Manaaki Whenua
Landcare Research

Soil Quality Data for Land 2021

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Soil Quality and Trace Element Data for Land 2021

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Summary

The Ministry for the Environment (MfE) has requested delivery of regional soil quality, trace element, and site metadata to assess soil quality trends at a national scale for the Land 2021 report. The dataset includes data for the seven core soil quality (SQ) indicators, trace element (TE) data, site identifiers, and land use category for the period 1995–2018. The data and associated R scripts will be used 1) to generate statistics for sites meeting target and 2) for trend analysis of the indicator and TE data over time.

This report provides an overview of the first output, including data collation, downloading the indicators, trace element data and specified meta-data from the NSDR, and formatting the data so that previously composed R scripts can be used to generate soil quality statistics of sites and indicators meeting target ranges. We will report separately on the second output from the contracted work - analysis of temporal trends in the data at national and regional scales.

- The downloaded dataset (in csv format), along with scripts and R markdown (RMD) files are provided along with the report. The delivered dataset and associated materials include:
  - Tabular dataset of core variables of soil quality, site identifiers, and land use type for the period 1995–2018 by region.
  - Target ranges for soil quality (excluding native bush).
  - Metadata and data dictionary for the dataset(s).
  - Annotated code containing any steps taken to clean, analyse, transform, model, visualise and export data.

Tabular dataset of supplementary variables of soil quality, site identifiers, and land use type for the period 1995–2018 by region.

1 Objectives

The Ministry for the Environment (MfE) has requested delivery of regional soil quality, trace element, and site metadata to assess soil quality trends at a national scale for the Land 2021 report. The dataset includes data for the seven core soil quality (SQ) indicators, trace element (TE) data, site identifiers, and land use category for the period 1995–2018. The data and associated R scripts will be used 1) to generate statistics for sites meeting target and 2) for trend analysis of the indicator and TE data over time.

This report provides an overview of the first output, including data collation, downloading the indicators, trace element data and specified meta-data from the NSDR, and formatting the data so that previously composed R scripts can be used to generate soil quality statistics of sites and indicators meeting target ranges. We will report separately on the second output from the contracted work - analysis of temporal trends in the data at national and regional scales.

2 Background

The New Zealand soil quality monitoring programme began in earnest with the '500 Soils' programme in 1997, though precursor studies date back to 1995. The soil quality monitoring programme itself as well as the data generated from the programme continue to be a valuable scientific resource, generating a significant number of peer-reviewed journal publications and reports (see for instance Hermans et al. 2020; Curran-Cournane et al. 2015; Stevenson et al. 2015, 2012, 2010; Taylor et al. 2010; and Sparling et al. 2004, 2002, among others). Maintaining a cohesive and up-to-date dataset for national reporting, however, has proved difficult as there is currently no unified council approach to collating and updating data across regions. The Land and Water Aotearoa website appears to be the preferred option for future reporting, but no concrete plans are yet in place. Collation of regional soil quality data began as a simple spreadsheet at the inception of the '500 Soils' programme and has evolved since then. The consistent and accurate capture of historical data has increasingly been recognised as an essential step towards improving the national consistency of soil quality and trace element monitoring and data management to support the aims of the Environmental Monitoring and Reporting initiative and the development of National Environmental Monitoring Standards.

3 Collation of Soil Quality and Trace Element Data for the Current Dataset

The current iteration of the soil quality dataset was created through an Envirolink project with co-funding from the MBIE Endeavour funded programme Soil Health and Resilience: oneone ora tangata ora and MBIE Strategic Science Investment funding provided to Manaaki Whenua. The project collated regional council site soil quality (including trace element) data for State of the Environment (SOE) monitoring up to 1 July 2018. The full report (Cavanagh et al. 2020) is available from the Envirolink website (https://www.envirolink.govt.nz/assets/2050-HBRC254-Collating-soil-quality-and-trace-element-State-of-Environment-monitoring-data-v2.pdf). Further curation and capture of missing data since the completion of the Envirolink project were undertaken to provide the data used for this national reporting, with a summary of the process undertaken provided below.

