Soil Quality State and Trends in New Zealand's Largest City after 15 Years

Fiona Curran-Cournane

***Abstract*—**Soil quality monitoring is a science-based soil management tool that assesses soil ecosystem health.

A soil monitoring program in Auckland, New Zealand's largest city extends from 1995 to the present. The objective of this study was to firstly determine changes in soil parameters (basic soil properties and heavy metals) that were assessed from rural land in 1995-2000 and repeated in 2008-2012. The second objective was to determine differences in soil parameters across various land uses including native bush, rural (horticulture, pasture and plantation forestry) and urban land uses using soil data collected in more recent years (2009-2013).

Across rural land, mean concentrations of Olsen P had significantly increased in the second sampling period and was identified as the indicator of most concern, followed by soil macroporosity, particularly for horticultural and pastoral land. Mean concentrations of Cd were also greatest for pastoral and horticultural land and a positive correlation existed between these two parameters, which highlights the importance of analysing basic soil parameters in conjunction with heavy metals. In contrast, mean concentrations of As, Cr, Pb, Ni and Zn were greatest for urban sites. Native bush sites had the lowest concentrations of heavy metals and were used to calculate a 'pollution index' (PI). The mean PI was classified as high (PI > 3) for Cd and Ni and moderate for Pb, Zn, Cr, Cu, As and Hg, indicating high levels of heavy metal pollution across both rural and urban soils. From a land use perspective, the mean 'integrated pollution index' was highest for urban sites at 2.9 followed by pasture, horticulture and plantation forests at 2.7, 2.6 and 0.9, respectively.

It is recommended that soil sampling continues over time because a longer spanning record will allow further identification of where soil problems exist and where resources need to be targeted in the future. Findings from this study will also inform policy and science direction in regional councils.

***Keywords*—**Heavy metals, Pollution Index, Rural and Urban land use.

I. Introduction

Soil quality refers to the ability of the soil to sustain biological production, maintain environmental quality and promote both plant and animal health [1]-[3]. Soil quality monitoring is a science-based soil management tool that assesses soil ecosystem health. It provides an early warning of soil quality degradation or improvement which determines where resources may be required to mitigate the risk of land use activity on the soil ecosystem. Soil quality monitoring is undertaken in Auckland, New Zealand's largest city, where about one third of the population resides. Humans exert an enormous amount of pressure on the soil resource whether it is in relation to rural land use activity, which can significantly impact the receiving environment [4]; or through the development of land for residential and business purposes [5], which can be a significant source of heavy metal soil pollution via vehicle and industry emissions [6]. The global population is projected to reach 8.1 and 9.6 billion by years 2025 and 2050, respectively [7], putting immense pressures on our soil resources to provide sustenance and a place to live to the growing world so it is important that we safeguard the resource.

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In 1995 a soil monitoring program was established in Auckland which has continued to present. In its early establishment, soil monitoring was largely focused in rural land which concentrated on pastoral, horticultural, plantation forestry and native bush land uses. A total of 78 rural sites across all these land uses were first sampled in 1995-2000 and repeated again in 2008-2012 for a suite of basic soil parameters and the same was repeated for a total of 48 rural sites for a suite of heavy metals. The first objective of this study was to determine if changes in soil quality and heavy metals were apparent between the two sampling periods (i.e. pre and post 2000).

In 2012 soil monitoring was extended into the urban area, an important land use that had previously been excluded from the programme, to determine the status of soil health across 49 sites with a particular focus on heavy metals. The second objective of this study was to combine this data with that collected in 2009-2013 to determine if any soil quality and heavy metal differences exist across urban and rural land uses. Mean concentrations of heavy metals and land use information were also used to calculate a pollution index for each analyte. Data reported in this study provides a useful starting point to identify the soil quality parameters and heavy metals of most concern. This will inform land managers where efforts should be focused to mitigate these land use issues and risks.

II. Materials and Methods

A. Study Area

The Auckland region covers just over 5100 km^2 including a number of surrounding islands [8]. About 12% of the area is built-up urban land with the majority of the region considered rural land (Fig. 1). The mean annual rainfall in the study area is 1200 mm/yr. According to the World Reference Base for Soil Reference predominant soil orders across the Auckland region include Andosols, Cambisols, Gleysols, Ferralsols, Fluvisols and Arenosols and Acrisols soils.

Soil quality monitoring across rural land covers several land uses including pastoral (dairy, dairy-drystock converted land, drystock and lifestyle block converted land) (n=39), horticultural (orchards, market gardens and viticulture) (n=18), plantation forestry (n=7) and native bush (n=14) (Fig. 1). These sites were first sampled in 1995-2000 and repeated in 2008-2012. Soil data collected for these sites for both 1995-2000 and 2008-2012 sampling periods (i.e. pre and post 2000) will be used to determine soil quality and heavy metal trends.

