Mchunu, S. E. (2012). Distribution and Stability of Soil Carbon in Spekboom Thicket , Eastern Cape , South Africa. Stellenbosch University.

All References for Appendix 4

Abera, Y., & Belachew, T. (2011). Effects of land use on soil organic carbon and nitrogen in soils of Bale, South Eastern Ethiopia. Tropical and Subtropical Agroecosystems, 14(14), 229–235. Retrieved from http://www.redalyc.org/articulo.oa?id=93915703022

Bruce, J.P., Frome, M., Haites, E., Janzen, H., Lal, R. and Paustian, K. (1999). Carbon sequestration in soils. Journal of Soil and Water Conservation 54:382-389.

Conant, R.T., Paustian, K. and Elliott, E.T. (2001). Grassland management and conversion into grassland: Effects on soil carbon. Ecological Application 11:343 355.

DEA. (2015). The South African National Terrestrial Carbon Sink Assessment. Pretoria, South Africa.

Dlamini, P., Chivenge, P., Manson, A., & Chaplot, V. (2014). Land degradation impact on soil organic carbon and nitrogen stocks of sub-tropical humid grasslands in South Africa. Geoderma, 235– 236(January 2018), 372–381. https://doi.org/10.1016/j.geoderma.2014.07.016

du Preez, C. C., & Wiltshire, G. H. (1997). Changes in the organic matter and nutrientcontents of some South African irrigated soils. South African Journal of Plant and Soil, 14(2), 49–53. https://doi.org/10.1080/02571862.1997.10635080

Du Preez, C. C., Van Huyssteen, C. W., & Mnkeni, P. N. S. (2011). Land use and soil organic matter in South Africa 2: A review on the influence of arable crop production. South African Journal of Science, 107(5/6), 2–9. https://doi.org/10.4102/sajs.v107i5/6.358

Ellery, W. N., Scholes, R. J., & Mentis, M. T. (1991). An initial approach to predicting the sensitivity of the South African grassland biome to climate change. South African Journal of Science, 87, 499–503.

Fourie, J. C. (2012). Soil Management in the Breede River Valley Wine Grape Region, South Africa. 4. Organic Matter and Macro-nutrient Content of a Medium-textured Soil, 33(1), 105–114. Retrieved from https://www.afranjournal.org/index.php/sajev/article/viewFile/1312/527

Graham, M. H., Haynes, R. J., & Meyer, J. H. (2002). Changes in soil chemistry and aggregate stability induced by fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. European Journal of Soil Science, 53(4), 589–598. https://doi.org/10.1046/j.1365-2389.2002.00472.x

IPCC. (2013). Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol. (T. Hiraishi, T. Krug, K. Tanabe, N. Srivastava, J. Baasansuren, M. Fukuda, & T. . Troxler, Eds.). Switzerland: IPCC.

IPCC. (2006). IPCC Guidelines for National Greenhouse Gas Inventories; Vol.4 Agriculture, Forestry and Other Land-Use; Prepared by the National Greenhouse Gas Inventories Programme. (S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.). Kanagawa: IGES, Japan, http://www.ipcc-nggip.iges.or.jp.

IPCC. (2019). Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. (E. Calvo Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, N. S., … S. Federici, Eds.) (Vol. 4). Switzerland: Intergovernmental Panel on Climate Change. Retrieved from https://www.ipccnggip.iges.or.jp/public/2019rf/index.html

Lechmere-Oertel, R. G., Kerley, G. I. H., & Cowling, R. M. (2005). Patterns and implications of transformation in semi-arid succulent thicket, South Africa. Journal of Arid Environments, 62(3), 459–474. Retrieved from h

Lobe, I., Amelung, W., & Du Preez, C. C. (2001). Losses of carbon and nitrogen with prolonged arable cropping from sandy soils of the South African Highveld. European Journal of Soil Science, 52(1), 93–101. https://doi.org/10.1046/j.1365-2389.2001.t01-1-00362.x

Loke, P. F., Kotzé, E., Du Preez, C. C., & Twigge, L. (2019). Dynamics of soil carbon concentrations and quality induced by agricultural land use in central South Africa. Soil Science Society of America Journal, 83(2), 366–379. https://doi.org/10.2136/sssaj2018.11.0423

Lynch, S. D. (2004). Development of a Raster Database of Annual, Monthly and Daily Rainfall for Southern Africa. Pretoria.

Mchunu, S. E. (2012). Distribution and Stability of Soil Carbon in Spekboom Thicket , Eastern Cape , South Africa. Stellenbosch University.

Miles, N., Meyer, J. H., & Antwerpen, R. van. (2008). Soil organic matter data: what do they mean? Proceedings of the Annual Congress - South African Sugar Technologists' Association, (February 2017), 324–332. Retrieved from https://pdfs.semanticscholar.org/1f48/a285461ef09b6318dfcd73914f7d620f8bcc.pdf

Mills, A. J., & Cowling, R. M. (2010). Below-ground carbon stocks in intact and transformed subtropical thicket landscapes in semi-arid South Africa. Journal of Arid Environments, 74, 93–100.

Mills, A. J., Birch, S. C., Stephenson, J. D., & Bailey, R. V. (2012). Carbon stocks in fynbos, pastures and vineyards on the Agulhas Plain, South Africa: A preliminary assessment. South African Journal of Plant and Soil, 29(3–4), 191–193. https://doi.org/10.1080/02571862.2012.730636

Mills, A. J. (2003). Reciprocal relationships between vegetation structure and soil properties in selected biomes of South Africa. Stellenbosch University. Retrieved from http://scholar.sun.ac.za/handle/10019.1/53567

Mills, A. J., Birch, S. J. C., Stanway, R., Huyser, O., Chisholm, R. A., Sirami, C., & Spear, D. (2013). Sequestering carbon and restoring renosterveld through fallowing: a practical conservation approach for the Overberg, Cape Floristic Region, South Africa. Conservation Letters, 6(4), 255–263. https://doi.org/10.1111/conl.12003

Mucina, L., & Rutherford, M. C. (2006). The vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19, (December 2015), 1–30. https://doi.org/10.1007/s

Nel, P. C., Barnard, R. O., Steynberg, R. E., de Beer, J. M., & Groeneveld, H. T. (1996). Trends in maize grain yields in a long-term fertilizer trial. Field Crops Research, 47(1), 53–64. https://doi.org/https://doi.org/10.1016/0378-4290(96)00006-8

Ogle, S.M., Breidt, F.J. and Paustian, K (2005). Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry 72:87-121.

Ogle, S.M., Conant, R.T. and Paustian, K. (2004). Deriving grassland management factors for a carbon accounting approach developed by the Intergovernmental Panel on Climate Change. Environmental Management 33:474-484.

Paustian, K, Andren, O., Janzen, H.H., Lal, R., Smith, P., Tian, G., Tiessen, H., van Noordwijk, M. and Woomer, P.L. (1997). Agricultural soils as a sink to mitigate CO_2 emissions. Soil Use and Management 13:230-244.

Powell, M. J. (2009). Restoration of degraded subtropical thickets in the Baviaanskloof MegaReserve, South Africa. Master Thesis, Rhodes University.

Ros Mesa, I. (2015). Stochastic modelling of soil carbon stocks under different land uses: a case study in South Africa. Stellenbosch University.

Schulze, R. E. (2012). A 2011 Perspective On Climate Change And The South African Water Sector. WRC. Report No. TT 518/12. https://doi.org/10.1177/0950017011407975

Solomon, D., Fritzsche, F., Tekalign, M., Lehmann, J., & Zech, W. (2002). Soil Organic Matter Composition in the Sub-humid Ethiopian Highlands as Influenced by Deforestation and Agricultural Management. Soil Science Society of America Journal, 66, 68. https://doi.org/10.2136/sssaj2002.6800

Swanepoel, C. M., van der Laan, M., Weepener, H. L., du Preez, C. C., & Annandale, J. G. (2016). Review and meta-analysis of organic matter in cultivated soils in southern Africa. Nutrient Cycling in Agroecosystems, 104(2), 107–123. https://doi.org/10.1007/s10705-016-9763-4

Walker, S. M., & Desanker, P. V. (2004). The impact of land use on soil carbon in Miombo Woodlands of Malawi. Forest Ecology and Management, 203, 345–360.

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lützow, M., Marin-Spiotta, E., … Kögel-Knabner, I. (2019). Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales. Geoderma, 333(November 2017), 149–162. https://doi.org/10.1016/j.geoderma.2018.07.026

Key land conversions driving changes in emissions and sinks

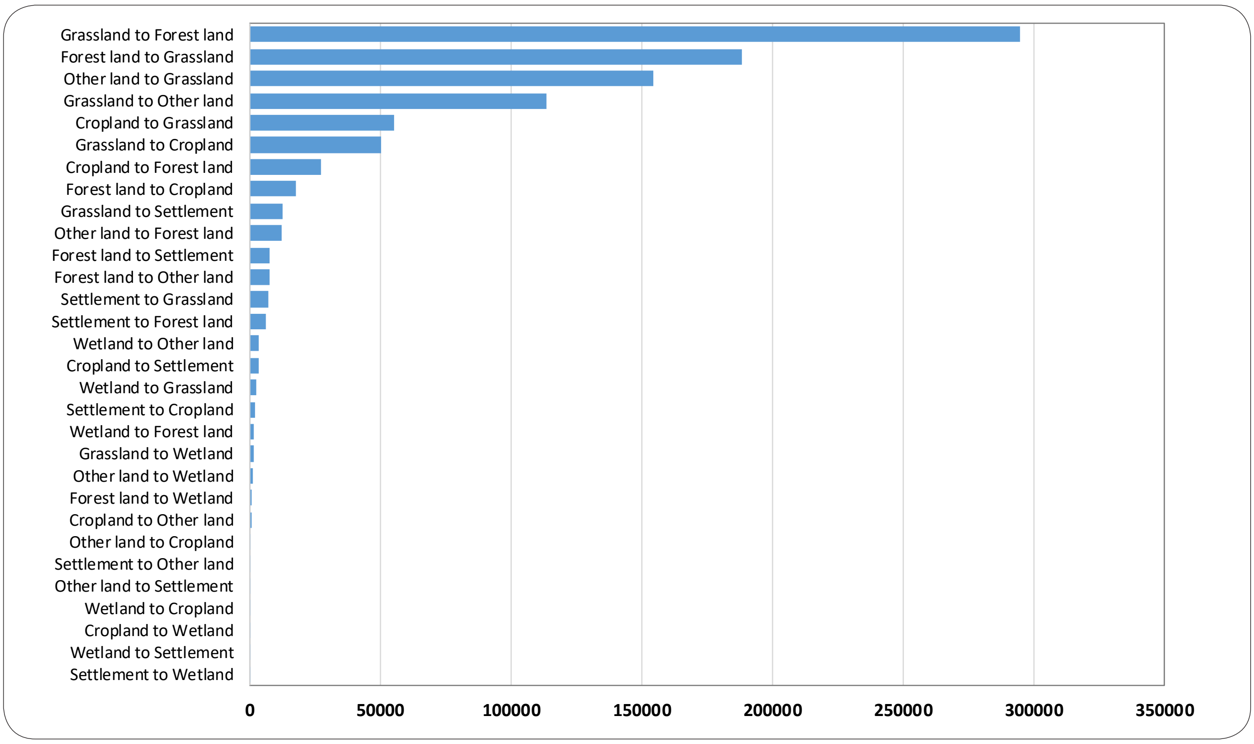


Figure A4.2: Annual area converted between 1990 and 2014 from largest to smallest.