The Envirolink project built on previous collations of soil quality data for various purposes and undertook extensive data checking alongside the collection of additional data to collate soil quality data (including trace element data) undertaken by regional authorities for State of the Environment (SoE) monitoring programmes. Data are included from the 12 councils currently undertaking SOE monitoring and the data captured extends from 1995 (the commencement of precursor studies to the '500 Soils' programme, to 1 July 2018 (as a nominal end point). These data were uploaded to the National Soils Data Repository (NSDR) and gaps identified through comparison of the data held by councils. Missing site and monitoring data were then requested from councils with a data template (excel workbook) provided to capture these data. All data received underwent a data check before uploading to the NSDR. After the completion of the Envirolink project, datasets exported from the NSDR were independently cross-checked by councils to ensure robustness and provide any further identified missing data (primarily approximate date of sampling (to month and year). Required corrections (primarily sampling date) and any further missing data were uploaded to the NSDR. Additional cross-checks of the data were undertaken prior to the final export of data.

4 NSDR and Data Download

The National Soils Data Repository (NSDR) is a system designed to manage the long-term storage of soil data from a variety of sources. It is the next generation of the original New Zealand Soil Bureau National Soil Database (NSD) but with an intent to capture a larger set of data (the original NSD is now a formal data set within the NSDR). Whereas the original NSD was specifically geared toward soil survey information recorded by soil horizon, the NSDR can accommodate depth sampling and resampling over time such as occurs in soil quality monitoring. Laboratory results along with site meta-data can be captured and collated for subsequent analysis and re-use by soil scientists, systems such as SMAP, and other interested parties. The individual datasets within the NSDR can have differing levels of protections, allowing full or limited access to specific groups or persons.

The NSDR is inherently flexible in that any soil sampling and lab data can be organised and stored according to a sampling location, horizon or depth description and a set of measured property values. This ensures that all data can be archived in a managed environment. That said, the system provides tools for the organisation of data into managed datasets that are subject to clear rules for quality and content (including the use of authoritative vocabularies) and structured according to formalised information models and vocabularies.

Access is via web services, a RESTful API and a managed import/export system that loads data and creates bespoke data products for analysis and publication. A limited set of user interfaces are provided: a map-based viewer, a data entry tool and an administration tool for vocabulary and property definitions. It is envisaged that the NSDR will support a variety of user interfaces, and data services and products tailored to very specific requirements.

Data for the Soil Quality dataset was extracted from the NSDR into a set of site, sample, lab result and other tables. SQL was then used to transpose the lab results into a standardised format containing measured properties as columns and samples as rows, joined to site-related data at the time of the sample. The only manipulation of the data during extraction from the database was averaging of the three soil physical measurements per site for bulk density and macroporosity (see Indicators and Trace Elements section).

5 Indicator Data, Trace Element Data and Metadata

5.1 Indicators and Trace Elements

The indicators currently measured against target ranges include: pH, total carbon (TC), total nitrogen (TN), anaerobically mineralizable nitrogen (AMN), Olsen phosphorus (Olsen P), bulk density, and macroporosity measured at –10 kPa (technically defined as air-filled porosity, measured as the difference between total porosity and volumetric water content of soil measured at a tension of 10 kPa). Trace element data (As, Cd, Cr, Cu, F, Pb, Ni, Zn) were also included. Data dictionaries for parameters are included in the RMD document.

Sample collection followed that reported in Hill and Sparling (2009). Briefly, at each site 10-cm-depth soil cores were taken approximately every 2 m along a 50-m transect and bulked for soil chemical analyses. Three undisturbed soil samples were obtained along the transect for field bulk density and macroporosity by pressing steel liners (10 cm in diameter and 7.5 cm in depth) into the soil. The three bulk density and macroporosity values were averaged to give an overall site value for the soil physical indicators. Soils were classified according to the New Zealand Soil Classification and land use information was also collected. Analytical methods follow that described in Hill and Sparling (2009), but there has been variation noted specifically in the Olsen P analysis as discussed below.

While the same general 'method' is used to analyse for Olsen P by a number of laboratories, there is a key difference in how the samples are analysed. Specifically, most research laboratories (including the Manaaki Whenua Environmental Chemistry Laboratory) analyse a known mass of soil and provide results on a gravimetric (per gram) basis, whereas most commercial laboratories utilise a scoop method to analyse a known volume of soil and report results on a volumetric basis (i.e. per cm3 of soil). The latter results in a variable mass of soil being analysed, and consequently, measurable differences in the results from these two ways of measuring Olsen P have been observed with the volumetric measure producing a somewhat lower number than the gravimetric method) (Taylor et al. 2018).