In sampling years 2012 and 2013, new additional sites were identified and included 15 native bush and eight horticultural sites.

Furthermore, in 2012, 49 urban soil sites were identified and sampled (Fig. 1). Considering that no previous urban soil quality data existed, this data collected was compared with the more recent soil data collected in 2009-2013 to determine any differences in soil quality and heavy metals between rural and urban land uses. The comparison of land uses determined:

1. differences between native bush (n=29), rural (n=65) and urban (n=49) land uses and
2. differences between urban and native bush with rural land split into pastoral (n=24), horticulture (n=26) and plantation forest (n=15) land uses.

B. Sampling

At each sampling site a 50 m transect was laid out as per the standard protocol for national soil quality monitoring in rural New Zealand [9]. A GPS was used at either end of the transect to plot the site. Soil samples were collected for both chemical and physical analysis. For chemical analysis, soil cores were collected at 0-10 cm soil depths. To achieve this, 2.5 cm diameter soil samples were composited from 25 soil cores (every 2 m interval) for rural sites and composited from 10 soil cores (every 5 m interval) for urban sites across the 50 m transect. For the determination of soil physical characteristics, stainless steel rings (10 cm in diameter and 7.5 cm depth) were placed at the 15 m, 30 m and 45 m intervals across the transect and intact soil samples were excavated within the 0-7.5 cm soil depths. Soil sampling tends to be carried out in late winter/early spring and is therefore likely to represent worst-case scenario conditions when soil moisture is close to field capacity rendering the soil more vulnerable to soil compaction.

C. Analysis

All chemical analyses were carried out at International Accreditation New Zealand (IANZ) laboratories according to the Land and Soil Monitoring Guidelines [9], [10]. Analyses included pH, organic carbon (OC), total nitrogen (TN), Olsen P, anaerobic mineralisable nitrogen (AMN), bulk density, macroporosity (-5kPa i.e. pore sizes >60microns), (hereafter collectively referred to as soil quality); arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) (hereafter collectively referred to as heavy metals albeit noting that As is a metalloid). Note, Olsen P, AMN and macroporosity analyses were not conducted on the urban soils.

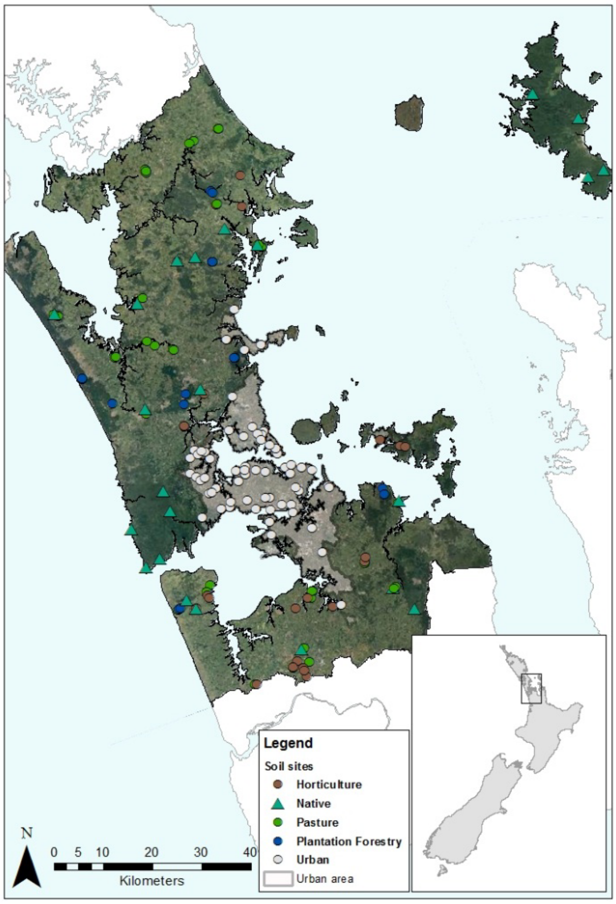

Fig. 1 Distribution of soil monitoring sites across rural and urban Auckland

The methods used for the determination of all soil physical, chemical and biological analyses are outlined in [9]. Briefly, prior to analysis the composite samples were well mixed, air-dried and sieved (< 2 mm) for Olsen P analyses [11]. High temperature (1050 °C) combustion methods were used for organic carbon (OC) and total nitrogen (TN) analyses [12]. Soil pH was measured in deionised water at a 2.5:1 water to soil ratio [12] and AMN was determined under the anaerobic (waterlogged) incubation method from field moist conditions [13]. Total recoverable As, Cd, Cr, Cu, Pb, Hg, Ni, Zn and P were determined by digesting soil in nitric/hydrochloric acid and the elements were analysed in the digest by inductively coupled plasma mass spectrometry (USEPA 200.8). While this method does not fully destroy the silica matrix or fully extract strongly interstitially held metals [14], it is an internationally recognised method that represents the readily extractable fraction of metals that are likely to be extracted or leached under normal environmental conditions. All chemical soil parameters are presented as concentrations.

