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Environmental justice analyses may hide inequalities in Indigenous people’s exposure to lead in Mount Isa, Queensland

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Abstract

Distributive environmental justice studies frequently identify how ethnic minorities and communities of low socio-economic status (SES) are disproportionately likely to live in areas with an elevated risk of exposure to pollution. Few distributive justice studies have been conducted in Australia to explore whether this relationship is relevant to rural mining communities. In the remote mining city of Mount Isa, studies have found higher geometric mean blood lead levels (BLLs) among Indigenous children compared to non-Indigenous children. However, there is a lack of recent BLL data to determine conclusively if Indigenous children in Mount Isa are disproportionately exposed to lead pollution. We employed a common distributive environmental justice analysis approach to determine if Indigenous residents are disproportionately likely to live in areas with elevated soil lead concentrations. We analysed soil samples from 49 of 51 census areas at the Statistical Area 1 (SA1) level and measured the statistical correlation between soil lead concentration and the percentage of residents living in each SA1 who were of Indigenous status using Kendall’s tau and linear regression. We found little evidence of an association between soil lead concentration and either Indigenous status or SES, indicating that Indigenous and low-SES residents are not disproportionately likely to live in areas with elevated concentrations of soil lead. The results of this study, along with prior research on mining emissions and housing quality in Mount Isa, indicate that elevated BLLs among Indigenous children may be due to low-SES increasing the risk of exposure as a result of lower quality housing. Actions by governing and mining bodies to address children’s elevated BLLs in Mount Isa should give greater attention to risk factors related to SES. Furthermore, distributive environmental justice research must account for disparities in exposure which are not the result of disproportionate proximity to polluting sources.

Introduction

Distributive environmental justice studies are primarily concerned with assessing whether communities defined by race, ethnicity, class and gender are disproportionately exposed to environmental hazards. Studies examining this phenomenon have typically assessed the risk of exposure by statistically analysing if certain populations designated by ethnicity and socio-economic status (SES) are disproportionately likely to live near environmental hazards, particularly industrial pollution (Bullard 1983, GAO 1983, UCC 1987, Chakraborty et al. 2011, Taylor 2011). The majority of these studies have found that ethnic minorities and low-SES communities are disproportionately likely to live in areas with high levels of pollution (Chakraborty et al. 2011, Taylor 2011). Based on the results of these studies, it has been theorised that disproportionate proximity to polluting facilities is caused by various forms of disadvantage such
as economic and socio-political disadvantage, as well as interpersonal and institutional racial discrimination (Mohai et al 2009, Mohai and Saha 2013). These forms of disadvantage may cause polluting facilities to be sited near ethnic minority communities or cause privileged and wealthy populations to move away from polluting facilities, resulting in ethnic minorities remaining in these areas or moving in (Mohai et al 2009, Mohai and Saha 2015). These processes may take place over generations as these forms of disadvantage continue to influence the spatial distribution of ethnic communities decades after facilities are first built. While there has been limited study of how different forms of disadvantage influence the distribution of communities within distributive environmental justice research, it is understood that the causes of distributive injustice are complex and have considerable historical roots (Pulido 2000).

In the US, distributive justice studies have influenced a range of legislation at different levels of government and caused environmental justice research to expand to an increasing number of countries (Walker 2009, Public Law Research Institute 2010, Agyeman et al 2016). Despite this, very little distributive environmental justice research has been conducted in Australia (Chakraborty and Green 2014, Masterman-Smith et al 2016). This is particularly true for rural areas, despite well-publicised concerns about disparities in the health effects from pollution between Indigenous and non-Indigenous communities in rural Australia towns (Masterman-Smith et al 2016). One example of this is the mining city of Mount Isa, Queensland, which has a large Indigenous population, and some of the largest lead mining and smelting facilities in Australia.

There is considerable evidence that Indigenous residents in Mount Isa are disproportionately exposed to lead pollution, from the mines (QH 2008, 2010, Taylor et al 2010, Mackay et al 2013, Taylor et al 2014). There is insufficient data from these studies or more recent blood lead level (BLL) data to demonstrate with certainty that Indigenous children are disproportionately exposed to lead pollution, due to concerns with bias and unrepresentative sample sizes (Green et al 2017). However, a number of Australian studies (Fett et al 1992, Young et al 1992, Gulson et al 2006, Willmore et al 2006) and studies outside Australia (Sedman 1989, Mielke et al 1997, 2007, 2017, Johnson and Bretsch 2002, Malcoe et al 2002, Zahran et al 2010) have found a significant association between children’s BLLs and the concentration of lead in soil where they live. This suggests that Indigenous children and their families may be disproportionately likely to live in areas with elevated levels of lead pollution. If this was mapped and calculated, it could demonstrate that Indigenous residents in Mount Isa are disproportionately exposed to lead pollution, which could then be considered a case of distributive environmental injustice.