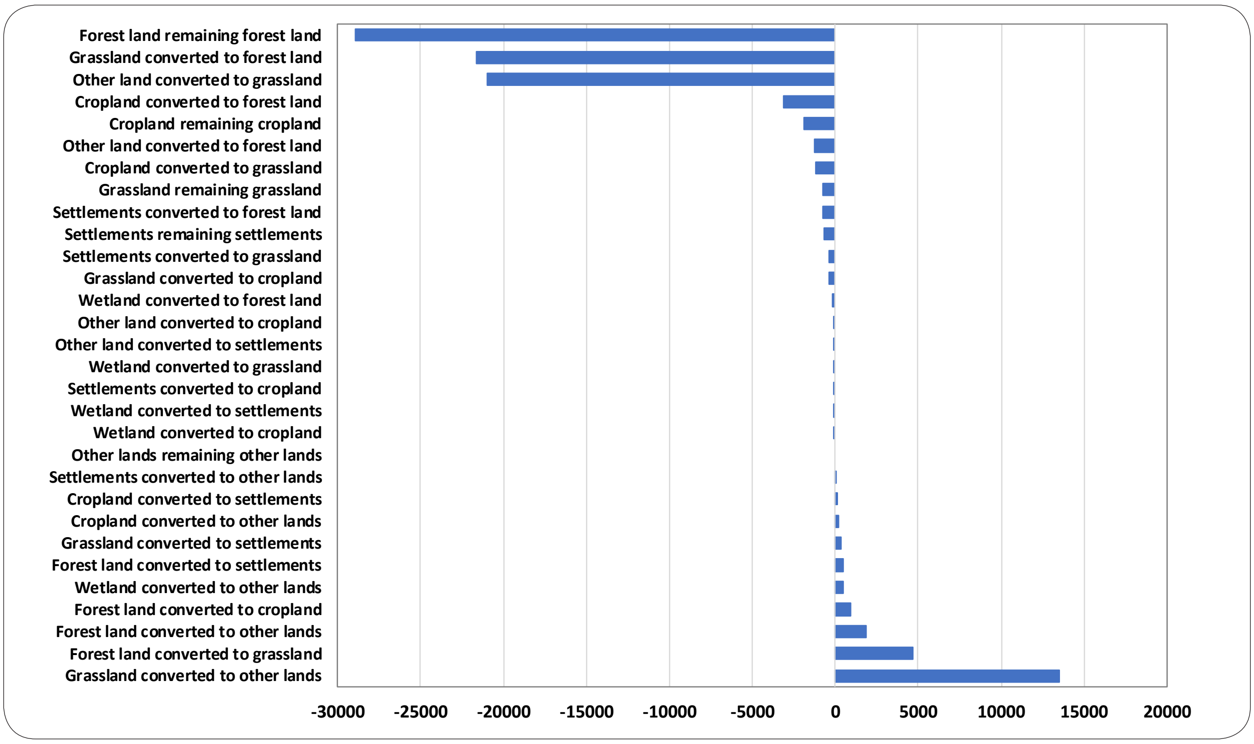


Figure A4.3: Contribution of land conversions to the sources and sinks (Gg CO_2) in the Land sectorin 2017.

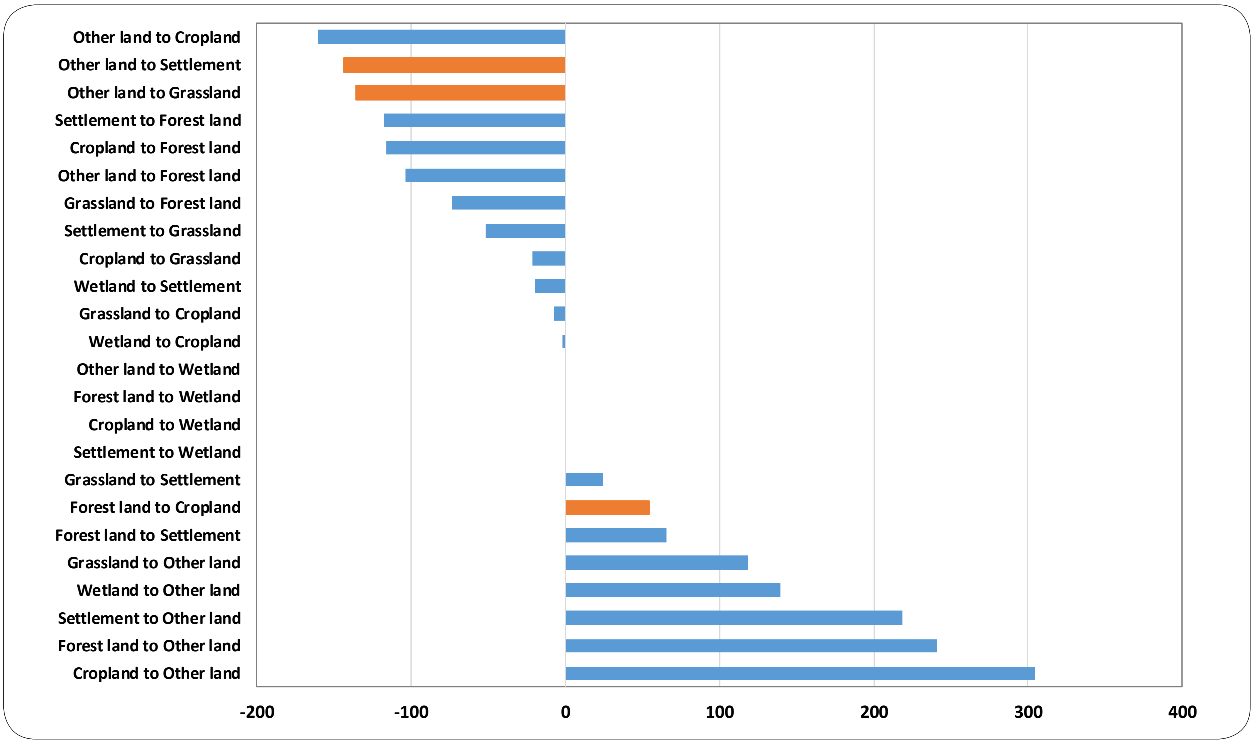


Figure A4.4: Emissions per ha (t CO_2/ha) contribution of the land conversions to land sinks and sources. Orange bars show the ones that are large conversions in terms of area.

SOIL CARBON MAPS FOR SOUTH AFRICA

RJ Scholes
June 2019

The purpose of this note is to evaluate the three detailed spatial databases and maps of soil organic carbon which have become available over the past decade or so, in terms of their suitability for use in estimating the land-based carbon budget of South Africa.

The first South African terrestrial carbon budget was performed in 2013 (DEA 2015). The largest single stock, by far, is the soil organic carbon (SOC), was then estimated at 6.62 PgC (6.1-15.4PgC for the 95% confidence range). The soil estimate was based on an Africa-wide soil database and Bayesian interpolation procedure, called the African Soil Information System (AfSIS) (http://www.africasoils.net/data/digital-soil-mapping, downloaded in March 2013). At that stage AfSIS was based on about 11000 soil profiles, of which 3600 were for South Africa. Since that time, AfSIS has grown to include over 17 000 profiles, the majority of which are not from South Africa, and the interpolation algorithm has evolved to now become the basis for the global SoilGrids dataset, curated out of ISRIC/World Soil Resources in Wageningen.

Subsequently, two other relevant databases and maps have also become available (Table A5.1). The first is a study for the DEA Carbon Sinks Atlas, performed by Schulze and Schütte (2018) and called the 'Carbon-rich soils of South Africa' (HiCSoils). In practice, it covers all the soils of South Africa, most of which are 'low carbon' by international standards, since high carbon soils were found to only occupy about 3% of the landscapes. It uses a completely different interpolation approach to AFSIS and GCSOM, based on the traditional way in which soil scientists work – associating a soil series with mapped polygons. The second 'new' database is the Global Soil Organic Carbon Map (GSOCM), prepared in 2018 under the auspices of the FAO in collaboration with the Institute of Soil, Climate and Water of the South African Agricultural Research Council and the Global Soils Partnership, in support of Sustainable Development Goal 15. Both the latter two datasets use essentially the same set of 11000 profiles curated by ISCW-ARC, but interpolate them in different ways. GSCOM uses a machine learning approach.

A fourth product, by CopperLeaf Consulting, is not worth considering separately since it just uses HiCSoil.

Table A5.1: Summary of the attributes of the three spatial representations of SOC which could be used for estimation of the South African land carbon budget.

Data source	Number of SA profiles	Spatial resolution and interpolation	Strengths and weaknesses
High Carbon Soils (HiCSoils)	11000	6.7 km on average (variable because polygon-based)	Used SA clay-based pedotransfer function for bulk density. Non-explicit depth function. No correction
Global Soil C map (GSOCM)	11000	5 km, (30 arc sec) vector support machine	Used international pedotransfer function for bulk density. No correction for stone content. Linked to an international approach.
AfSIS 2019 (AFSIS)	(3600?) 17160 Africawide	250 m or 1 km Random forest	The effect of land use is apparently based on Globcover as a covariate

Key considerations to be addressed in the 2019 revision of the SA soil carbon budget

1. **SOC determination method**. All the SA databases apparently use Walkley-Black wet-digestion SOC estimates. These underestimate SOC, and should be corrected (and reported as such) using the standard factor $SOC_{complete} = SOC_{WB} * 1.33$

2. **Bulk density**. Errors in bulk density translate linearly into errors in the estimation of carbon density. Very few of the profiles on which the carbon maps are produced have accompanying bulk density measurements, so all use a pedotransfer function to first estimate the bulk density. The South African-derived function synthesised and reported in HiCSoils as ρb (Mg m^{-3})= - 0.0079 * Clay % +1.7243 should be used, rather than a general globally-derived function such as that used by GSOCM. This pedotransfer function calculates the density of the undisturbed non-stone fraction of the soil (<2mm), and must still be corrected for whole soil bulk density, as influenced by stone fraction (see 3. below). A different pedotransfer function must be used for disturbed soils, such as those in croplands. Estimation errors must be calculated for all the pedotransfer functions used, and carried through in the error propagation procedure when soil carbon density is calculated.

3. **Coarse fragment content** (synonymies: =stone content, =gravel content). Many South African soils (possibly most, especially in arid, steep and non-cultivated areas) contain a large fraction of coarse fragments (i.e. mineral particles that do not pass through a 2 mm grid sieve after gentle crushing), especially in the subsoil. These reduce the soil carbon density in direct proportion to the volume which they occupy, since they are assumed to contain zero SOC themselves. The volume fraction of coarse fragments can be estimated from their mass fraction (F_m = mass of coarse fragments/whole-soil dry mass): $F_{v,fragments} = F_{m,fragments}/2.64$. The problem is that the coarse fraction is usually not reported, because by definition, it is not soil and therefore thrown away! Neither the GSOCM nor the HCsoil apparently correct for coarse fragments; AfSIS has a field for coarse fragments and therefore has the capability to calculate it, but it is not clear if they included it in their estimates of C density.

4. **Depth of reporting and method of depth integration**. The C density (gC m^{-2}) depends nonproportionally on the depth to which it is calculated, because soil carbon declines approximately exponentially with depth. Most carbon is typically in the upper layers: Schulze and Schütte (2018) estimate that for South Africa as a whole 62-66% is in the topsoil. Some allowance needs to be made for soils which encounter bedrock within the integration depth, since this truncates the distribution. It is further true that most decadal-scale changes in SOC take place in the topsoil, so for purposes like the SDGs, the SOC is often only integrated to 300 mm depth – but this cam miss a very substantial part of the carbon (1/3), some which is subject to change. Therefore it is more robust to report both the 0-300 mm SOC, and the deeper SOC, to a standardised depth of 1000mm or bedrock, whichever is encountered first. The HiCSoils product assumes that topsoils extend to 300 mm (except if the whole soil is shallow, in which case they apply a proportional reduction). This makes it impossible to rigorously compare their 'topsoil' estimates with the depth-corrected values of GSOCM of AfSIS, both of which *first* apply a way of standardising to a given depth from horizon data of differing thicknesses. This is important for both intercomparison between products and intercomparison over time. For instance, one way the soil carbon density can change is by topsoil loss, which results in a change in the intercept of the depth function. In general, an 'equivalent volume' spline technique should be applied, such as Jaquier and Seaton (2010).

5. **Spatial interpolation method** (including considerations of resolution, and which covariate data are used to guide the interpolation). Soil carbon density varies from place to place, often at a scale of a few tens of meters. To calculate the total C stocks of a large area therefore requires a way of interpolating the limited number of profiles over

the landscape. Even the densest available sampling works out on average at one sample every 10 km (and much more in some landscapes, i.e. 1 per 100 km^2). Two fundamentally-different interpolation methods are used for soil data. HiCSoils uses the 'traditional' method applied by soil scientists, which is to stratify the area into homogeneous units ('landscapes', or in South African terminology, 'land types'), then associate an average profile with that unit, and 'paint' the entire unit with the soil attributes of that average profile. One of the problems is that in South Africa (and elsewhere) soils are not mapped at the scale of their fundamental variation. In South Africa the mapped scale is 1:250 000, and the units therefore include topographic variation and many different soil series, whose proportions are given but not explicitly mapped. HiCSoils solves this problem by overlaying the Land Type units with a DEM-derived topographical segmentation into up-slopes, mid-slopes and bottomlands, and then associates proportions of different soils to the resulting polygons. AfSIS and GSOCM, in contrast, both use a 'geostatistical' approach, where the data itself guides the estimate. This is done as a spatially-continuous way (i.e. on a fixed grid of given spacing, between 250 and 5000m), rather than an assumption about the extent of a mapping unit. Both AFsis and GSOCM use very advanced statistical techniques for the spatial interpolation, which are robust and generally outperform the 'traditional' approach substantially when tested; but the price paid is a loss of transparency. AfSIS uses a multiple regression against a long set of factors known to influence soil attributes, to get a broad pattern of SOC, and then uses co-kriging to adjust this according to the values reported by nearby observations. This approach has subsequently been adopted by SoilGrids, the global effort which has subsumed AfSIS. A problem is that the distance over which kriging of soil properties is effective is typically quite short (<1 km) but the samples are often much further apart. A machine-learning approach called 'random forest' is then used to combine the regression and kriged estimates. GCSOM describes many different approaches in its 'cookbook', and allows individual countries to select their own preferred approach. In the case of South Africa, GSP and ISCW chose a machine leaning technique called a vector support machine.