For soil physical analyses, smaller stainless steel rings (5.5 cm width and 3 cm depth) were used to subsample the larger rings by pressing into the larger core using a bench mounted drill press. This ensured the measurement of a fully intact soil core and minimised any ‘edge effects’ of core soil loss during sampling and transportation. The smaller cores were saturated and equilibrated at -5 kPa (i.e. pore sizes > 60 microns) on ceramic tension plates to determine macroporosities. Dry bulk densities and total porosities were calculated gravimetrically from oven (105°C) dry weights.

D. Statistical Methods

The soil chemical and physical results were tested for normality and log transformed if necessary before being subjected to analysis of variance (ANOVA) fitting terms for sampling period (i.e. 1995-2000 and 2008-2012; hereafter referred to as pre and post 2000) for trend analyses and land use using 2009-2013 data. For trend analyses, 78 repeat sites were included to determine soil quality changes (including pH, OC, TN, Olsen P, AMN, bulk density and macroporosity) pre and post 2000, while 48 repeat sites were included in the ANOVA to determine changes in heavy metals. The factorial interaction between sampling period and rural land use was investigated for soil quality parameters for the 78 repeat sites. Blocking was used when comparing between the two sampling periods and site number used as the blocking factor. Mean replicate data were used when comparing soil physical quality (bulk density and macroporosity -5 kPa). When combining the mean concentrations of Olsen P and Cd for pre and post 2000 sampling periods the correlation coefficients between these soil parameters were determined by fitting linear regressions and the level of significance was determined using the F-statistic. Where used, standard error of difference (SED- using back transformed SED log data where appropriate) and *P*-value are presented in tabular form while specific comparisons in graphs are made with the least significant difference (LSD) at the 5% significance level. Where provided *, **and *** indicate the level of significance at the $P< 0.05$, $P < 0.01$ and $P < 0.001$, respectively, and ns denotes not significant.

Where boxplots are presented the boxes represent the inter-quartile range and the whiskers show the range of values that fall within the 10th and 90th percentile. Outliers are illustrated with black circles. The median and mean are shown as a straight and dashed line, respectively, in each box. All analyses were carried out using the statistical package Genstat 17th edition [15] and graphical package Sigmaplot 12.0 edition [16].

To assess the soil environmental quality using heavy metal data a pollution index (PI) was calculated for each heavy metal at each site (adapted by [17], [18]). The PI was defined as the mean ratio of a heavy metal to the mean of the corresponding heavy metal sampled at the native bush sites, the latter acting as an indicator for contextual background conditions. Thus for the purposes of this study, background conditions are defined as those concentrations naturally occurring in soils in areas uninfluenced by anthropogenic activity. The PI was calculated for each site and classified as either low (PI ≤ 1), moderate (1 < PI ≤ 3) or high (PI > 3). When PI's were combined together and averaged an integrated pollution index (IPI) was calculated and classified as low (IPI ≤ 1), moderate (1 < IPI ≤ 3) or high (IPI > 3).

III. Results and Discussion

A. Changes in Soil Quality and Heavy Metals in Rural Land over Time

There were significant differences in soil macroporosity, pH, Olsen P and bulk density for sampling periods pre and post 2000 (Table I). For soil macroporosity, macropores decreased from 12% v/v to 8% v/v ($P< 0.001$) for sampling periods pre and post 2000, respectively, indicating a significant increase in soil compaction. Furthermore, for pastoral sites more than half the soil samples collected across both sampling periods failed to meet the recommended guideline (8% v/v) for macroporosity (Table II). In pastoral systems, soil compaction issues are related not only to grazing management but also to soil type. It was reported [19] that for some soils, particularly Acrisols which are regarded as having drainage impediments and being susceptible to treading damage [20], [21], soil macroporosity was just within the recommended guideline range for ungrazed pasture. Therefore, these soils are unlikely to meet the target range under livestock grazing.

Soil pH increased from 5.85 to 5.96 ($P< 0.05$) pre and post the 2000 sampling periods, respectively (Table I). There were no significant differences in mean concentrations of OC, TN, AMN and heavy metals between the sampling periods (Table I). There were no significant differences observed for pH for the factorial interaction between sampling period and land use and significance was observed at the $P<0.05$ level for macroporosity (data not shown).