It is important to assess whether distributive environmental injustice exists in Mount Isa, as it may demonstrate that the most historically disadvantaged community is disproportionately exposed to pollution; a serious social justice issue. It is also important for informing actions to address disparities in BLLs between Indigenous and non-Indigenous children, as it could indicate that the causes of this disparity have significant historical and institutional roots which need to be addressed. For these reasons, the aim of this study is to apply geospatial distributive environmental justice methods to determine if Indigenous residents and low-SES residents are significantly more likely to live in areas with elevated levels of lead in Mount Isa, Australia.

Background

Health effects of lead

Lead is a neurotoxin which causes permanent neurological effects in humans at low doses of exposure (Lanphear et al 2005, Wani et al 2015). The effects of lead include: increased risk of cognitive deficits including decreased IQ, learning difficulties, impaired executive function and various psychosocial problems including attention deficit hyperactivity disorder (ADHD) (Laidlaw and Filippelli 2008, Csavina et al 2012, NTP 2012, Forbes and Taylor 2015, Lanphear 2015). Children, in particular, are at risk of developing neurological effects if exposed to lead because they are in the early stages of their neurological development (Laidlaw and Filippelli 2008, Csavina et al 2012, Forbes and Taylor 2015, Lanphear 2015, Leech et al 2016). Babies and children are more likely to ingest lead in soil due to greater prevalence of hand-to-mouth behaviours, which is one of the primary pathways of lead uptake (Woolf et al 2007, Laidlaw and Filippelli 2008, Filippelli and Laidlaw 2010). Lead particles can also be ingested through consumption of contaminated food and water and, in addition to ingestion, can also be absorbed through inhalation and through contact with abrasions on skin (Laidlaw and Filippelli 2008, WHO 2010). However, ingestion of lead particles from soil adhering to skin is typically the most significant source of lead uptake in children (Laidlaw and Filippelli 2008, Filippelli and Laidlaw 2010).

Smaller soil particles are more likely to adhere to hands and be ingested (Laidlaw and Filippelli 2008, Beamer et al 2012, Csavina et al 2012, Ikegami et al 2014, Goix et al 2016). Current Australian guidelines for lead state that soil in residential areas within the <2 mm size fraction should have a lead concentration of <300 mg kg$^{-1}$ (NEPC 2011a, 2011b). The Australian guidelines on the size fraction of soil to be analysed are inconsistent with the recommendations of recent research (Beamer et al 2012, Csavina et al 2012, Ikegami et al 2014, Goix et al 2016) and recommendations from the USEPA, which state that soil within the size fraction <150 μm is more representative of the risk of exposure
Smelter and mining emissions, which consist mostly of ultra-fine particles, have a significantly greater chance of being ingested compared to natural lead in soil, which has a much coarser size fraction (Csavina et al. 2012). Ultra-fine particles are more easily mobilized by air movement and hence more likely to be deposited indoors through gaps in doors and windows, posing an increased risk of elevated levels of lead in house dust (Kelly and Fussell 2016). Housing quality, especially that of doors and windows, is one of the major risk factors influencing exposure to lead in soil and air (Lanphear et al. 2005, Laidlaw and Filippelli 2008).

Current Australian guidelines from the NHMRC state that public health intervention should begin when children’s BLLs are ≥5 μg/dL (NHMRC 2015). This is consistent with US guidelines (CDC 2012) but is not as stringent as the German guideline of 3.5 μg/dL (Schulz et al. 2009). Research has not, however, found a safe level of lead and even BLLs under national limits are associated with permanent neurological effects (WHO 2010, Forbes and Taylor 2015).

**Location of study**

Mount Isa is a large regional city, located in north-west Queensland, Australia (20.7803°S-20.6497°S, 139.5626°E-139.4746°E). The city was founded as a result of the discovery of ore bodies in 1923, leading to the establishment of large-scale mining in 1929 and the lead smelter in 1931 (Eklund 2012). The mining and smelting facilities have been substantial throughout the existence of Mount Isa (Taylor et al. 2014). The ongoing mining operations have led to Mount Isa becoming a regional economic and service centre in this part of rural Australia, with many residents from smaller towns in the region, including many Indigenous residents, visiting Mount Isa to use its services (Memmott and Nash 2016).