The preferred method for reporting at present is the gravimetric method. To convert the values generated by the volumetric Olsen P method to the preferred gravimetric equivalent, we used a regression model based on a Gamma response generalized linear mixed effects model (GLMM), with the log-transformed volumetric Olsen P as a fixed effect and the soil order as a random effect. Data for the model were generated from 319 soil samples on twelve different soil orders where both gravimetric and volumetric Olsen P measurements were obtained. The R-squared for the model was 0.935 with an index of agreement of 0.983. The mixed effects model is contained as an R script within the data curation step. This work is being written up as a peer-review journal article.

While the number of values in the dataset converted from volumetric to gravimetric values is relatively small, the difference in values between the two methods (which is dependent on soil type) does highlight that there may be some tension between values used for SoE reporting and those used for fertility recommendations that are generally based on the volumetric method (and produce somewhat lower Olsen P values).

Trace element analyses follow that described in Kim and Taylor (2009). Briefly, a total recoverable trace element extraction method using a strong acid-extraction followed by analysis of the extract by Inductively coupled plasma-mass spectrometry (ICP-MS) is used to provide concentrations for all trace elements except fluorine. Fluorine is typically extracted using alkali-fusion, with concentrations measured using a specific probe.

5.2 Metadata

Region, site location (pending council data use agreement on landowner data being kept confidential), soil order, land use (specific land use classification scheme and curated LU table) are provided as metadata.

Land use has been variably captured among, and within, councils in relation to: 1) the land use categories used within a council; 2) the apparently subjective application of the categories; and 3) the specific terminology used to refer to those categories, e.g. dairy, dairying, dairy farm, dairy pasture, etc. As such, curation of land use as captured by individual councils is required to provide consistent land use categories that can be reported on at a national level. Specifically, after the data were exported, further processing was undertaken to provide more consistent land use categorisation based on information captured as vegetation cover, land use and land use notes.

A mapping approach was used to provide a normalized land use classification scheme to identify a set of national land use categories consistent with previous national reporting (i.e. curated land uses). The modelling exercise performed was semantic in nature, utilising the Simple Knowledge Organization Framework (SKOS) (Isaac & Summers 2009). A very basic relationship model was used to fit within the scope of the current project. This model identified linkages between variable terminologies and the specified categories, and a text-processing script was generated to utilize this mapping to populate the national land use categories. The script uses a series of regular expression filters to find matching text values, either exact values or a closest match, using the Jaro-Winkler distance method[1]. This process enabled categorisation of most samples, with only some unique terms

[1] https://en.wikipedia.org/wiki/Jaro%E2%80%93Winkler_distance

requiring exclusion or manual allocation to a curated land use category. The curated land use, with examples of the varying terminologies captured under these land use categories, is shown in Table 1.

Curated land use classes are matched against the appropriate target values (pasture, exotic forestry, crop/hort) for generation of target value statistics. Curated land use categories include dairy, drystock, exotic forestry, cropping, and orchard/vineyard. Dairy and drystock are measured against the pastoral target ranges, cropping and orchard/vineyard against the crop/hort target ranges, and exotic forestry against the forestry target values. Although indigenous vegetation also forms a curated land use, it is not compared with target ranges as it is not a managed system (though trends over time in indigenous vegetation can be an important indicator of anthropogenic influence on these sites).

In recognition of changing land uses, particularly in the Auckland region, additional curated land use classes have been added on a trial basis to account for samples that do not neatly fit into other land use classes. The added land use classes are for urban parks/reserves, lifestyle blocks, tussock and scrub. While lifestyle blocks are measured against pasture target ranges (and could be grouped back into the drystock curated land use class if desired), urban sites often present difficulties as they can be varied but are often urban grassland parks. Scrub and Tussock categories have relatively few sites and are not resampled very frequently but do not fit well within other categories. We have tentatively set tussock against pastoral target values and scrub against forestry. We suggest review and discussion around these decisions before inclusion into the Land 2021 report, as for some cases (and for some specific indicators) the target value ranges are not particularly well suited to these land use categories.