Furthermore, significant differences were observed for mean concentrations of Olsen P and bulk density for sampling period (Table I) and the factorial interaction of sampling period and rural land use for these soil parameters (Fig. 2). Mean concentrations of Olsen P were greatest ($P< 0.001$) for horticultural sites. Mean concentrations of Olsen P were higher ($P< 0.05$) during the post 2000 sampling period and this was largely influenced by pastoral sites (Table I and Fig. 2). Olsen P was the indicator of most concern with more than half the horticultural and pastoral sites exceeding the upper limit (Table II). Olsen P is both a sensitive and useful indicator of the soil nutrient status. Elevated concentrations of soil P can influence stream P concentrations contributing to freshwater pollution and eutrophication [22], [23]. This is discussed in more detail at a later section in relation to mean concentrations of Cd. Mean bulk density, an indicator of soil compaction, was significantly higher ($P< 0.001$) in the post 2000 sampling event which is on par with what was recorded for soil macroporosity for the same sampling period. Furthermore, bulk density was greatest ($P< 0.05$) for plantation forestry sites followed by horticulture, pastoral and native bush sites (Fig. 2).

TABLE I
MEAN RESULTS OF SOIL PARAMETERS FOR SAMPLING PERIOD.

Soil parameter	Pre 2000	Post 2000	SED[2]	*P* value
Soil pH	5.85	5.96	0.047	**<0.05**
Olsen P[1]	37	44	3.5	**<0.05**
AMN[1]	145	153	7.2	ns
Organic C (%)	7.24	6.84	0.231	ns
Total N (%)	0.54	0.53	0.020	ns
Macroporosity (-5kPa)	12	8	1.0	**<0.001**
Bulk density (g/cm^3)	0.92	0.98	0.02	**<0.001**
Arsenic[1]	3.7	3.6	0.226	ns
Cadmium [1]	0.38	0.40	0.016	ns
Chromium[1]	11.7	11.5	0.586	ns
Copper [1]	14.9	15.6	0.845	ns
Lead[1]	11.9	11.4	0.659	ns
Nickel[1]	3.77	4.03	0.216	ns
Zinc[1]	20.7	23.7	3.223	ns

Significant differences are highlighted in bold
Mercury is excluded from the analysis because a large number of samples had readings below the detection limit.
[1] mg/kg
[2] denotes standard error of difference

Although caution is recommended when only two sampling periods are being used to determine changes in soil quality, it is a useful starting point which identifies the soil quality parameters and heavy metals of most concern. As soil monitoring continues over time, the use of a longer spanning data record will allow more confident identification of where soil problems exist and where resources need to be targeted.

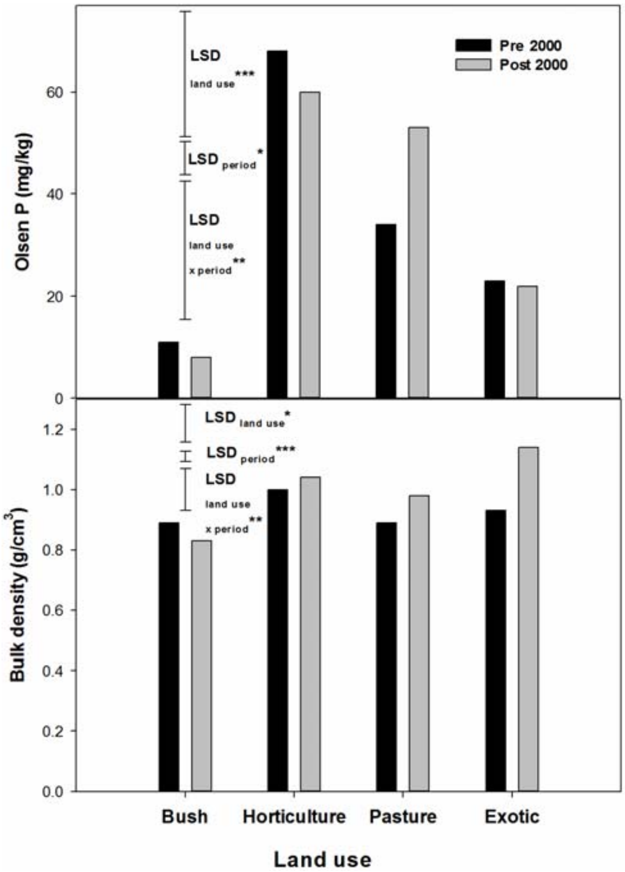

Fig. 2 Mean concentrations of Olsen P (top) and bulk density (bottom) for sampling period, land use and the factorial interaction of land use and period with corresponding least significant differences (LSD_{05})

TABLE II
NUMBER (PERCENTAGE IN PARENTHESES) OF SOIL SAMPLES OUTSIDE TARGET RANGES FOR SOIL QUALITY INDICATORS FOR EACH LAND USE. BROAD TARGET RANGES ARE GIVEN WITH FOOTNOTES CONTAINING SPECIFIC TARGET RANGES FOR SOIL ORDERS AND LAND USES.