6. **Non-independence and error quantification.** All three databases share the same basic dataset on soil carbon, collated by the ISCW from the national soil database they hold. AfSIS was granted access to 3600 of these records, GSOCM uses 11019, and HiCsoil used 10 000, after rejecting some outliers. So the three products are not truly independent, and this affects how they can and cannot be used for 'cross-validation'. The key concern is that they all contain the same *systematic biases* (which almost certainly exist: for instance in their use of the Walkley-Black analysis for SOC, which underestimates by about a quarter). These biases would not be detected in an intercomparison, and are not reflected in the error statistics reported by the products. All products and sub-products in an exercise of this nature (i.e. national carbon budgeting) must be accompanied by an uncertainty estimate, which must be rigorously derived rather than just qualitatively guessed at. The C density, which is the fundamental end product needed, is the ***sum*** over depth intervals of a ***product*** of C content (C) by bulk density (ρ) by ($1-F_{coarse}$). The error propagation rules for products are different than those for sums: for products, assuming that the errors in the individual elements being estimated are independent (which is not strictly true here, since for instance in most cases ρ is estimated from %clay, and C content is known to be highly dependent on clay as well), the relative standard deviation of carbon density is the root mean square of the relative standard deviations of C, F_{coarse} and ρ; whereas the cumulative error of the profile sum is the square root of the summed squared standard deviation of each layer. When aggregated to the level of a whole landscape or country the error of estimation depends on the interpolation method (the two geostatistical methods provide spatial error terms, the mapping method does not, though in principle it is the combination of a map accuracy with the errors of associating a set of modal profiles to that map unit, both of which are quite high, though seldom reported). When you then aggregate many, many raster points or polygons to get the whole-country

estimate, the overall error estimates *if random and independent* decrease by 1/sqrt (number of samples) – in other words, for the mapping approach by about 99.396%, or in the AFSIS 1km dataset, by 99.908%. However, an unknown part of the error is not independent between samples, and this does not go down at all when the sample number goes up. It is this, largely unquantified, systematic error which makes it currently essentially impossible to estimate the change in soil C stocks between two times around a decade apart (see note 8. below).

7. **Validation**. None of the three datasets has been independently validated for South Africa. Therefore it is impossible to say which is 'more correct'. Validation would require a well-distributed dataset, optimally probably in the order of 2000 profiles, which were NOT used in the derivation of the estimate which is being validated. These validation data should also be bias-controlled by referencing them against international standards and/or archived samples, if the systematic error is to be controlled for as well. This excludes simply reserving a fraction of the data in the current datasets. It would require a new sampling and analysis programme.

8. **The detectability of change over decadal-length periods**. Realistically, the uncertainty of estimation of carbon density for individual profiles is in the order of 15%, once the errors in % C, bulk density and stone content have been included. Since the average topsoil SOC content in South Africa is in the order of 2000 g m^{-2}, the uncertainty translates to 300 gC m^{-2}. Further assuming a thickness of 300 mm and a bulk density of 1.5 Mg m^{-3}, this is a variation of an absolute value of 0.066%, on a mean soil C percentage of 0.44%. Some of the target interventions, such as 'climate smart agriculture' claim increases in soil C over a decadal period which is larger than this uncertainty, and should therefore in principle be detectable by paired (before and after) repeat sampling 5 or ten years apart. However, given that such practices typically only take place on a tiny fraction of the national landscape, they become invisible to a nationwide repeat carbon budget estimate, or by a non-paired change in an approach which simply averages the point samples over the whole landscape – they become diluted out. The only way to quantify such location-specific or land-use specific changes is either to implement a paired sample approach on participating projects, or to apply a validated model to a well-established baseline.

Recommendations

1. In all cases report SOC both for topsoil (0-300 mm) and subsoil (301-1000 mm). By default this also gives their sum, the 0-1000mm Soil density.

2. Use a rigorous depth-integration procedure before interpolation (and equal-volume spline, e.g. Jaquier and Seaton 2010) so that the results are comparable over time and between products.

3. Commission a nationwide soil depth map, and a map of bulk density and stone content. The latter two need to be quantified by at least topsoil and subsoil, and preferably using a continuous depth function. All surfaces must be accompanied by uncertainty estimates, the Standard Error of the Mean SEM). These studies can use existing data and products, where they exist and are adequate, but in some cases may need dedicated sampling.

4. Extract the actual 'high carbon soil' polygons using the national wetlands database in conjunction with the pedon data for series with 'organic' or 'humic' diagnostic A horizons to estimate the carbon content of high-C soils. These soils are disproportionately important, relatively well-mapped, and lead to outlier problems when combined in interpolation schemes with the mineral soils, which are much more extensive.

5. Segregate the remaining 'mineral' soils, into 'disturbed soils' and 'undisturbed soils' using the national field map (which should also include, as separate categories, plantation forestry areas, mine clearance and rehabilitation areas, and human settlement areas). It would be ideal to associate each disturbed soil patch (e.g. agricultural field or

plantation compartment) with the date of conversion from undisturbed, and/or the date at which the patch was put under carbon accumulation management. In practice, it is the recent conversions (less than a decade) which matter most, so the successive land cover maps could be used for this purpose, in bins of 5 years and combining all areas converted before 1995 into one category.

6. For the undisturbed soils use the GSOC map interpolation scheme, because it is the official source for reporting to the SDG, and is based on a large number of 'official' profiles and a well-documented interpolation procedure. Accompany it with map of uncertainty of the interpolation scheme.

7. For the same area, extract the AFSIS 2019 (i.e. the SoilGrids) 0-300 and 301-1000 mm SOC data and their confidence ranges, and determine the interconversion factors with the GSOCM, by broad soil group. This is a way of estimating the inter-interpolation scheme error, and paves the way to perhaps going to the SoilGrids interpolation scheme in future.

8. For the disturbed soils, estimate the undisturbed soil carbon content from the GSOCM map and then apply the HiCSoil correction factors for soil disturbance, separately for topsoil (0-300) and subsoil (301-1000mm), and preferably taking into account both the time since conversion and the land management applied. This will require a systematic modelling effort, preferably using one well-calibrated model (either Rothampsted or CENTURY are acceptable), covering a selected set of management interventions and environmental circumstances, and consistent with the database results and the IPCC guidelines.

References

DEA (2015) National Terrestrial Carbon Sink Assessment Department of Environmental Affairs, Pretoria, South Africa.

Chang, C.-C. and Lin, C.-J. (2001). Libsvm: A library for support vector machines [eb/ol].

Friedman, J., Hastie, T., and Tibshirani, R. (2001). The elements of statistical learning, volume 1. Springer series in statistics New York.

Guevara, M. *et al*. 2018 No silver bullet for digital soil mapping: Country-specific soil organic carbon estimates across latin america. SOIL Discussions, 2018:1{20}. doi: 10.5194/soil-2017-40.
URL https://www.soil-discuss.net/soil-2017-40/.

Hengl, T., de Jesus, J. M., MacMillan, R. A., Batjes, N. H., Heuvelink, G. B., Ribeiro, E., Samuel-Rosa, A., Kempen, B., Leenaars, J. G., Walsh, M. G., *et al.* (2014). Soilgrids1km—global soil information based on automated mapping. PLoS One, 9(8):e105992.

Hengl T, de Jesus JM, MacMillan RA, Batjes NH, Heuvelink GBM, et al. (2014) SoilGrids1km — Global Soil Information Based on Automated Mapping. PLoS ONE 9(8): e105992. doi:10.1371/journal.pone.0105992

Hengl, T., Heuvelink, G. B., Kempen, B., Leenaars, J. G., Walsh, M. G., Shepherd, K. D., Sila, A., MacMillan, R. A., de Jesus, J. M., Tamene, L., *et al.* (2015a). Mapping soil properties of Africa at 250 m resolution: random forests significantly improve current predictions. Plos one, 10(6):e0125814.

Leenaars J.G.B., A.J.M. van Oostrum and M. Ruiperez Gonzalez, 2014. Africa Soil Profiles Database, Version 1.2. A compilation of georeferenced and standardised legacy soil profile data for Sub-Saharan Africa (with dataset). ISRIC Report 2014/01. Africa Soil Information Service (AfSIS) project and ISRIC - World Soil Information, Wageningen, the Netherlands. 162 pp.; 16 fig.; 10 tab.; 25 ref.

Jacquier D and S Seaton, 2010. Spline tool for estimating soil attributes at standard depths. CSIRO, Land and Water, Australia, 4 p.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., and Duchesnay, E. (2011). Scikitlearn: Machine learning in Python. Journal of Machine Learning Research, 12:2825–2830.

Tomislav Hengl, Jorge Mendes de Jesus, Gerard B. M. Heuvelink, Maria Ruiperez Gonzalez, Milan Kilibarda, Aleksandar Blagotic, Wei Shangguan, Marvin N. Wright, Xiaoyuan Geng, Bernhard Bauer-Marschallinger, Mario Antonio Guevara, Rodrigo Vargas, Robert A. MacMillan, Niels H. Batjes, Johan G. B. Leenaars, Eloi Ribeiro, Ichsani Wheeler, Stephan Mantel, and Bas Kempen. SoilGrids250m: Global gridded soil information based on machine learning. 12(2):1{40, 2017. doi: 10.1371/journal.pone.0169748.
URL https://doi.org/10.1371/journal.pone.0169748.

M. Henry, R. Valentini, and M. Bernoux. Soil carbon stocks in ecoregions of Africa. Biogeosciences Discussions, 6:797{823, 2009. doi: 10.5194/bgd-6-797-2009. URL https://www.biogeosciences-discuss.net/6/797/2009/.

C. Poeplau, C. Vos, and A. Don. Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content. SOIL, 3(1):61{66, 2017. doi: 10.5194/soil-3-61-2017.
URL https://www.soil-journal.net/3/61/2017/.

Vapnik, V. (2013). The nature of statistical learning theory. Springer science & business media.

Walsh, M.G., Ahamed, S., Hartemink, A.E., Huising, J., Okoth, P., and Palm, C.A. A new information system for managing sub-saharan african soil: Why and how?, 2009.

Yusuf Yigini, Guillermo Federico Olmedo, Kostiantyn Viatkin, Rainer Baritz, and Ronald R Vargas, editors. Soil Organic Carbon Mapping Cookbook. FAO, 2nd edition, 2017 220pp. URL http://www.fao.org/3/a-bs901e.pdf.

Other useful resources

See the USGS global map of rock types at 250m (a layer in the global ecosystem classification) (http://rmgsc.cr.usgs.gov/outgoing/ecosystems/Global/). [This may be a useful covariate for soil depth and stone content.]

Appendix to Appendix 5: Technical details of the major soil carbon mapping approaches

Global Soil Organic Carbon Map

This product was generated under the auspices of the Food and Agriculture Organisation (FAO), in collaboration with many national-level soil agencies and the Global Soil Partnership (GSP), under the guidance of the Intergovernmental Technical Panel on Soils (ITPS). It was released in 2018. A key purpose is to support the SDG 15.3.1 indicator on SOC.

Where to find it and IP issues:
http://www.fao.org/documents/card/en/c/I8891EN

FAO and ITPS (2018) Global Soil Organic Carbon Map (GSOCmap). Technical Report, FAO, Rome. 167 pp. ISBN: 978-92-5-130439-6

It is accompanied by

Yusuf Yigini, Guillermo Federico Olmedo, Kostiantyn Viatkin, Rainer Baritz, and Ronald R Vargas, (eds) 2018 Soil Organic Carbon Mapping Cookbook. FAO, Rome. ISBN 978-92-5-130440-2

The following is a complete (but reorganised) quote from the text in FAO and ITPS (2018) on the data use policy:

'The shared data-sets contain the best available information for a given area and topic, however, they are subject to potential restrictions based on the institutions' or countries' data policy. The data shared by the countries have been quality controlled which means that the data have been technically evaluated to ensure data integrity, correctness, and completeness; errors and omissions are identified and, if possible, addressed.'