Table 1. Curated land uses generated from the SKOS modelling framework

Classification	Specific terms included in each class
Dairy	Dairy, dairying, intensive grazing for dairy
Drystock	Sheep, beef, deer, pasture, pastoral farming, cut & carry pasture, intensive and extensive grazing for drystock
Cropping	Arable, market garden, specific crops, e.g. maize, potatoes, onions, cut & carry maize
Orchard/Vineyard	Grapes, kiwifruit, viticulture, horticulture, apples, pip fruit
Exotic Forestry	plantation forestry, production forestry, woodlot, *Pinus radiata*,
Indigenous vegetation	Native forest, indigenous forest
Lifestyle	Lifestyle block, dairy-lifestyle (mainly/only Auckland)
Urban Park/Reserve	Urban park, including schools (mainly/only Auckland)
Scrub	Indigenous (mānuka, kānuka), exotic (gorse, broom)
Tussock	Tussock

6 Data Formatting R script and target value statistics

6.1 R Script background, data manipulation and formatting

Earlier generations of soil quality data (pre 2015) relied on spreadsheets to combine data from councils and generate soil quality statistics through simple lookup functions within the spreadsheets. It was difficult to document data manipulation and the method of determination of soil quality statistics was found to contain errors when dealing with missing data. For the 2015 report, R Scripts were developed in association with MfE (Dr Ignatius Menzies), that were used to generate the soil quality statistics (e.g. overall number of indicators and sites meeting target values and indicators that meet targets grouped by land use). The same basic R coding was used in the 2018 report, and a slightly modified version (largely to accommodate changes in data structure from the NSDR download) is used here.

All data manipulation, formatting, and target value comparison steps performed on the data downloaded from the NSDR data are documented in the R markdown file included with the report.

6.2 Target Values and generation of indicator statistics

6.2.1 Indicator target values

The initial set of indicator target value ranges that have been used for State of the Environment monitoring were first documented in Sparling et al. (2008). Modifications to some indicator target ranges have occurred as documented in Mackay et al. 2013. There has been several recent suggestions for change in target value ranges, and although a review of the ranges is likely to occur in the near future, there has been no official change to target range values since the last Land Domains report in 2018. Consequently, the same set of target ranges are employed for the Land 2021 report as were used in the 2018 report. The full set of target value ranges (by soil order and land use) are contained in the accompanying RMD file.

6.2.2 Proposed guidelines for assessment of trace element concentrations for soil quality monitoring

Ecological soil guideline values

Currently there is no national approach or consensus for trace element concentrations in the context of national soil health reporting. Eco-SGVs developed to protect terrestrial biota (soil microbes, invertebrates, plants, wildlife and livestock) provide a useful way to readily assess the potential environmental impact from environmental contaminants, and thus provide an option for future reporting of trace elements.

The development of Eco-SGVs for common soil contaminants to assist in protecting environmental receptors (including microbes, invertebrates, plants, and higher animals) in soils and their associated ecosystems for New Zealand was funded through an Envirolink Tools Grant C09X1402 and completed in 2016. These Eco-SGVs were updated in 2019 in light of a national review undertaken in 2018 and international developments in the methodology for the development of such values since completion of the tools project. The detailed methodology, and changes made during the update are provided in Cavanagh (2019a, b).

Briefly, these values are based on toxicological studies of the effect of different contaminants on different organisms and take into account spatial variation in naturally occurring background concentrations. Eco-SGVs have been developed for different land use categories and provide differing level of protection for different biota. For copper and zinc, sufficient information is available to provide Eco-SGVs for different soil types. These soil types were classified as typical, sensitive, and tolerant soils based on pH, clay content, organic C, and CEC. Sensitive soils are those in which lower concentrations may give rise to negative effects on soil biota compared with typical or tolerant soils, and would have lower pH, carbon, and/or CEC. The properties of these soils were based on values of Brown, Recent and Allophanic Soils for typical, sensitive, and tolerant respectively, determined from soils data held in the NSD data. The derived Eco-SGVs for commonly measured trace elements for different land uses are shown in Tables 2 and 3. The proposed values could provide an initial assessment of the potential impact of trace elements on soil biota in future reports; however, national consensus on the application of Eco-SGVs is still required, thus we have not attempted their incorporation here.