Land use	Indicator and broad target ranges							
	Organic C[1]: >3%	**Total N[2]**: 0.35-0.7%	**AMN[3]**: >40mg/kg	**pH[4]**: 5.5-7.5	**Olsen P[5]**: 5-50 mg/kg	**Macroporosity(-5kPa)[6]**: 8-30% v/v	**Bulk density[7]**: 0.6-1.3g/cm^3	**C:N ratio[8]**:
Bush (n=28)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Horticulture (n=36)	6 (17%)	0	5 (14%)	1 (3%)	29 (**81%**)	16 (44%)	2 (6%)	0
Pasture (n=77)	1 (1)	25 (32%)	2 (3%)	7 (9%)	55 (**71%**)	51 (**66%**)	4 (5%)	0
Exotic (n=15)	5 (33%)	7 (47%)	3 (20%)	0	5 (33%)	3 (20%)	3 (20%)	1 (7%)
Urban (n=50)	1 (2%)	15 (30%)	-[9]	10 (33%)	-[9]	-[9]	2 (4%)	0

Percentages in **bold** highlight the indicators by land use whereby more than half the soil samples failed to meet.
[1] **Total C:**Andosols>4%; Fluvisols>3%; Cambisols, Gleysols, Ferralsols and Acrisols>3.5%; Excludes Histosols.
[2] **Total N**: Pasture 0.35-0.7%; Forestry 0.2-0.7%; Excludes horticulture
[3] **AMN:** Pasture >60mg/kg; Horticulture and Forestry >40mg/kg
[4] **pH:** Pasture (excl Histosols) 5.5-6.6; Pasture (Histosols) 5.0-6.7; Horticulture (excl Histosols) 5.5-7.5; 5.5-7.5; Horticulture (Histosols) 5.0-7.5; Forestry (excl Histosols) 4.0-7.5
[5] **Olsen P:** Pasture and Horticulture (Cambisols, Gleysols, Histosols, Fluvisols and Acrisols) 20-35mg/kg; Pasture and Horticulture (Andosols and Ferralsols) 20-50mg/kg; Hill country 15-20mg/kg; Forestry 5-30mg/kg
[6] **Macroporosity:** Forestry 5-30%; Other 8-30%
[7] **Bulk density:** Andosols: 0.6-1.2 g/cm^3; Cambisols, Gleysols, Ferralsols and Acrisols 0.7-1.3g/cm^3; Histosols 0.2-1.0g/cm^3; Fluvisols 0.8-1.3g/cm^3
[8] **C: N ratio:** 7-30 for all soil orders and land uses
[9] Denotes that AMN, Olsen P or macroporosity analysis were not conducted at these sites

B. Influence of Rural and Urban Land Uses on Soil Parameters

There were significant differences between mean concentrations of As, Cd, Cr, Pb, Ni, Zn, pH, OC, C/N and bulk density between native bush, rural and urban land uses in 2009-2013 (Table III). Mean concentrations of As, Cr, Pb, Ni and Zn were greatest for urban sites and concentrations of Cd, Cu and Hg were greatest for rural sites (although not significant for Cu and Hg). Mean concentrations of all heavy metals were least for native bush sites, suggesting these sites act as a good indicator of background conditions (Table III).

High concentrations of As, Cr, Pb, Ni and Zn in urban spaces are commonly reported. Sources of heavy metals in urban areas originate from vehicle emissions that are added to gasoline or contained in engines and galvanized parts, tyres and lubricating oils, coal and fuel combustion, paint, local industry, and current and past use of fertilisers and pesticides [6], [18], [24]-[30]. It was estimated that in 1999 the quantity of Zn released by the wearing of tyres in the United States of America was between 10,000-11,000 metric tonnes [31]. These vehicle emissions and debris are dispersed in the atmosphere and deposited as fine dust to soil, thus reflecting the impact of high traffic areas [6], [32].