In the case of original data, the rightful data owner keeps full ownership of it. All intellectual property rights (IPR) and copyrights pertaining to the data owner remain intact and are respected by the soil data facility (SDF) host. All data providers must communicate to the SDI host their IPR and data use policies. Thus, the ownership of all data made available through the GSP soil portal needs to be clearly specified. This is an important prerequisite to allow this data to be accessible through the soil SDF. In the case of derived data, the deriving institution becomes the rightful owner. However, all original data must be accredited and correctly cited. According to the Pillar 4 Implementation Plan, each global-level derived GSP data product will be quality-assured by the Pillar 4 Working Group. This includes agreements about the correct citation. The data owner shall ensure that the data shared can be used and interpreted by the authorized users in general; this includes providing the proper citations, as well as providing information over the ownership of such data for acknowledgement purposes. Users shall acknowledge the source of data provided through the Global Soil Information System. All providers of original data (data owners) are responsible to define and clarify the IPR and licensing. Any user of this data, such as the SDF host, has to respect the national data policies and/or licensing involved with the retrieval of the respective web services. In the case of data provided to the central repository, a bilateral agreement/license may be required (between the national data owner and SDF host), depending on and in conformity with national rules.

The GSP data policy (South Africa is represented in the GSP) aims to ensure that:

- *every existing ownership right to shared soil data are respected;*
- *the specific level of access and the conditions for data sharing are clearly specified;*
- *the ownership of each dataset and web service are properly acknowledged and well-referenced;*
- *the data owners are protected from any liability arising from the use of their original and/or derived data.*

It is recommended that data owners comply with the following open data principles:

a. *Accessibility: the data shall be divulged through the Internet (web services).*

b. *Availability: the data is presented in a convenient, platform-independent and standards conformant format (e.g. web feature service WFS).*

c. *License: the formal concession of the usage and access rights over the data shared.*

d. *Cost: data shall be shared free of cost, or at no more than a reasonable reproduction cost, preferably by downloading it from the Internet.*

e. *Re-use and Redistribution: data must be provided and licensed under terms that permit its reuse and redistribution, including intermixing with other data-sets.*

f. *Global benefit: any user must be able to access, use and redistribute data of the Global Soil Information System. However, inherited restrictions by national data policies shall be accepted.*

g. *Metadata: data describing the products of the Global Soil Information System will by default be open for access.'*

{end of quote}

The South African participant is the Institute for Soils, Climate and Water, part of the Agricultural Research Council. Dr Maila. scwinfo@arc.gis.za .

Technical issues

South Africa was one of the countries that supplied a national map to GSOCM, in a joint effort with GSP. GSP gap filled 35% of the world, and soilgrids.org was used to gap fill 2% of the world land area.

The map was produced in a joint effort with Global Soils Partnership, using their techniques. The number of profile samples used for South Africa was 11257, collected between 1972-2014. No bulk density data was supplied by ISCW-ARC, so a pedotransfer function must have been used, presumably the international one described in the cookbook. No validation statistics were used.

A large number of covariate maps were generated globally by ISRIC, at 30 arc seconds (about 1km x 1km) resolution. These define the target resolution of the SOC map. Many of these covariates will be correlated, which may be one reason why a SVM was used (see below), but adds to lack of transparency.

0-30 cm is the minimum information required for GSOCM, though countries are encouraged to provide other depth increments in addition. It is not clear if South Africa did or not.

Any SOC measurement method is accepted (the SA version uses Walkley-Black). The approach allows SOC stock [t/ha], bulk density (BD) [kg/m^3] and stone content [%] to be estimated or measured; it is not clear if the latter was done.

The South African map was generated using a Support Vector Machine (SVM), which is a machine-learning algorithm, implemented in R. The code is available in FAO and ITPS (2018) appendix.

Global Soil Organic Carbon Stock for topsoil (0 to 30 cm) is 680 Petagrams. This value is 3.2% lower than the value provided for by the 'best previous' estimate, HWSDa [Kochy *et al.*, 2015] (Table 6.1).

The RMSE, a measure of accuracy, is 24.66 Mg ha-1 for the 'mineral soils' . The SD in South Africa is less than 10tC/ha, from the map provided, but topsoil SOC in South Africa is on average only 20 Mg/ha! As a rough estimate, South Africa should contain about 1% of the world's soil carbon.

From the cookbook, here are some comments relating to errors:

'The estimation of stoniness is difficult and time-consuming, and therefore not carried out in many national soil inventories, or only estimated visually in the profile. Unfortunately, if soil inventories and sampling are done with simple pits or augers rather than standard soil pits, stones are very often not assessed. As a proxy, it is recommended to derive national default values from well-described soil profile pits by soil type.

Most of the soil profiles in national databases come from agricultural land. Very often, BD estimates do not consider fine stones because top soils (e.g. plough layers) seem to be free of visible stones. For mineral soil, default values from the 'General Guide for Estimating Moist Bulk Density' given by United States Department of Agriculture. Soil Conservation Service (2018). If analytical BD is missing, BD can be estimated using pedotransfer functions.'

Table 6.4: Mean SOC stocks per WRB soil types

Soil Type	SOC, t/ha	Soil Type	SOC, t/ha	Soil Type	SOC, t/ha
Histosol	132.12	Regosol	57.32	Ferralsol	42.9
Chernozem	89.07	Fluvisol	57.12	Solonetz	40.55
Gleysol	88.36	Alisol	51.29	Anthrosol	40.2
Podzol	80.59	Nitisol	50.26	Lixisol	37.19
Andosol	76.16	Leptosol	49.63	Vertisol	30.68
Cambisol	62.94	Planosol	47.72	Gypsisol	24.26
Phaeozem	61.2	Kastanozem	47.59	Arenosol	24.17
Albeluvisol	60.73	Luvisol	44.71	Solonchak	22.01
Acrisol	58.87	Plinthosol	43.01	Calcisol	21.22

[illegible] Mg ha-1. This is the Mean Error, a measure of bias.

The cookbook provides the following useful information:

SOM = SOC · 1.724 (Van Bemmelen factor, ie SOM is 58% C) Usually, an average of 76% organic carbon is recovered by wet digestion relative to CNS analyser, leading to a standard oxidation factor of 1.33 (Lettens *et al*., 2005).

Support vector machines is a kernel-based machine learning technique suitable for mapping SOC. SVM use decision surfaces (defined by a kernel function) to map non-linear relationships across a high-dimension induced feature space (Cortes and Vapnik, 1995). SVM is widely used to perform classification and regression analysis on Digital Soil Models (DSM). According to Pedregosa *et al.* (2011) the advantages of SVM are:

- Effective in high dimensional spaces.
- Still effective in cases where the number of dimensions is greater than the number of samples.
- Uses a subset of training points in the decision function (called support vectors), so it is also memory efficient.
- Versatile: different Kernel functions can be specified for the decision function. Common kernels are provided, but it is also possible to specify custom kernels.

And the disadvantages of SVM include:

- If the number of features is much greater than the number of samples, avoid over-fitting in choosing Kernel functions and regularization term is crucial.
- SVM do not directly provide probability estimates, these are calculated using an expensive five-fold cross-validation.

In DSM, the problems usually involve working in high dimensional spaces (where the dimensions are the covariates) with a limited number of samples. SVM is a technique mostly used in classification problems, but it can be used to solve regression problems, such as modelling the continuous variability of SOC using environmental covariates. When SVM is used to solve a regression problem, it is called support vector regression. Support vector regression applies a simple linear method to the data but in a high dimensional feature space non-linearly related to the input space. It creates n hyperplanes through the n-dimensional spectral-space and each hyperplane separates numerical data based on a Kernel function (e.g., Gaussian). SVM uses parameters such as gamma, cost and epsilon. These parameters are used to define the shape of the hyperplane, including the margin from the closest point to the hyperplane that divides data with the largest possible margin and defines the tolerance to errors on each single training. Linear models are fitted to the support vectors and used for prediction purposes. The support vectors are the points which fall within each hyperplane (Guevara *et al*., 2018). Implementation of SVM is in the R package e1071 (Meyer *et al*., 2017). The mathematical background is in Vapnik (2013), Friedman *et al.* (2001), and James *et al.* (2013).

African Soil Information System

The AFSIS product is an evolution of the product used in the first SA C budget in 2013. AfSIS was a Gates Foundation funded project, which is now housed at Columbia University in the USA with strong intellectual and personnel links to ISRIC in the Netherlands (SoilGrids), which seems to have taken over the AfSIS database and approaches now that the Gates funding is over.

Where to find it and IP issues

http://africasoils.net/publications/

In principle it is open source; but documentation is sometimes not completely up to date.

See also Hengl *et al.* 2015. They used Random Forests as an interpolation framework in Africa, apparently on the AfSIS pedon data, and found that it greatly outperformed linear regression. The Random Forest inputs included both linear models and kriging.

Technical issues

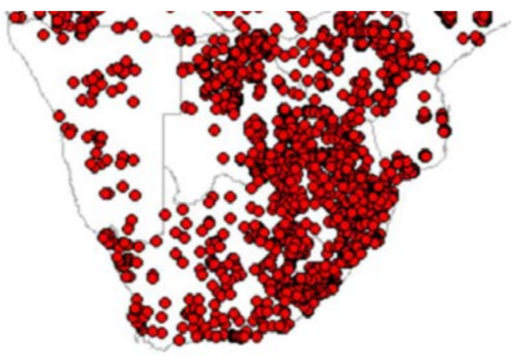


Figure A5.1: AFSIS samples in Southern Africa.

As kriging covariates, the following have been used:

1. MODIS products at 250 m resolution— Mid-infrared (MIR) Reflectance (Band 7) Long-Term and Monthly Averages and Enhanced Vegetation Index (EVI) Long-Term and Monthly Averages (MOD13Q1 product). These layers were prepared for the purpose of the AfSIS project by the Earth Institute at Columbia University and are available for download at http://africasoils.net/data/datasets.

2. SRTM DEM v4.1 derived covariates—Elevation, slope and SAGA GIS Topographic Wetness Index (TWI), all derived at 250 m resolution.

3. GlobeLand30—The fraction of coverage for ten land use classes from the global land cover map for 2010, which were resampled from 30 m to 250 m resolution in SAGA GIS. These layers were also used to determine the soil mask i.e. the areas of interest for soil mapping, for instance by excluding water bodies.

4. SoilGrids1km—Used 1 km–resolution predictions of soil properties and classes produced previously using global models. These were first downscaled to 250m resolution by bicubic resampling, as implemented in the SAGA GIS software.

They found that mapped soil type was a powerful predictor, especially the presence of Alfisols and Mollisols.

For more information on Random Forests, see S1 Regression-kriging in R using the Meuse data set. Regression-kriging and comparison of spatial prediction efficiency explained using the Meuse data set [30]. For more R code examples please also refer to the GSIF tutorial at http://gsif.isric.org. (PDF).

Table 2. Summary statistics for mapping accuracy assessed using 5–fold cross-validation. *ME* is the mean error, *RMSE* the root mean squared error, `sg1km` are the SoilGrids1km map, `rf` represents random forest model predictions and `lm` the linear model predictions (trend model predictions only). The *t*-test evaluates the difference between the mean errors of the `rf` and `lm` models with alternative hypothesis that the difference is greater than 0. The *F*-test evaluates the ratio between the residual variances of the `rf` and `lm` models with alternative hypothesis that the difference is greater than 1. $\Sigma_{\%}$ indicates amount of variation explained by the prediction models and $\Delta RMSE_{\%}$ indicates improvement in *RMSE* in percentages compared to the `lm` model. The '⋆⋆⋆' indicates significance at the 99% probability level. For all soil properties except `PHIHOX`, `SNDPPT`, `SLTPPT`, `CLYPPT` and `BLD`, the $\Sigma_{\%}$, the *t*-test, and the *F*-test have been calculated in log-transformed space. `SP-SS` are the predictions at Sentinel Sites produced using models fitted from AfSP data, `SS-SP` are the predictions at legacy soil profiles produced using AfSS data. See Table 1 for more details.