Table 2. Eco-SGVs (mg/kg) developed for arsenic (As), boron (B), cadmium (Cd), chromium (Cr), fluorine (F) and lead (Pb) for the lowest median background concentration. Eco-SGVs should be based on background concentrations relevant to the site under assessment and are considered applicable to all soil types[1]

Land use (% protection)	As Eco-SGV[2] $_{(EC30)}$ (mg/kg)	Cd Eco-SGV $_{BM}$ [3] (mg/kg)	Cr Eco-SGV[4] $_{(EC30)}$ (mg/kg)	Pb Eco-SGV[5] $_{(EC30)}$ (mg/kg)
Areas of ecological significance (99%) [e.g. Indigenous forest]	6	1.5	100	55
Non-food production land (95%) [Forestry]	20	1.5	190	280
Agricultural land (95% plants, 80% microbes and invertebrates) [Pastoral and crop/hort]	20	1.5	300	530
Residential/recreational area (80%)	60	12	390	900[6]
Commercial/industrial (60%)	150	33	650	2500[6]

[1]This may be the median background concentration for the relevant geological grouping obtained from https://lris.scinfo.org.nz/, or other site-specific information, if available

[2]Median background concentration range: 2.2–4 mg/kg

[3]Median background concentration range: 0.05–0.1 mg/kg, BM – value accounts for biomagnification in the food chain

[4]Median background concentration range: 9–27 mg/kg

[5]Background concentration range: 7–15 mg/kg

[6]an extra 5% protection applied to this land use to provide protection against secondary poisoning; na – not available

Table 3. Eco-SGVs[1] (mg/kg) developed for copper (Cu) and zinc (Zn) concentrations in the three New Zealand reference soils, using the lowest median background concentration for Cu and Zn[2]. Eco-SGVs should be based on background concentrations relevant to the site under assessment[3]

Land use (% protection)	Cu Eco-SGV$_{(EC30)}$ Typical soil	Cu Eco-SGV$_{(EC30)}$ Sensitive soil	Cu Eco-SGV$_{(EC30)}$ Tolerant soil	Zn Eco-SGV$_{(EC30)}$ Typical soil	Zn Eco-SGV$_{(EC30)}$ Sensitive soil	Zn Eco-SGV$_{(EC30)}$ Tolerant soil
Areas of ecological significance (99%)	45	45	45	120	110	160
Non-food production land (95%)	100	85	120	170	150	230
Agricultural land (95% plants, 80% microbes and invertebrates)	220	150	340	190	130	265
Residential/recreational area (80%)	240	180	340	300	260	380
Commercial/industrial (60%)	420	320	630	480	430	620

[1]Eco-SGVs were developed for fresh contamination such as stormwater discharge, and aged contamination, which is more applicable for most other situations; the Eco-SGVs for aged contamination are shown here.

[2]Median background concentration range for Cu: 7–25 mg/kg; [1]Median background concentration range for Zn: 24–44 mg/kg.

[3] This may be the median background concentration for the relevant geological grouping obtained from https://lris.scinfo.org.nz/, or other site-specific information, if available

Tiered Fertiliser Management System

For cadmium, which is a contaminant present in phosphate fertilisers, it is also useful to compare concentrations with those specified in the Tiered Fertiliser Management System (TFMS). The TFMS has been developed as part of the National Cadmium Management Strategy (Cadmium Management Group, 2019) to help minimise accumulation of cadmium in soil arising from fertiliser use. The TFMS identified sets out increasingly stringent restrictions on the choice and rate of phosphate fertiliser as soil cadmium increases. The trigger values identifying the change to different management tiers, and the management actions required are shown in Table 4.

Table 4. Summary of Tiered Fertiliser Management System Tiers, trigger values and management action required at different cadmium concentrations

Tier number	Cd concentration (mg/kg)	Description
Tier 0	<0.6	Considered to be within naturally occurring background concentrations. A repeat soil cadmium sampling in 5 years is recommended.
Tier 1	0.6	The choice of fertiliser product and rates are restricted to those which follow Tier 1 to Tier 3 recommendations presented in the TFMS document.
Tier 2	1.0	
Tier 3	1.4	
Tier 4	1.8	No net accumulation soil cadmium

7 Acknowledgements

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