**Mount Isa Mines’ lead emissions**

Emissions from the mining and smelting facilities have been substantial throughout the existence of Mount Isa. For example, it has been estimated that over 300 tonnes of lead was emitted from the mining and smelting facilities over the 2005–2006 financial year (NPI 2018). The magnitude of historic and current lead emissions from the mines is far greater than other historical sources of lead including leaded petrol and natural geological formations in the region (Taylor et al. 2010, Mackay et al. 2013). This has led to high lead levels being measured in Mount Isa’s air (Taylor et al. 2014), soil (Taylor et al. 2010, Mackay et al. 2013) and water (Taylor and Hudson-Edwards 2008, Taylor et al. 2009, Mackay and Taylor 2013).

**Blood lead levels in Mount Isa**

Elevated BLLs in children were first documented in Mount Isa in the 1990s (Taylor et al. 2010). The Queensland Health department responded by conducting two studies investigating the proportion of children in Mount Isa with BLLs above 10 μg m⁻³, which was the then current Australian guideline for public health intervention (QH 2008, 2010). The proportion of children with BLLs above 10 μg m⁻³ in the 2008 and 2010 studies was 11.3% and 4.8% respectively, and in both studies the percentage of children with BLLs above 5 μg m⁻³ was above 30%, demonstrating widespread elevated BLLs in Mount Isa (QH 2008, 2010). In both studies the geometric mean BLL recorded was significantly higher for Indigenous children compared with non-Indigenous children, which is consistent with BLL data from other mining towns in Australia (QH 2008, 2010). Since the Queensland Health studies, subsequent BLL testing has relied upon small convenience samples that are not representative of the population of children in Mount Isa (Green et al. 2017). In addition, the number of Indigenous children tested since the 2010 Queensland Health study is unknown (Green et al. 2017). It has been announced recently by Queensland Health that more comprehensive BLL data collected in 2016–2017 will be released. Nonetheless, as of publication of this paper (2018) these data have not been made public.

The main intervention attempting to address the health threat from lead exposure is through the creation of community education programs on the dangers of lead and ways of minimising personal exposure. It has been claimed that the provision of educational resources has assisted in lowering children’s BLLs (ABC 2017a, The North West Star 2017a, 2017b) however, due to inadequate surveillance of children’s BLLs in Mount Isa it is unknown if children’s BLLs are declining (Green et al. 2017). Certain measures recommended for reducing lead uptake have a questionable basis, for example recommendations to consume more fresh fruit and vegetables have been found to have an insufficient scientific basis in current research (Kordas 2017). Further criticisms have been expressed over the failure of the program to adequately communicate the dangers of exposure to lead (Sullivan and Green 2016) and the lack of outreach to the Indigenous community in Mount Isa (Forbes and Taylor 2015, ABC 2017a, Green et al. 2017). The lack of outreach to the Indigenous community has resulted in further criticism regarding the focus on individual behaviours, such as regularly cleaning hands and tables and growing lawns, while not addressing the underlying factors which make these changes unviable, such as poverty in some of Mount Isa’s Indigenous community (ABC 2017a). A review of research on the effects of programs aimed at adjusting household behaviour found insufficient evidence that household educational interventions were effective at lowering children’s BLLs (Nussbaumer-Streit et al. 2016). In addition to these programs, Mount Isa Mines claims to have reduced its emissions significantly over the last decade in response to the health threat from lead exposure (ABC 2017b, NPI 2018), although concerns
about the accuracy of this data (Cooper et al 2017) and the health risks from current airborne emissions (Taylor et al 2014) continue to be raised.

Mount Isa’s Indigenous population

Indigenous residents make up 16.6% of the population of Mount Isa, compared with 2.8% in all of Australia and 4% in the State of Queensland (ABS 2016a). The Indigenous population of Mount Isa has grown substantially since the 1960s, as many Indigenous families from surrounding rural and remote towns have moved there over this time (Memmott et al 2012). The socio-economic status of Mount Isa’s Indigenous community is quite low, particularly in relation to the rest of Mount Isa’s residents. Many Indigenous families residing in Mount Isa live in public housing and are reliant on welfare assistance (Memmott and Nash 2016). Data from the 2016 census showed that the median weekly personal income for the Indigenous population in Mount Isa was $400–649, compared with $1000–1249 for the non-Indigenous population (ABS 2016a). Only 60.7% of Indigenous residents over 15 were recorded as being in the labour force compared to 86.5% of non-Indigenous residents, and only 35% Indigenous over 15 were recorded as having completed their High School Certificate compared to 55.1% of non-Indigenous residents (ABS 2016a).