	sg1km	lm	rf		sg1km	lm	rf			rf	SP-SS	SS-SP
GSIF code	*ME*	*ME*	*ME*	*t*-test	*RMSE*	*RMSE*	*RMSE*	*F*-test	$\Sigma_{\%}$	$\Delta RMSE_{\%}$	*RMSE*	*RMSE*
ORCDRC	1.429	0.113	0.308	1.000	13.0	12.2	10.6	0.000***	61.3	+15.1	11.4	14.4
PHIHOX	-0.063	0.002	0.006	0.985	0.933	0.886	0.673	0.000***	66.9	+31.6	0.69	1.01
SNDPPT	-1.117	-0.035	-0.066	0.209	23.0	21.2	15.9	0.000***	61.1	+33.3	27.2	29.7
SLTPPT	-2.396	0.040	0.190	1.000	11.9	10.9	8.31	0.000***	56.1	+31.2	NA	NA
CLYPPT	-3.087	0.005	0.183	1.000	18.1	17.1	13.7	0.000***	52.4	+24.8	NA	NA
BLD	0.007	0.000	0.002	0.749	0.227	0.213	0.141	0.000***	70.4	+51.1	NA	NA
CEC	1.114	-0.050	0.152	0.000***	11.4	11.0	7.92	0.000***	66.3	+38.9	NA	NA
NTO	NA	0.001	0.015	0.000***	NA	0.818	0.691	0.000***	61.0	+18.4	0.688	0.977
ALUM3S	NA	0.016	0.535	0.000***	NA	279	160	0.000***	86.3	+74.4	912	NA
EACKCL	NA	-0.004	0.033	0.000***	NA	2.14	1.30	0.000***	77.3	+64.6	NA	NA
ECAX	NA	-0.027	0.295	1.000	NA	16.2	12.7	0.000***	67.2	+27.6	27.9	18.4
EXKX	NA	-0.002	0.017	0.817	NA	0.740	0.599	0.000***	58.6	+23.5	0.435	0.925
EMGX	NA	0.016	0.083	0.000***	NA	3.58	2.52	0.000***	66.0	+42.1	2.40	4.41
ENAX	NA	0.001	0.085	0.000***	NA	4.25	3.61	0.000***	46.7	+17.7	5.63	5.82
EXBX	NA	0.022	0.314	1.000	NA	15.5	11.0	0.000***	68.8	+40.9	20.9	17.8

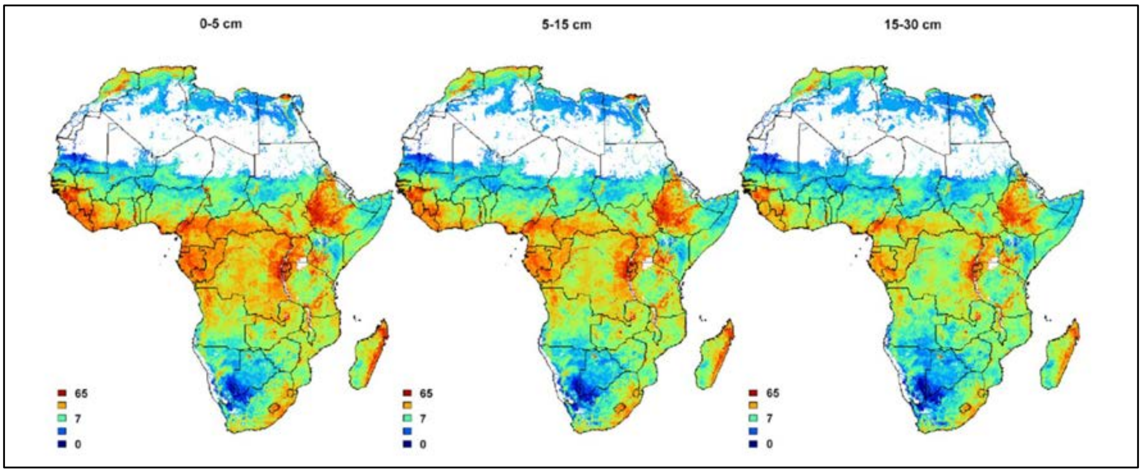


Figure A5.2: Soil carbon 0 to 30 cm by Random Forests. Units are permilles (i.e. tenths of a percent).

Carbon rich soils in South Africa (HiCSoils)

The purpose of this 2018 project, funded by GIZ and executed by consultants Roland Schulze and Stephanie Schütte, associated with UKZN, was to develop maps at high resolution of soil organic carbon stocks across the entire South Africa, for use in the National Carbon Sinks Atlas. The focus was intended to be on areas with soils high in organic carbon (those which have a humic or organic A horizon), in order to guide soil C loss mitigation targeted specifically at these soils.

Where to find it and IP issues

Schulze, RE and S Schütte 2018 IDENTIFICATION AND MAPPING OF SOILS RICH IN ORGANIC CARBON IN SOUTH AFRICA AS A CLIMATE CHANGE MITIGATION OPTION Contributing also as an Input to the Electronic National Carbon Sinks Atlas Developed by DEA. GIZ Contract No: 83258289. Schulze and Associates. May 2018.

In principle the products are open source, since the project was done for use in the SA Soils Atlas. However, the underlying profile data are held by ISCW-ARC and are not likely to be released without new negotiation. The full raster database (i.e. the carbon densities, but not the underlying data) is available on Dropbox, but is large (600 Mb).

Technical issues

The method adopted in this project is quite different to the other two. Its original focus was on soils rich in organic carbon, though the mapping is national. In practice, since the high-C soils are so small in area, especially west of the escarpment, they ended up doing all polygons in South Africa, regardless if they are high-C or not. HiCSoils follows a classical soil science 'paint-by-numbers' approach, rather than a geostatistical approach. Traditionalists in the soil science fraternity find geostatistics abhorrent, largely because it renders their traditional field skills of profile description and pedon mapping irrelevant.

The data is based on soil horizons, within profiles classified to soil series in terms of the South African Binomial Soil Classification, or the South African Trinomial system, by the ISCW-ARC. The spatial extrapolation was via the 1 : 250 000 "Soils Land Types" maps of the ISCW-ARC. Each Land Type was then split (but not mapped), into the fractions occupied by each of five terrain units (crest, the scarp, the mid-slope, the foot-slope and the valley bottom), using a 90m Digital Elevation Model (DEM). The result was 27 491 terrain units (TU) covering South Africa. Each of these was accompanied by the percentage of each of the soil series they contain, and with other relevant information on each soil series within the terrain unit, such as the soil depth. The soil carbon content for the various soil series was extracted from the ARC's Soil Carbon Database and merged with the terrain unit database. The approach deals with both natural vegetation cover and soils modified by having been cultivated within the past several decades.

Of the 27491 Tus, 24.71% are convex-shaped crests, 24.95% are concave mid-slopes, 26.63% were foot-slopes and 25.70% were valley bottoms (these are TU count percentages rather than area percentages). Each TU record has a spatial extent of the TU, a list of all soil series in the TU up to a maximum of 15 and their percentage area contribution, the percentages which the TU makes up of the Land Type, the average profile depth of each soil series within a TU and several other attributes. A maximum soil profile thickness (i.e. soil depth) of 1.5m is assumed, and for all soils deeper than 0.5m the topsoil is assumed to be 0.3m thick with the balance being the subsoil. The topsoil is assumed to becoming progressively thinner when the soil is shallower than 0.5m, down to 0.005m for 'bare rock' , with an additional 0.005m as subsoil in this case.

Only 885 out of South Africa's 27 491 terrain units (i.e. 3.2%) contain either humic or organic soils, in terms of the Binomial classification system.

A much larger sample of profiles was available in the ISCW Soil Carbon database, but they are classified in different system (the later Trinomial system). So a translation process was developed. The samples were split into those under natural vegetation, and those under crop agriculture, and an average % soil carbon content in topsoil and subsoil was calculated for all 501 soil series, under each land use case. A pedotransfer function (based on Van der Merwe, 1973; Hutson, 1984; Schulze, 1995) was used to estimate the dry bulk density

ρb (Mg m^{-3})= - 0.0079 * Clay % +1.7243

The range was 0.969 to 1.724 Mgm^{-3}, with an average of 1.524 Mgm^{-3}. No error statistics are given for this transfer function, but it is unlikely to produce a bulk density estimate with less than about a 10% uncertainty (SD).

Using the measured % SOC, the estimated bulk density, the horizon thicknesses and the areas that each soil made up in each TU, and each TU made up in each LU, the carbon density could be calculated for the entire country (not just the humic and organic soils).

Over most of the country 62-66% of the C was in the topsoil. For the topsoil in the humid east, where most of South Africa's intensive agriculture is practised, about half of SOC is lost under agriculture after about 20 years, agreeing with Swanepoel *et al.* (2015). Subsoil C decreases by a similar amount. In the arid west, subsoil C decreases under agriculture, but topsoil C does not. For topsoils under natural vegetation, carbon stocks are in the range of 3-10 kg m^{-2} in the east of South Africa, decreasing to 1-2 and even < 1 kg m^{-2} in the west. For subsoil, the average is 2-3 kg m^{-2}, only rarely reaching 3-5 kg m^{-2}.

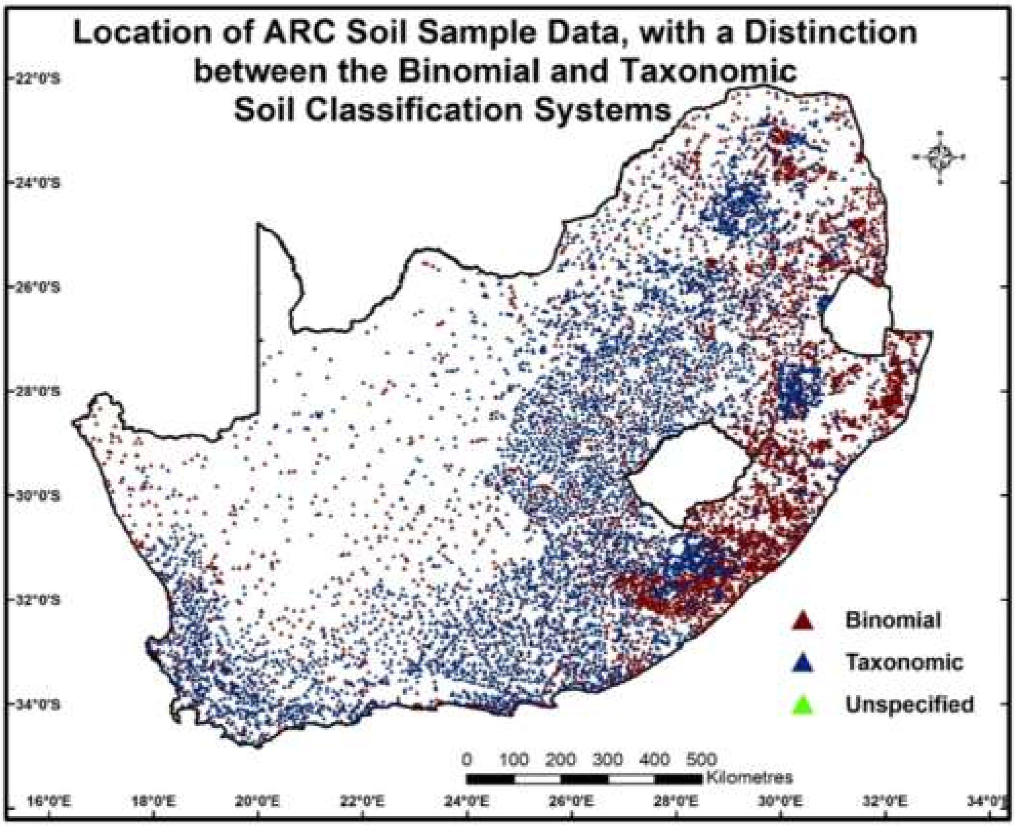


Figure A5.3: The 11099 data points in the ISCW-ARC soil carbon database, by classification system.

References cited in HiCSoils

Bauer, A. 1974. Influence of soil organic matter on bulk density and available water capacity of soils. Farm Research, 31(5):44–52.

du Preez, CC, van Huyssteen, CW and Mnkeni, PNS. 2011a. Land use and soil organic matter in South Africa 1: A review on spatial variability and the influence of rangeland stock production. South African Journal of Science 107:27–34.

du Preez CC, Van Huyssteen, CW and Mnkeni, PNS. 2011b. Land use and soil organic matter in South Africa 2: A review on the influence of arable crop production. South African Journal of Science 107(5/6):2–9.

Hutson, JL 1984. Estimation of Hydrological Properties of South African Soils. Unpublished PhD thesis, University of Natal, Pietermaritzburg, RSA. pp 232.

Rawls, WJ, Pachepsky, YA, Ritchie, JC, Sobecki, TM and Bloodworth, H. 2003. Effect of soil organic carbon on soil water retention. Geoderma 116(1–2):61–76.

Saxton, K and Rawls, W. 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Science Society of America Journal 70:1569–1578.

Stronkhorst, L and Venter, A. 2008. Investigating the soil organic carbon status in South African soils and the relationship between soil organic carbon and other soil chemical properties. Agricultural Research Council - Institute for Soil, Climate and Water, Pretoria, South Africa.

Swanepoel, C.M., van der Laan, M., Weepener, H.L., du Preez, C.C. and Annandale, J.G. 2015. Review and meta-analysis of organic matter in cultivated soils in southern Africa. Nutrient Cycling in Agroecosystems, DOI 10.1007/s10705-016-9763-4

Van der Merwe, AJ. 1973. Physico-Chemical Relationships of Selected OFS Soils: A Statistical Approach based on Taxonomic Criteria. Unpublished PhD thesis, University of the Orange Free State.

CopperLeaf consortium for GIZ

The report provides the baseline information and methodology used to determine the proposed accounting system, rules and guidelines for greenhouse gas (GHG) emissions and sinks Measurement, Reporting and Verification (MRV) within the grassland, reduced / zero till and soil systems of the Agriculture, Forestry, and Other Land-uses (AFLOU) sector of South Africa.