TABLE III
MEAN CONCENTRATIONS OF SOIL PARAMETERS FOR NATIVE BUSH, RURAL AND URBAN SITES IN AUCKLAND

Soil Parameter	Native bush	Rural	Urban	SED[1]	*P*-value
Arsenic	3	4.12	4.97	0.561	**<0.05**
Cadmium	0.05	0.41	0.21	0.044	**<0.001**
Chromium	12	14.6	23.3	2.016	**<0.05**
Copper	15.3	22.8	22.3	3.211	ns
Lead	11.1	14.5	39.8	3.128	**<0.001**
Mercury	0.12	0.16	0.12	0.020	ns
Nickel	3.9	5.2	24.9	1.836	**<0.001**
Zinc	25.6	38.5	64.9	5.665	**<0.001**
pH	5.4	5.9	5.9	0.093	**<0.001**
Organic C	7.63	6.26	5.95	0.527	**<0.05**
Total N	0.43	0.49	0.48	0.044	ns
C/N	17.4	14.0	12.7	0.546	**<0.001**
Bulk density	0.79	1.02	0.93	0.033	**<0.001**

Significant differences are highlighted in bold
[1] denotes standard error of difference

Mean concentrations of Cd, Cu and Hg were greatest for rural sites (although not significant for Cu and Hg) and Fig. 3 illustrates where concentrations were greatest by rural land use. Mean concentrations Cd, Cu and Hg were significantly different across all five land uses (Fig. 3).

Mean concentrations of Cd were greatest for pastoral land followed by horticulture, urban, plantation forestry and native bush sites (Fig. 3). These land use trends were similar for concentrations of Hg. Phosphorus fertiliser is a significant source of Cd [33]-[35] and is predominately applied to pastoral and horticultural based systems. Furthermore, mean concentrations of Olsen P was identified as the indicator of most concern for pastoral and horticultural land uses (Table II) and a significant, positive correlation existed between these two parameters when the mean concentrations of Olsen P and Cd for pre and post 2000 sampling periods were combined (Fig. 4); albeit recognising that this is the comparison of both total recoverable and plant/bio available fractions of two different soil parameters since methods for bio-available or bio-accessible fractions of Cd are still being debated [10]. That said, it does reiterate the importance of analysing basic soil parameters in conjunction with heavy metals to aid with the identification of potential pollutant sources, implications, and to assist and inform options for mitigation.

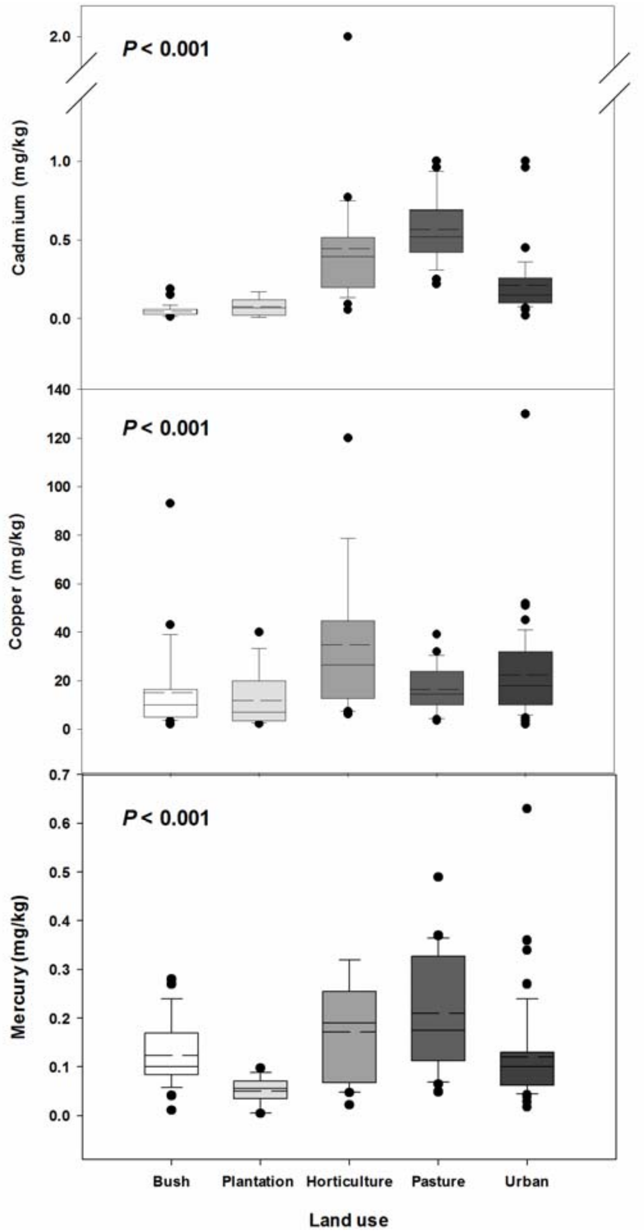

Fig. 3 Concentrations of cadmium (top), copper (middle) and mercury (bottom) for rural and urban land uses

It should be noted and as stated previously, pastoral land encompasses dairy, dairy-drystock converted land, drystock and lifestyle block converted land [19]. When these sites were originally selected pre 2000, only two land use categories existed (dairy and drystock) that has subsequently increased to four. As a result of land use changes over time, it makes it difficult to determine trends in soil quality for individual pastoral land use categories therefore pastoral land comprises all to assist with trend analysis.