Methods

Soil sampling and preparation

A representative soil sample suite was collected in the Mount Isa area, including one sample from 49 of the 51 Statistical Area Level 1 (SA1) zones in the city of Mount Isa. SA1s are the smallest geographical unit predefined by the Australian Bureau of Statistics (ABS) which have cultural and socio-economic characteristic information publicly available, and in the city of Mount Isa contain an average population of ~350 people and an average area of ~1.2 km² (ABS 2016a, 2016b). Sites were selected near the centre of each SA1 from locations visually determined to be representative of the SA1, and which were publically accessible but away from roadsides to minimise the influence of historical petrol emissions (Laidlaw and Taylor 2011). Vegetation such as grass was removed, and a 150 g soil sample collected from the top 5 cm and placed in a Minisam Kraft paper packet. In seven SA1s a second sample was collected due to the presence of different soil types or land uses (e.g. residential versus public parks). Samples were not collected in two SA1s due to either there being too few residents to be included in our analysis or being on private land.

The soils were dry sieved using nylon mesh to <2000μm and subsequently wet sieved into the 180–2000 μm, 63–180 μm and <63 μm fractions, with selection of size ranges based on previous studies (Juhasz et al 2011, Beamer et al 2012, Cohen et al 2012, Ikegami et al 2014, Goix et al 2016). The sieved material was milled in a WC mill.

Analysis

Lead and other elements in the milled samples were analysed using the Olympus Delta Premium fpXRF in Soils mode (with 30s counts on beams 1 and 2 and 20s on beam 3). Accuracy was determined using GXR-6 (a contaminated soil) and silica blanks, and the method precision established by multiple analysis of selected samples. Analytical precision for lead (and a number of other key elements) was better than ±10% and accuracy ±5%, which was within the typical quality control limits set for such studies (USEPA 2007, Zissimos et al 2018). The fit-for-purpose quality of the data was further indicated by the very high parametric and spatial correlation between copper, lead and zinc (the main metals extracted from the ore) and between iron and manganese (associated with secondary iron minerals in the soil).

Population data

Indigenous status

Using 2016 ABS census data, we calculated the overall percentage of residents who are of Indigenous status in each SA1. We defined Indigenous residents as those who self-identified as either Aboriginal, Torres Strait Islander, or both. We calculated the percentage of residents 15 years of age or younger who were of Indigenous status in each SA1. Although BLLs are typically measured in children of ages six or less, this younger age group is too small for the census to provide accurate figures for each SA1 (ABS 2011a). We decided that the number of children aged 15 or younger was the best measure of the percentage of Indigenous children in each SA1 that was large enough to be calculated accurately.

Socio-economic status

To measure the socio-economic status of residents in each SA1, we used the Socio-Economic Indexes for Areas (SEIFA) values calculated from 2011 ABS census data; the most recent SEIFA values available at the time of our analysis. The SEIFA data consists of four different variables which act as a summary measure of a particular aspect of socio-economic status: the Index of Relative Socio-Economic Advantage and Disadvantage (IRSD), the Index of Relative Socio-Economic Disadvantage (IRSD), the Index of Economic Resources (IER) and the Index of Education and Occupation (IEO). These variables are calculated from a weighted combination of variables typically used as indicators of SES including measures of education, income and employment, depending on the aspect of socio-economic status that they represent (ABS 2013).

Although SEIFA values are unlikely to have changed significantly for each SA1 in Mount Isa since 2011, as a more current measure of socio-economic status we also used 2016 ABS census data to calculate individ-
ual variables that are typically used as indicators of socio-economic status. These individual variables were different measures of income, education, employment and the occupation of residents.

For income, we calculated both the median personal income and the median household equivalised income of each SA1. The value for household equivalised income is calculated by applying weights from the ‘modified OECD’ equivalence scale to the total household income, allowing for comparisons between households of different sizes and compositions (ABS 2016c). For education, we separately calculated the percentage of residents over 15 years of age who had completed Year 10, Year 12, and had earned a diploma or an equivalent or higher educational qualification in each SA1. For employment, we separately calculated the percentage of residents over 15 years of age who were unemployed, and the percent not in the labour force in each SA1. For occupation, we calculated the percentage of residents over 15 who were employed in blue collar or white collar occupations. Blue collar occupations are typically associated with trades and lower skilled jobs, and according to the ABS include technicians and trades workers, and labourers. By contrast, white collar occupations are higher-paying occupations, including managers, community and personal service workers, and sales workers (ABS 2011b).  