Where to get it and IP issues

CopperLeaf Consortium 2018. AFOLU Sector South Africa Greenhouse Gas Accounting Rulebook Supplement: Baseline Methodology Report. GIZ Contract number: 83258887 / 16.9002.3-001.00 Report dated 2018-08-20. Contributors: Leonie Berjak, Khatab Abdalla, Warren Heathman, Anthony Mills, Ed Granger, Nigel Berjak, Jan Meyer, Gavin Schafer, Don McArthur, Michael Berjak, Digby Gold.

It should in principle be open source, and available through the SA Carbon Sinks Atlas.

Technical details

The CopperLeaf document largely follows IPCC 2006 tier 2 procedures and definitions, and uses the Schulze and Schütte (2018) topsoil and subsoil C values. The Surfer software was used for interpolation, which is completely inappropriate! The authors make no comment on how to estimate bulk density, stone content or profile depth.

The report deals mostly with crop agricultural soils and grasslands (including, separately, pastures). There is extensive treatment of reduced tillage, but little novel guidance on how to estimate emissions or sink strengths. There is a cursory discussion of forests and plantations, an uncritical discussion of thickets, a brief treatment of wetlands, and a paragraph each on Karoo and Fynbos.

MUNICIPAL LEVEL BASELINE AND CHANGE DATA

The following two tables (Table A6a and A6b) give municipal level data on changes in land cover classes (in ha) between 1990 and 2018.

Table A6a: Change in land cover of natural vegetation per municipality between 1990 and 2018 sorted by reduction in natural vegetation.

Municipality	Natural veg	Bare / degraded	Fallow	Water	Wet-lands	Indig Forest
Hantam (NC065)	-411354	408747	29967	-27982	-5594	3
Kai !Garib (NC082)	-185494	182392	1300	-9854	-4012	0
Emalahleni (EC136)	-178991	-2245	23526	1634	16125	0
Kamiesberg (NC064)	-110052	94074	17035	-121	-148	0
Witzenberg (WC022)	-101829	87730	19915	-1038	-4938	9
Senqu (EC142)	-97807	94349	6311	901	-7008	-1
Matzikama (WC011)	-90323	57996	37088	597	-1466	29
Greater Tubatse/Fetakgomo (LIM476)	-80886	34563	15881	823	-2197	42
Nama Khoi (NC062)	-75015	48914	23768	-270	-1249	0
Msukaligwa (MP302)	-73936	1334	46434	2030	11468	8
City of Tshwane (TSH)	-70605	7697	39528	1107	-1429	-1
Kagisano/Molopo (NW397)	-68767	9517	125298	234	-1523	0
Abaqulusi (KZN263)	-60656	2223	35775	405	2114	1346
Richtersveld (NC061)	-58039	53077	309	-651	-753	0
Molemole (LIM353)	-56679	920	47685	84	-746	-830
Mkhondo (MP303)	-55784	3388	16281	185	1514	630
Laingsburg (WC051)	-55745	51784	4586	-606	-1067	0
Emakhazeni (MP314)	-54703	3965	23610	808	6531	1274
Polokwane (LIM354)	-52292	468	42913	2	-1920	1
Modimolle/Mookgophong (LIM368)	-51953	9128	98944	679	-3450	0
Dr Pixley Ka Isaka Seme (MP304)	-51743	1605	38155	761	6672	966
Cederberg (WC012)	-51550	22207	31203	-134	-2830	0
Langeberg (WC026)	-51049	40685	15753	-119	-2855	0
Blouberg (LIM351)	-49974	1879	49116	163	-434	-1424
Rustenburg (NW373)	-49055	3671	40925	918	-1040	-221
Moses Kotane (NW375)	-47211	509	50744	136	-718	0
Makhuduthamaga (LIM473)	-45657	14748	8461	-76	-996	0
Lephalale (LIM362)	-45472	8797	44885	1420	283	0
Mogalakwena (LIM367)	-44707	4150	59639	526	-1858	0

Municipality	Natural veg	Bare / degraded	Fallow	Water	Wet-lands	Indig Forest
Enoch Mgijima (EC139)	-43858	26698	22140	525	-10942	101
Chief Albert Luthuli (MP301)	-43659	3349	29822	529	3873	626
Mangaung (MAN)	-41779	23401	23435	-654	-10345	-241
Lekwa (MP305)	-41654	366	27547	1784	13770	0
Makhado (LIM344)	-41517	1581	45655	455	-2138	-7276
Mbizana (EC443)	-40688	734	36122	349	-1196	1730
Emthanjeni (NC073)	-40688	39259	11403	-1679	-10813	0
Mohokare (FS163)	-40375	27334	19061	1092	-10669	-156
Alfred Duma (KZN238)	-39941	1504	25897	795	1766	-586
Mnquma (EC122)	-39764	34	36658	533	-1309	1349
Nkomazi (MP324)	-39243	1813	13326	3108	2034	1886
Walter Sisulu (EC145)	-39105	30140	26051	2545	-20663	0
Elias Motsoaledi (LIM472)	-38316	8615	27179	1588	-3732	0
Steve Tshwete (MP313)	-37409	3139	38658	2812	4926	0
Greater Giyani (LIM331)	-37392	1351	37118	-278	-177	0
Kannaland (WC041)	-37100	36224	2706	52	-3291	0
Elundini (EC141)	-36639	3747	8251	888	-4754	842
Emadlangeni (KZN253)	-36551	1755	25656	548	3960	1485
Mhlontlo (EC156)	-36412	2475	26116	1441	-1086	4266
Swellendam (WC034)	-34566	23195	11559	-226	-2012	402
Mantsopa (FS196)	-34382	18823	21622	986	-3108	-2538
Msinga (KZN244)	-34302	5955	22544	602	441	41
Dr Nkosazana Dlamini Zuma (KZN436)	-34208	-1382	9929	1273	-767	3180
Umhlabuyalingana (KZN271)	-34175	9744	7492	-4705	2424	3594
Lepele-Nkumpi (LIM355)	-34144	10279	19395	78	-1695	-1477
Mbhashe (EC121)	-34048	1153	28468	1008	-648	2324
Breede Valley (WC025)	-33207	28292	10003	-193	-3984	8
Ditsobotla (NW384)	-33159	1891	45426	-47	-5363	0
Local Municipality of Madibeng (NW372)	-32926	2045	28336	1142	-3138	-403
Thembisile (MP315)	-32499	2693	23731	142	-192	0
Joe Morolong (NC451)	-30980	14867	11919	1067	-1535	0
Maluti a Phofung (FS194)	-30706	5770	22035	668	-5262	33
Ramotshere Moiloa (NW385)	-30557	-5904	50250	375	-2810	0
Ngquza Hill (EC153)	-29948	-1188	30605	565	-2104	907
King Sabata Dalindyebo (EC157)	-29822	2915	20245	863	-951	1437
Setsoto (FS191)	-29758	14389	17724	1015	-2229	-1881

Municipality	Natural veg	Bare / degraded	Fallow	Water	Wet-lands	Indig Forest
Okhahlamba (KZN235)	-29341	587	14989	1439	1245	112
Ulundi (KZN266)	-28820	5458	25040	280	198	53
eThekwini (ETH)	-28228	796	18797	215	-53	5137
Hessequa (WC042)	-28184	11540	15079	347	-5320	337
Inkosi Langalibalele (KZN327)	-27942	3103	16990	716	7	150
Thabazimbi (LIM361)	-27886	4053	39462	1647	-2984	0
Ventersdorp/Tlokwe (NW405)	-27586	855	44091	292	-7586	0
Bergrivier (WC013)	-27492	10438	24272	-2165	-1562	0
Dr JS Moroka (MP316)	-26457	554	23295	318	-505	0
Bushbuckridge (MP325)	-26373	20832	5290	800	4306	980
Umzimkhulu (KZN435)	-26359	1249	16255	412	-88	3489
Lekwa-Teemane (NW396)	-26235	763	42948	159	-2067	0
Maquassi Hills (NW404)	-25933	536	49074	-260	-6040	0
eDumbe (KZN261)	-25855	1041	4617	945	28	151
Umzumbe (KZN213)	-24358	365	23375	321	-159	1177
Govan Mbeki (MP307)	-23825	366	23457	1468	3629	0
Dihlabeng (FS192)	-23342	11982	14510	828	-7955	-880
Matatiele (EC441)	-23104	2548	25190	1702	-6971	804
Nyandeni (EC155)	-22162	-183	17445	570	-487	2641
Engcobo (EC137)	-22113	2285	14464	695	-694	3584
Umvoti (KZN245)	-21825	2553	12678	150	357	76
Mafikeng (NW383)	-21394	1186	24239	395	-2105	0
Umzimvubu (EC442)	-21388	3639	13079	995	-809	1143
Newcastle (KZN252)	-21228	-4	10745	449	514	-258
Musina (LIM341)	-21167	-1276	10934	1469	-723	3033
uPhongolo (KZN262)	-21139	1519	14714	-1878	1078	55
Nqutu (KZN242)	-21066	5525	11036	311	319	3
Phumelela (FS195)	-20871	1376	26866	2099	-21354	-179
Sundays River Valley (EC106)	-20831	-5461	14398	396	-596	11795
Kgetlengrivier (NW374)	-20512	1010	25946	160	-1153	0
Ephraim Mogale (LIM471)	-20084	3619	5773	978	-1088	0
Ngqushwa (EC126)	-20078	508	19521	351	-459	267
Intsika Yethu (EC135)	-19955	3715	14871	576	-1832	610
Maruleng (LIM335)	-19939	7495	10883	279	-2687	-1249
Oudtshoorn (WC045)	-19854	17720	6590	70	-2832	2
Ratlou (NW381)	-19748	1511	37176	-239	-6207	0

Municipality	Natural veg	Bare / degraded	Fallow	Water	Wet-lands	Indig Forest
Umdoni (KZN212)	-19556	104	16215	154	38	2426
City of Matlosana (NW403)	-19325	173	28861	-538	-4074	0
Tsantsabane (NC085)	-19208	14653	2993	-79	-3086	0
Ray Nkonyeni (KZN216)	-18334	718	13508	578	39	2030
Endumeni (KZN241)	-18315	-311	18017	382	-556	102
City of Johannesburg (JHB)	-18073	2338	8943	318	-53	0
Greater Kokstad (KZN433)	-17447	-71	9221	1005	-10	41
Ubuhlebezwe (KZN434)	-17296	220	12397	328	58	134
Greater Letaba (LIM332)	-17077	333	22078	45	-217	-1404
Jozini (KZN272)	-16980	1476	13591	-1260	-2513	3888
Ntabankulu (EC444)	-16213	-342	14739	540	-764	1299
Moretele (NW371)	-16204	4	21420	58	-2211	0
Victor Khanye (MP311)	-15901	703	12820	646	4369	0
Tokologo (FS182)	-15758	7390	52481	-17720	-6700	0
City of Cape Town (CPT)	-15740	3466	12442	635	-2222	-56
Sakhisizwe (EC138)	-15508	844	9128	288	-1186	119
Nongoma (KZN265)	-14987	5438	12714	-181	259	28
Naledi (NW392)	-14905	1142	32345	398	-2503	0
Thaba Chweu (MP321)	-14699	5879	16906	-22	1280	5687
Dannhauser (KZN254)	-14565	531	6776	178	1855	42
Dipaleseng (MP306)	-14395	711	10016	903	2777	0
Nkandla (KZN286)	-13733	1819	11025	313	2	396
Ekurhuleni (EKU)	-13566	1737	12659	1071	146	0
Big Five Hlabisa (KZN276)	-13278	1234	15963	-2535	4813	2400
Buffalo City (BUF)	-12964	838	12703	777	-1174	-3346
Swartland (WC015)	-12963	409	19831	239	-3430	0
Mpofana (KZN223)	-12928	336	6539	733	663	57
uMlalazi (KZN284)	-12606	1799	10252	-675	-5	-572
Moqhaka (FS201)	-12434	1889	29600	732	-12562	0
Thembelihle (NC076)	-12263	9337	1481	-2217	-2989	0
Ndlambe (EC105)	-12255	1754	8779	635	-329	2062
City of Mbombela (MP326)	-12211	2755	21155	560	-1530	3363
Ba-Phalaborwa (LIM334)	-11788	4015	4670	337	-994	0
Mamusa (NW393)	-11744	1467	25294	-76	-1187	0
Port St Johns (EC154)	-11704	-575	13530	734	-507	-587
Amahlathi (EC124)	-11700	-150	17374	1027	-2306	-7827