Furthermore, horticultural land comprises of orchards, vineyards and market gardening sites which have been grouped together in order to conduct more robust statistical analysis with a larger sample size. That said, when separated out, market gardening sites were outside the guideline ranges for multiple soil quality parameters including Olsen P, Organic C and AMN [36]. Market gardening is a highly intensive land use activity whereby the soil continually gets worked up via rotary hoeing, deep ripping and harvesting. Over time, this can deplete concentrations of carbon content in the soil, subsequently reducing microbial biomass and activity [37]. Large quantities of fertiliser are also applied to these systems which were reflected in the high Olsen P concentrations that were observed to range between 73-361 mg/kg [36]. It is therefore important to consider soil quality for individual land uses to determine what issues exist so they can be rectified by the incorporation of green manure crop residues or the reduction of fertiliser application as was the case for market gardening sites in this instance.

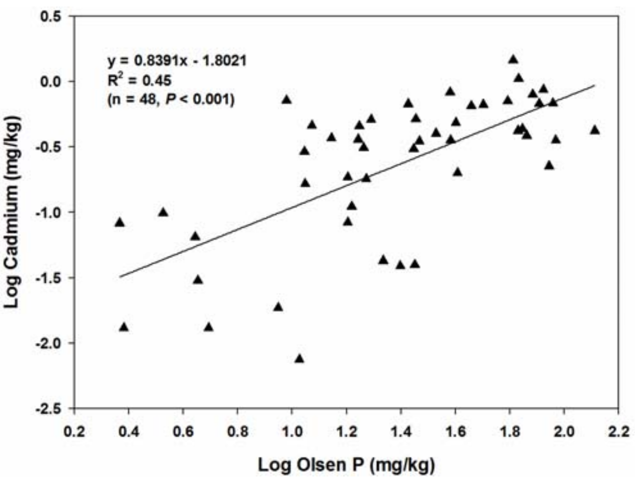

Fig. 4 Correlation between mean concentrations of log Olsen P and log Cadmium

Lastly, mean concentrations of Cu were greatest (*P*< 0.001) for horticultural sites followed by urban and pastoral sites and levels were least for plantation forestry and native bush sites. Horticultural soils have previously been reported to have higher levels of Cu than pastoral soils and this was attributed to the spraying of copper-based fungicides on horticultural crops [38].

C. Pollution Index

Since native bush sites had the lowest mean concentrations of heavy metals across all the land uses, it was considered appropriate that these sites act as an indicator for background conditions i.e. uninfluenced by anthropogenic activity [17], [18], [39]. Based on this concept, a pollution index (PI) for the rural and urban sites was calculated. The mean PI was classified as high (PI > 3) for, and by order, Cd > Ni, indicating that these heavy metals were more than three times greater than concentrations recorded at native bush sites (Table IV A). Moderate PI's (1 < PI ≤ 3) were calculated for, and by order, Pb> Zn > Cr = Cu = As > Hg and no PI's were classified as low (PI ≤ 1). For Cd, the maximum PI recorded as 42.6 was a horticultural site, identified as an orchard. The concentration of Cd recorded at the site was 2 mg/kg which is double the recommended upper limit of 1 mg/kg [40]. However, the site is located on a Histosol soil and is described as a peaty loam with a recorded bulk density of 0.54 g/cm^3. Therefore, if the PI for the site was recorded on a volumetric basis it would be given a PI score of 23 which is on par with other sites that were classified as high. It is therefore important to consider the bulk density of soils otherwise presenting data on a gravimetric basis can potentially overestimate the true pools of heavy metals for some soils [41], [42].

TABLE IV
STATISTICAL RESULTS OF (A) THE POLLUTION INDEX AND (B) THE INTEGRATED POLLUTION INDEX (IPI) FOR POOLS OF EIGHT HEAVY METALS SAMPLED ACROSS 114 RURAL AND URBAN SOIL SITES

A	**Pollution index**			**Number of sites** (n = 114)		
	Mean	**Min**	**Max**	**Low** (PI ≤ 1)	**Moderate** (1< PI ≤3)	**High** (PI > 3)
As (moderate)	1.5	0.1	1.8	51	55	8
Cd (high)	6.9	0.2	42.6	8	29	77
Cr (moderate)	1.5	0.2	9.1	43	62	9
Cu (moderate)	1.5	0.1	8.5	54	51	9
Pb (moderate)	2.3	0.2	14.5	43	47	24
Hg (moderate)	1.1	0.04	5.1	69	43	2
Ni (high)	3.5	0.2	38.5	36	53	25
Zn (moderate)	2.0	0.2	9.0	32	64	18