Statistical analysis

We calculated bivariate correlations between the concentration of lead in soil and measures of each population variable in each SA1. Each SA1 was allocated one lead concentration value for each soil size fraction analysed (<180 μm and <63 μm) based on the results of the analysis of the soil sample collected in that SA1. Values for the lead concentration of soil in the <180 μm size fraction were calculated based on the weighted average of the concentration of lead in the <63 μm and 180–63 μm size fractions of each sample. SA1s with more than one soil sample had their values either averaged or one sample excluded, depending on how representative the samples were of the soil in that SA1. Summary statistics of the concentration of lead in soil measured for both size fractions are shown in table 1.

To account for possible variation in the soil lead concentration within each SA1, we calculated the bivariate correlations between the soil lead concentration from each soil sample, and the distance of each sample to the lead smelter and the mines, based on the location of the mining pits. This was to determine if distance from the mines could be used as a proxy measure for the representative soil lead concentration of each SA1, thereby overcoming any issues with variation in soil lead concentration not measured by our soil samples. Using a log-transformed regression, we found significant negative correlations between soil lead concentration with smelter distance (P-value: <0.001) and mine distance (P-value: <0.001, see table S1 in supplementary material available at stacks.iop.org/ERL/13/084004/mmedia for more details). These results align with previous research that found that the lead smelter and mining facilities were the main sources of lead in soil in Mount Isa (Taylor et al 2010, Mackay et al 2013). As a result, we decided that distance from the smelter and distance from the mines were both suitable proxies for the soil lead concentration of each SA1. Therefore, the distance from the centre of each SA1 to the lead smelter and the mining lease was calculated.  

Bivariate correlations between all population variables with soil lead concentration, as well as distance from the smelter and mining lease, were calculated using Kendall’s tau. Kendall’s tau is a non-parametric measure with no assumptions about the distribution of data, overcoming problems with datasets having non-normal distributions, which was common in our analysis. We also calculated a linear regression for each bivariate correlation, however the results of our regressions were fairly consistent with our results using Kendall’s tau. The methods and results of our linear regressions, are included in the supplementary material (tables S2–S4 in supplementary material). All relationships were measured for statistical significance at the 90%, 95% and 99% confidence levels.  

Results

Indigenous status

There was no statistically significant relationship calculated between the concentration of lead in either soil fraction or distances to the mine or smelter, and the percentage of Indigenous residents in the total population or of people aged under 15 in each SA1 (table 2).

There were no statistically significant correlations at the 90% confidence level between any dependent variables and the percentage of Indigenous residents in either the total population or people aged under 15. The correlation coefficient was positive for all relationships

6 The categorisation of occupations into blue and white collar occupations applied in this study was originally designed and used by the ABS. However, this categorisation may not be entirely representative of SES in Mount Isa, due to the significantly higher income of mine workers in low-skilled positions relative to other low-skilled occupations.

7 For three SA1s we used the location where the soil sample was collected instead of the centre of the SA1, because the centre was not in a location that was representative of the location of residents within the SA1 (see figure S1 in supplementary material).

8 Typically, statistical analyses focus on the 95% confidence interval to determine whether the correlation between two variables is significant or not. This can have the effect of ignoring potentially influential explanatory variables with p-values that are slightly outside the 95% confidence level. The 90% confidence level was included in our analysis to account for this.
where the dependent variable was either size fraction of soil lead concentration, and negative for all relationships where the dependent variables was distance from either the smelter or the mine. Although they were not statistically significant, these relationships suggest that Indigenous residents are more likely to reside in SA1s further from mining facilities, with relatively low concentrations of soil lead.

**Socio-economic status**

The relationship between the concentration of soil lead and SES showed very little evidence of a statistically significant relationship between the concentration of lead in soil and the SES of residents (table 3). No statistically significant relationships were found between any of the SES variables and lead in either size fraction at the 95% confidence level (table 3). The percentage of residents with a diploma was significantly correlated at the 90% confidence level with both size fractions of soil lead, while the percentage of residents that had completed Year 12 was significantly correlated with soil lead in the <180 μm size fraction at the 90% confidence level. These relationships were negative, indicating that less educated residents were more likely to live in SA1s with low concentrations of lead in soil.