Municipality	Natural veg	Bare / degraded	Fallow	Water	Wet-lands	Indig Forest
Renosterberg (NC075)	-10609	14457	1657	1230	-8411	0
Cape Agulhas (WC033)	-10561	5259	8710	-1925	-288	20
Tswelopele (FS183)	-10373	3032	25155	-7158	-9407	0
Siyancuma (NC078)	-10105	2534	5046	-299	-6758	0
Drakenstein (WC023)	-9554	2634	6256	316	-2022	23
uMuziwabantu (KZN214)	-9339	-59	6229	215	-114	1379
uMngeni (KZN222)	-9175	34	3315	1040	202	1280
Ga-Segonyana (NC452)	-8985	961	5641	-62	-2160	0
Saldanha Bay (WC014)	-8722	1738	15222	-76	-1659	0
Matjhabeng (FS184)	-8528	1976	23030	318	-8074	0
Gamagara (NC453)	-8217	3697	1915	88	-664	0
Mossel Bay (WC043)	-8213	1908	6559	235	-2639	755
Mkhambathini (KZN226)	-7990	45	6569	124	-234	284
Makana (EC104)	-7731	317	6615	521	-530	514
Richmond (KZN227)	-7711	-171	4405	269	-9	551
Mogale City (GT481)	-7642	1859	4331	120	-905	-4
Greater Taung (NW394)	-7616	-276	12031	486	-3641	0
Impendle (KZN224)	-7441	-2066	4552	342	69	852
Nketoana (FS193)	-7407	2249	11965	1645	-9429	0
Overstrand (WC032)	-7318	2939	5584	375	-1698	836
Masilonyana (FS181)	-7298	2832	16777	-715	-6914	-28
uMhlathuze (KZN282)	-7165	-18	7338	59	481	1616
The Msunduzi (KZN225)	-7140	-27	3455	25	-135	383
Mafube (FS205)	-6980	896	8784	1218	-6108	0
uMshwathi (KZN221)	-6203	521	4478	-364	321	1160
Mthonjaneni (KZN285)	-6178	1035	4276	-256	13	106
Midvaal (GT422)	-6100	766	7773	473	-3826	0
Lesedi (GT423)	-5792	1068	8296	308	-1112	0
Great Kei (EC123)	-5541	-246	5875	496	-183	601
Tswaing (NW382)	-5539	1925	18637	-397	-10574	0
Nelson Mandela Bay (NMA)	-5515	722	4461	1248	-419	51
Theewaterskloof (WC031)	-5298	5571	4695	-493	-4279	122
KwaDukuza (KZN292)	-5293	58	682	-167	339	427
George (WC044)	-4776	2318	17346	405	-5269	-978
Kouga (EC108)	-4739	1322	6453	847	-1922	362
Kou-Kamma (EC109)	-4232	2553	7356	824	-3837	-1236

Municipality	Natural veg	Bare / degraded	Fallow	Water	Wet-lands	Indig Forest
Emfuleni (GT421)	-4135	575	5355	266	-2394	0
Greater Tzaneen (LIM333)	-4119	1596	14983	-820	-2328	-4065
Merafong City (GT484)	-4045	220	13094	112	-2730	0
Bela-Bela (LIM366)	-3851	1117	23340	202	-1209	0
New (LIM345)	-3802	207	11683	469	49	40
Sol Plaatjie (NC091)	-3736	-226	2370	278	-1675	0
Magareng (NC093)	-3438	-883	2208	455	-616	0
Rand West City (GT485)	-3097	512	12236	48	-1554	0
Metsimaholo (FS204)	-3067	-85	4593	1628	-4810	0
Mfolozi (KZN281)	-2943	-230	3575	-72	1681	1781
Maphumulo (KZN294)	-2773	21	4053	60	32	27
Letsemeng (FS161)	-2607	-3783	28458	-10040	-17289	0
Ndwedwe (KZN293)	-2435	367	2802	-52	16	343
Raymond Mhlaba (EC129)	-2381	-1024	18298	406	-2265	-11993
Mandeni (KZN291)	-2280	148	797	-223	-205	119
Kopanong (FS162)	-2224	18185	11929	2360	-37376	0
Prince Albert (WC052)	-1978	512	1676	-276	-1573	0
Nala (FS185)	-720	1188	10568	-1960	-8167	0
Bitou (WC047)	-234	-6	1165	301	-214	-494
Phokwane (NC094)	-85	26	584	155	-1479	0
Ngwathe (FS203)	729	2306	18039	676	-22571	0
Kgatelopele (NC086)	1356	224	630	-1793	-589	0
Stellenbosch (WC024)	1500	654	2364	632	-1250	4
Dikgatlong (NC092)	2704	-318	3856	165	-4266	0
Knysna (WC048)	3405	132	1323	225	-266	2536
Thulamela (LIM343)	4494	508	7184	1195	-857	-2675
Mtubatuba (KZN275)	6037	781	1957	-738	2994	6560
Umsobomvu (NC072)	15140	-5246	2355	711	-13808	0
KhÃƒÂ¢i-Ma (NC067)	24610	-20379	477	-7621	-2687	0
Inxuba Yethemba (EC131)	24902	-33606	6759	1323	-4391	0
Siyathemba (NC077)	26999	-30795	1606	-538	-1416	0
Dawid Kruiper (NC087)	63754	-56748	473	-18797	-897	0
!Kheis (NC084)	79592	-81512	637	-245	-1039	0
Karoo Hoogland (NC066)	95457	-109374	13793	-1025	-4450	0
Emalahleni (MP312)	130015	17574	9406	622	-13947	106
Blue Crane Rout/ie (EC102)	173460	-183403	3369	674	-1792	1799

Municipality	Natural veg	Bare / degraded	Fallow	Water	Wet-lands	Indig Forest
Kareeberg (NC074)	185612	-196811	10099	-481	-948	0
Ubuntu (NC071)	637786	-645734	9526	-303	-2378	0
Beaufort West (WC053)	682707	-687838	6493	-119	-4547	0
Dr Beyers Naude (EC101)	767807	-770077	9211	124	-9830	0
TOTAL	**-2 517 011**	**-923 674**	**3 710 470**	**-31 498**	**-471 527**	**57 963**

Table A6b: Change in land cover (in ha) of transformed land per municipality between 1990 and 2018 sorted by reduction in natural vegetation.

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Hantam (NC065)	-2902	400	12	0	126	0	0	371	307
Kai !Garib (NC082)	460	387	459	6599	0	0	0	18	576
Emalahleni (EC136)	63195	2602	7	0	-37681	0	0	6333	27188
Kamiesberg (NC064)	-203	2	0	0	-272	0	0	0	-1721
Witzenberg (WC022)	-1919	3338	214	-2208	0	0	0	-1955	25
Senqu (EC142)	-11228	11049	0	0	398	0	0	151	19
Matzikama (WC011)	-3352	2210	-5383	-1425	-587	0	0	265	1881
Greater Tubatse/ Fetakgomo (LIM476)	-2967	3191	-1135	0	18274	0	0	-9	3353
Nama Khoi (NC062)	-133	26	171	-423	0	0	0	0	997
Msukaligwa (MP302)	-10612	3218	68	0	-121	0	0	18195	-1105
City of Tshwane (TSH)	-9459	5554	477	0	-39	0	0	-2729	-1058
Kagisano/Molopo (NW397)	-84835	16073	-173	0	-4467	0	0	656	1404
Abaqulusi (KZN263)	-4577	1927	-66	0	1598	0	174	18330	-349
Richtersveld (NC061)	-255	24	0	0	0	0	0	-60	3447
Molemole (LIM353)	-10501	14488	131	0	1519	0	0	-79	-536
Mkhondo (MP303)	-7912	3624	42	0	326	0	0	33573	-143
Laingsburg (WC051)	-1307	761	24	-11	0	0	0	34	81
Emakhazeni (MP314)	1157	2393	35	0	-1	0	0	12589	362
Polokwane (LIM354)	-5940	1241	-2297	0	1677	0	0	227	-1728
Modimolle/ Mookgophong (LIM368)	-67778	10726	-505	0	17	0	0	340	-1247
Dr Pixley Ka Isaka Seme (MP304)	-6876	3044	95	0	-317	0	0	4414	151

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Cederberg (WC012)	4615	18876	-22900	-195	-304	0	0	-535	-85
Langeberg (WC026)	-8005	4431	3485	-4468	0	0	0	-177	59
Blouberg (LIM351)	-20962	10908	166	0	6054	0	0	269	-247
Rustenburg (NW373)	-10706	1469	-2	0	131	0	0	2516	4257
Moses Kotane (NW375)	-4768	1	0	0	-5858	0	0	60	1224
Makhuduthamaga (LIM473)	-194	284	0	0	14492	0	0	-311	7
Lephalale (LIM362)	-33995	8263	12	0	8509	0	0	534	182
Mogalakwena (LIM367)	-22307	551	-1363	0	-3112	0	0	320	715
Enoch Mgijima (EC139)	-6701	6155	-375	0	239	0	0	763	-263
Chief Albert Luthuli (MP301)	-5553	588	134	0	-6258	0	-1	6211	1515
Mangaung (MAN)	-27350	13473	10	0	10425	0	0	3388	-311
Lekwa (MP305)	-9819	4569	6	0	0	0	0	1628	-354
Makhado (LIM344)	-5074	6521	476	0	-9311	0	0	-78	-465
Mbizana (EC443)	-30	14	-1	0	672	0	0	3732	66
Emthanjeni (NC073)	-351	434	0	0	341	0	0	-83	73
Mohokare (FS163)	-8317	5953	240	0	17	0	0	3870	-75
Alfred Duma (KZN238)	-1426	2872	0	0	4826	0	0	-329	-43
Mnquma (EC122)	-15	0	0	0	1215	0	0	420	-42
Nkomazi (MP324)	-3699	358	720	0	-10438	6852	10247	-1613	28
Walter Sisulu (EC145)	-15206	14809	-720	0	-9	0	0	715	-244
Elias Motsoaledi (LIM472)	-12265	5125	2064	0	1049	0	0	79	-18
Steve Tshwete (MP313)	-22964	7304	143	0	0	0	0	11	781
Greater Giyani (LIM331)	-1196	-344	-179	0	-4081	0	0	46	-140
Kannaland (WC041)	-6364	6418	338	-468	0	0	0	-26	10
Elundini (EC141)	-2110	2435	35	0	769	0	0	24747	-7
Emadlangeni (KZN253)	-7468	2552	-7	0	390	0	0	6101	-191
Mhlontlo (EC156)	16	0	1	0	598	0	0	498	-2
Swellendam (WC034)	-4889	6216	-343	-77	0	0	0	-1081	54
Mantsopa (FS196)	-7250	3095	0	0	229	0	0	252	-53
Msinga (KZN244)	-664	582	3	0	1061	0	5	-511	60

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Dr Nkosazana Dlamini Zuma (KZN436)	-10712	13744	33	0	4368	0	0	17087	16
Umhlabuyalingana (KZN271)	-32	0	702	0	5889	0	0	6840	3
Lepele-Nkumpi (LIM355)	-2068	38	-1344	0	2028	0	0	158	-66
Mbhashe (EC121)	-68	0	489	0	1085	0	0	572	-49
Breede Valley (WC025)	-3523	701	902	-1378	0	0	0	-209	16
Ditsobotla (NW384)	-20942	8584	-2	0	-137	0	0	3584	-3094
Local Municipality of Madibeng (NW372)	-27653	19430	-34	0	-12	0	0	1402	2061
Thembisile (MP315)	-3547	396	0	0	989	0	0	416	-341
Joe Morolong (NC451)	-2162	-4	0	0	-284	0	0	25	843
Maluti a Phofung (FS194)	860	1939	17	0	62	0	0	1189	-244
Ramotshere Moiloa (NW385)	-19677	3074	-4	0	324	0	0	1431	-825
Ngquza Hill (EC153)	0	0	13	0	1621	0	0	159	-13
King Sabata Dalindyebo (EC157)	-82	52	0	0	730	0	0	104	5
Setsoto (FS191)	-6786	3257	-107	0	10	0	0	1008	-48
Okhahlamba (KZN235)	-10462	17005	-29	0	7703	0	0	-46	8
Ulundi (KZN266)	-690	-1	2	0	-97	0	0	-2114	-16
eThekwini (ETH)	-393	55	-94	0	2520	0	554	-1488	314
Hessequa (WC042)	-1181	6913	103	-112	0	0	0	-2218	133
Inkosi Langalibalele (KZN327)	-2793	3314	33	0	2434	0	0	3040	18
Thabazimbi (LIM361)	-35879	18204	-26	0	-54	0	0	92	508
Ventersdorp/Tlokwe (NW405)	-27166	11943	8	0	-17	0	0	1724	-984
Bergrivier (WC013)	-15977	13733	-1578	-642	19	0	0	-98	-266
Dr JS Moroka (MP316)	-1935	45	0	0	1981	0	0	38	-452
Bushbuckridge (MP325)	-218	0	209	0	1284	0	0	-12699	-145
Umzimkhulu (KZN435)	-217	149	16	0	1939	0	8	1666	54
Lekwa-Teemane (NW396)	-15548	2722	-163	0	0	0	0	483	-4528