B Integrated PI	**Mean**	**Minimum**	**Maximum**
Low (IPI ≤ 1)	0.71 (n=17)	0.26	0.96
Moderate (1< IPI ≤ 3)	1.91 (n=62)	1.09	2.91
High (IPI > 3)	4.51 (n=35)	3.09	9.40

A high mean PI score was also calculated for Ni which can be largely attributed to urban land use activity (Table III). It is noteworthy that volcanically derived soils are prevalent in Auckland [43], which are reported to have naturally high levels of Ni [18], [28], therefore the high mean PI calculated for this analyte could partially reflect its natural origin. However, considering that mean concentrations of Ni were recorded to be about six times less under native bush than urban land use (Table III) suggests that urban land use activity is a major contributor of Ni soil pollution. In contrast, soil Ni was less of a problem in the city of Torino, Italy, when compared with concentrations from rural land (i.e. mean urban/mean rural) [17]. A mean PI of 7.5 was calculated for Pb followed by 3.3, 2.9, 2.8 and 2.0 for Cu, Zn, Ni and Cr, respectively [17], which are on the larger side of what has been reported for the same analytes in the current study. Furthermore, native bush sites formed the basis of the PI in the current study as opposed to rural land [17]. It is important to distinguish between native bush and rural sites when developing a PI because while some heavy metals are more of an issue for specific rural land uses, the same might not hold true in urban areas and vice versa. This can only be determined when establishing a PI using a land use uninfluenced by anthropogenic activity as a baseline.

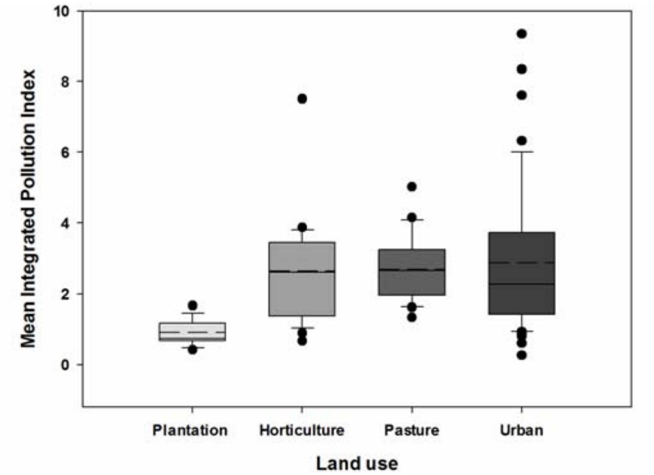

Fig. 5 Mean Integrated Pollution Index (IPI) by land use type

When the mean PI's for each analyte at each site were combined and averaged, a mean integrated pollution index (IPI) was calculated and deemed moderate at 2.5 (range 0.3-9.4) (Table IV B), indicating elevated levels of soil pollution. The majority of sites (n=62) were classified as having a moderate IPI followed by 35 sites calculated as having a high IPI and only seven sites were calculated as having a low IPI (Table IV B).

From a land use perspective, the mean IPIs were highest for urban sites at 2.9 followed by pasture, horticulture and plantation forests at 2.7, 2.6 and 0.9, respectively (Fig. 5). The site with the highest IPI of 9.4 was an urban site that was located in a high traffic zone whereby very high concentrations of Zn, Ni and Pb were recorded (Table III).

IV. Conclusions

Significant differences were observed in changes of certain soil quality parameters over time and mean concentrations of Olsen P and macroporosity were the indicators of most concern particularly for horticultural and pastoral systems. Results from the study indicate that rural and urban land uses have a significant impact on soil parameters. Mean concentrations of Cd, Hg and Cu tended to be higher for certain rural land uses and a significant positive correlation existed between Olsen P and Cd which highlights the importance of analysing basic soil parameters in conjunction with heavy metals. In contrast, mean concentrations of As, Cr, Pb, Ni and Zn were greatest for urban sites. Native bush sites had the lowest concentrations of heavy metals and as such, these sites act as a good indicator of background conditions. From a land use perspective, the mean IPIs were highest for urban sites, followed by pasture, horticulture and plantation forests. It was considered important to distinguish between native bush and rural sites when developing a PI because while some heavy metals are an issue for specific rural land uses, the same does not hold true in urban areas, and vice versa, as findings from this study demonstrate. It is recommended that soil monitoring continues over time because the use of a longer spanning record will allow further identification of where soil problems exist and where resources need to be targeted into the future.

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