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Maquassi Hills (NW404)	-22373	2576	17	0	0	0	0	1121	-861
eDumbe (KZN261)	-2066	1333	34	0	1529	0	0	17571	-72
Umzumbe (KZN213)	-47	27	4	0	4677	0	870	-580	1
Govan Mbeki (MP307)	-10775	1726	-12	0	0	0	0	827	625
Dihlabeng (FS192)	-3321	3574	185	0	0	0	0	1737	-154
Matatiele (EC441)	-9300	3616	-10	0	2234	0	0	1203	-97
Nyandeni (EC155)	12	0	0	0	415	0	0	284	16
Engcobo (EC137)	2	0	0	0	538	0	0	-550	47
Umvoti (KZN245)	-3130	2192	86	0	-364	0	-1303	5942	16
Mafikeng (NW383)	-4071	975	-2	0	-3499	0	0	395	-1107
Umzimvubu (EC442)	0	0	0	0	881	0	0	1207	-3
Newcastle (KZN252)	-1700	1446	20	0	478	0	0	3979	-151
Musina (LIM341)	-2043	1086	941	0	6095	0	0	163	-758
uPhongolo (KZN262)	-1213	105	323	0	1918	3212	393	155	12
Nqutu (KZN242)	-18	1	0	0	2439	0	0	-643	-12
Phumelela (FS195)	-1158	6720	47	0	0	0	0	4831	-353
Sundays River Valley (EC106)	-6657	2729	4022	0	0	0	0	-551	-121
Kgetlengrivier (NW374)	-11317	3281	0	0	-240	0	0	438	-99
Ephraim Mogale (LIM471)	-9445	5402	479	0	1845	0	0	52	-293
Ngqushwa (EC126)	59	79	-149	0	2673	0	0	298	-60
Intsika Yethu (EC135)	-558	357	0	0	1361	0	0	57	-18
Maruleng (LIM335)	-2524	712	1742	0	1902	0	0	363	-198
Oudtshoorn (WC045)	-15357	12138	-31	-59	0	0	0	-23	63
Ratlou (NW381)	-15005	995	0	0	-1704	0	0	252	586
Umdoni (KZN212)	-26	30	13	0	927	0	1414	-193	8
City of Matlosana (NW403)	-12017	2314	-1	0	0	0	0	1121	111
Tsantsabane (NC085)	-14	47	0	0	0	0	0	-49	1281
Ray Nkonyeni (KZN216)	-83	46	2845	0	4121	0	-398	-1172	119
Endumeni (KZN241)	-4666	3732	0	0	536	0	0	-175	-140
City of Johannesburg (JHB)	-7252	706	20	0	143	0	0	-3685	693

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Greater Kokstad (KZN433)	-6138	8133	14	0	97	0	0	3709	-16
Ubuhlebezwe (KZN434)	-3348	2949	113	0	3636	12	746	2487	20
Greater Letaba (LIM332)	-812	13	238	0	-6254	0	0	-760	-50
Jozini (KZN272)	-3889	482	13	0	5869	1378	4508	-41	39
Ntabankulu (EC444)	0	0	0	0	360	0	0	-72	-3
Moretele (NW371)	-1885	15	0	0	-3595	0	0	96	-94
Victor Khanye (MP311)	-15010	6268	2	0	0	0	0	414	4346
Tokologo (FS182)	-53955	31212	125	0	0	0	0	2556	-1374
City of Cape Town (CPT)	203	1144	330	-1238	0	0	0	-2973	486
Sakhisizwe (EC138)	-1225	770	0	0	541	0	0	4540	-32
Nongoma (KZN265)	-189	0	7	0	-1869	54	-12	42	4
Naledi (NW392)	-19662	2966	2	0	-10	0	0	1036	-3425
Thaba Chweu (MP321)	-5449	4789	2060	0	66	0	0	-20013	168
Dannhauser (KZN254)	-2963	2340	1	0	3123	0	0	1335	-149
Dipaleseng (MP306)	-4687	3330	0	0	0	0	0	484	-163
Nkandla (KZN286)	-38	0	1	0	1275	0	26	-1108	-4
Ekurhuleni (EKU)	-15004	1822	107	0	574	0	0	-3317	-801
Big Five Hlabisa (KZN276)	-3431	0	-2393	0	-1281	283	372	2240	13
Buffalo City (BUF)	1758	75	-877	0	1450	0	0	566	-120
Swartland (WC015)	-7069	3451	749	-3212	0	0	0	211	-19
Mpofana (KZN223)	-7708	8815	26	0	-164	0	0	2497	2
uMlalazi (KZN284)	-442	24	-443	0	-3046	0	15421	-2279	329
Moqhaka (FS201)	-19443	4188	68	0	0	0	0	4865	235
Thembelihle (NC076)	-1787	7818	135	0	0	0	0	-18	-469
Ndlambe (EC105)	-2666	650	-5557	0	-165	0	0	1398	29
City of Mbombela (MP326)	-13820	92	10973	0	-2073	372	706	-19056	-82
Ba-Phalaborwa (LIM334)	-1011	226	-79	0	2374	0	0	-30	-1202
Mamusa (NW393)	-16942	791	1	0	0	0	0	697	1
Port St Johns (EC154)	0	0	23	0	694	0	0	-181	24
Amahlathi (EC124)	-1280	543	-664	0	202	0	0	3262	-40

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Renosterberg (NC075)	-483	1245	0	0	0	0	0	-56	21
Cape Agulhas (WC033)	-601	481	1	-7	0	0	0	-2068	67
Tswelopele (FS183)	-29900	24457	206	0	0	0	0	1910	-53
Siyancuma (NC078)	-4568	11518	80	-31	0	0	0	66	-925
Drakenstein (WC023)	4549	1006	776	-4670	24	0	0	-425	-32
uMuziwabantu (KZN214)	-396	65	16	0	3569	0	1581	-28	13
uMngeni (KZN222)	-7199	6917	92	0	8	0	-136	1919	16
Ga-Segonyana (NC452)	159	84	0	0	0	0	0	54	-52
Saldanha Bay (WC014)	-8942	1080	27	1	19	0	0	-127	331
Matjhabeng (FS184)	-22423	8703	2	0	0	0	0	2471	14
Gamagara (NC453)	-33	-67	0	0	0	0	0	-16	1373
Mossel Bay (WC043)	-3546	4381	171	-34	0	0	0	-1051	51
Mkhambathini (KZN226)	-242	186	31	0	456	0	2657	-1757	70
Makana (EC104)	-395	701	-1534	0	-201	0	0	751	-161
Richmond (KZN227)	-839	816	-154	0	226	28	2141	55	7
Mogale City (GT481)	-1778	1919	246	0	53	0	0	204	226
Greater Taung (NW394)	-5507	1185	20	0	-178	0	0	510	-468
Impendle (KZN224)	-1541	1231	-5	0	403	0	0	3551	4
Nketoana (FS193)	-12392	9642	23	0	0	0	0	1981	-171
Overstrand (WC032)	-762	481	-94	-420	0	0	0	-1272	24
Masilonyana (FS181)	-14960	5754	-6	0	3	0	0	2677	-26
uMhlathuze (KZN282)	-1082	221	267	0	-1186	1337	2376	-5365	575
The Msunduzi (KZN225)	139	44	-11	0	48	0	-87	-1070	48
Mafube (FS205)	-8728	9513	1	0	0	0	0	153	-238
uMshwathi (KZN221)	-1181	410	34	0	3304	203	3662	-4480	32
Mthonjaneni (KZN285)	-252	0	43	0	1767	0	-602	1439	-5
Midvaal (GT422)	-4047	3355	16	0	14	0	0	-1190	94
Lesedi (GT423)	-5251	1206	0	0	-13	0	0	-73	-83
Great Kei (EC123)	-220	406	13	0	36	0	0	625	-21
Tswaing (NW382)	-16177	5888	1	0	-143	0	0	2294	98

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Nelson Mandela Bay (NMA)	-2154	672	-162	0	0	0	0	-171	-1758
Theewaterskloof (WC031)	-1004	3786	-464	-818	61	0	0	-3637	18
KwaDukuza (KZN292)	-339	0	15	0	-540	58	2211	-510	76
George (WC044)	-15632	9147	161	34	0	0	0	-4989	-29
Kouga (EC108)	-14981	13341	391	0	28	0	0	-1436	-3
Kou-Kamma (EC109)	-13517	14109	870	0	55	0	0	-3068	-21
Emfuleni (GT421)	-3634	504	-116	0	-13	0	0	-488	-258
Greater Tzaneen (LIM333)	-1920	470	-620	0	-4794	0	0	-4899	-149
Merafong City (GT484)	-9628	1080	-2	0	0	0	0	625	-363
Bela-Bela (LIM366)	-24698	4799	35	0	-10	0	0	125	-2209
New (LIM345)	78	254	-52	0	-17885	0	0	-21	-41
Sol Plaatjie (NC091)	-1081	3660	12	0	0	0	0	11	-1501
Magareng (NC093)	-4777	6791	412	0	20	0	0	15	-751
Rand West City (GT485)	-12717	3312	181	0	-1	0	0	358	-532
Metsimaholo (FS204)	-4246	2428	0	0	0	0	0	-163	1969
Mfolozi (KZN281)	-298	0	-32	0	-1695	103	1557	152	902
Maphumulo (KZN294)	27	0	0	0	1234	0	44	-1294	3
Letsemeng (FS161)	-31156	33176	248	0	1	0	0	1242	-401
Ndwedwe (KZN293)	-257	0	36	0	4875	0	1118	-931	7
Raymond Mhlaba (EC129)	-1433	373	-868	0	-67	0	0	243	-60
Mandeni (KZN291)	-225	0	3	0	4718	11	2707	-2478	18
Kopanong (FS162)	-6549	7764	-21	0	0	0	0	2789	43
Prince Albert (WC052)	-1633	1393	134	-57	0	0	0	21	38
Nala (FS185)	-10222	6496	3	0	0	0	0	851	-25
Bitou (WC047)	-467	945	32	57	0	0	0	-1502	11
Phokwane (NC094)	-18760	16657	2183	0	204	0	0	116	-4
Ngwathe (FS203)	-6059	1623	-2	0	0	0	0	2922	14
Kgatelopele (NC086)	31	110	0	0	0	0	0	-20	-324
Stellenbosch (WC024)	2692	773	584	-4043	0	0	0	-4185	-18
Dikgatlong (NC092)	-5024	4575	0	0	0	0	0	77	-3714

Municipality	Commercial Agriculture	Pivot Agriculture	Orchards	Viticulture	Subsistence Agriculture	Sugarcane Irrigated	Sugarcane Dry	Plantation Forest	Mines
Knysna (WC048)	-2799	3084	12	0	0	0	0	-7935	-6
Thulamela (LIM343)	-423	-82	-137	0	-16507	0	0	-260	18
Mtubatuba (KZN275)	-68	0	100	0	-6191	163	2875	-11939	668
Umsobomvu (NC072)	-1597	1582	0	0	0	0	0	135	-94
KhÃƒÂ¢i-Ma (NC067)	-132	237	305	-228	0	0	0	5	993
Inxuba Yethemba (EC131)	-14285	20279	-1530	0	140	0	0	421	-239
Siyathemba (NC077)	-918	4546	14	-70	0	0	0	32	-1362
Dawid Kruiper (NC087)	42	173	76	80	0	0	0	-12	-312
!Kheis (NC084)	-15	51	189	-229	0	0	0	2	110
Karoo Hoogland (NC066)	-1433	831	-8	0	0	0	0	35	347
Emalahleni (MP312)	-93050	351	-5	0	42461	0	0	-4226	-14298
Blue Crane Rout/ie (EC102)	-8572	12965	68	0	0	0	0	151	-178
Kareeberg (NC074)	-668	289	0	0	0	0	0	-14	118
Ubuntu (NC071)	-1565	904	-126	0	0	0	0	-38	-50
Beaufort West (WC053)	-3280	2604	94	4	0	0	0	155	45
Dr Beyers Naude (EC101)	-6513	4793	0	0	2	0	0	44	-34
TOTAL	**-1 449 231**	**790 013**	**-8 909**	**-19 748**	**71 495**	**14 067**	**55 834**	**139 182**	**5 524**

Environment House
473 Steve Biko
cnr Steve Biko and Soutpansberg Road
Arcadia
Pretoria, 0083
South Africa

Postal Address
Department of Environmental Affairs
P O Box 447
Pretoria
0001

Publishing date: November 2020

www.environment.gov.za