There was a limited number of statistically significant correlations between variables of SES and distance from the smelter and the mine, with mixed associations calculated between different measures of SES with distance from the smelter and mine (table 4).

Of the four SEIFA variables, no significant correlations were measured for distance from the mines and only IER had a statistically significant positive correlation with distance from the smelter. A positive but not quite statistically significant correlation between equivalised household income and distance from the smelter was also calculated, suggesting that residents with low economic resources are more likely to live closer to the smelter, but not the mines. Of nine individual SES variables measured, significant correlations were found for variables measuring education and labour force participation. The percentage of residents who had earned a Diploma had significant negative correlations with both measures of distance at the 95% confidence level, while the percentage who had completed Year 12 had a significant negative correlation with distance from the mines at the 95% confidence level, and at the 90% confidence level for distance from the smelter. The percentage of residents not in the labour force had a significant positive correlation with distance from the mine at the 90% confidence level. These results indicate that residents with lower levels of education and labour force participation are more likely to live away from the mining facilities. Overall, our results provide little evidence that individuals of low-SES are disproportionately likely to reside in areas with higher concentrations of lead in soil.

**Discussion**

Our analysis found almost no significant relationships between the concentration of lead in soil, and Indigenous status or SES at the level of the SA1 geographical unit. While there were a small number of statistically significant relationships between SES and distance from the smelter and mine, these relationships did not consistently show that either high-SES or low-SES residents were more likely to live close to the smelter and mine. Consequently, our results indicate that Indigenous residents and residents of low SES are not more likely to live in areas with high concentrations of lead in soil.

The results of this analysis do not fit with the majority of other published distributive environmental justice studies, which have typically found that non-white residents and residents of low SES are most likely to reside in areas with a high risk of pollution (Chakraborty et al 2011, Mohai and Saha 2015). This is surprising, as it is theorised that ethnic minorities are most likely to live nearest to polluting sources due to economic and socio-political disadvantage, and racial discrimination (Mohai et al 2009, Mohai and Saha 2015) and research shows that Indigenous Australians, including residents in Mount Isa, are disadvantaged in all these respects (Sherwood 2013). Our results are also surprising considering previous Queensland Health studies.

### Table 1. Summary statistics for lead concentration of all soil samples collected (all values in μg m⁻³).

| Size fraction | Average | Min. | Max. | Range | Median | Q₁ | Q₃ | IQR |
|---------------|---------|------|------|-------|--------|----|----|-----|
| <63μm         | 291     | 50   | 1326 | 1276  | 186    | 94 | 368| 274 |
| <180μm        | 235     | 39   | 1227 | 1187  | 141    | 79.2| 263| 183.8 |

### Table 2. Results of Kendall’s tau analysis for Indigenous status with soil lead concentration and distance from MIM.

| Independent variable | Dependent variable | Correlation coefficient | P-value |
|----------------------|--------------------|-------------------------|---------|
| Percent Indigenous   | Soil lead (<63 μm) | -0.067                  | 0.50135 |
|                      | Soil lead (<180 μm)| -0.083                  | 0.40309 |
|                      | Smelter distance   | 0.055                   | 0.38089 |
|                      | Mine distance      | 0.141                   | 0.15022 |
| Percent Indigenous ≤15| Soil lead (<63 μm) | -0.084                  | 0.39824 |
|                      | Soil lead (<180 μm)| -0.087                  | 0.38397 |
|                      | Smelter distance   | 0.038                   | 0.7004  |
|                      | Mine distance      | 0.128                   | 0.19192 |
have found higher geometric mean BLLs for Indigenous children compared to non-Indigenous children, which suggests that Indigenous children and their families are disproportionately exposed to lead pollution (QH 2008, 2010, Green et al. 2017). Yet there are explanations for why Indigenous residents are not disproportionately likely to live in areas with high lead concentrations and why despite this, Indigenous children are more likely to have elevated BLLs. The implications of these explanations indicate that Indigenous children and their families are still likely to be disproportionately exposed to lead pollution in Mount Isa. As a result, it is also likely that current theories for distributive justice are too reliant on the relationship between

| Independent variable | Dependent variable | Correlation coefficient | P-value |
|----------------------|--------------------|-------------------------|---------|
| IRSAD                | Soil lead (<63 μm) | 0.015                   | 0.890   |
|                      | Soil lead (<180 μm)| 0.015                   | 0.883   |
| IRSD                 | Soil lead (<63 μm) | 0.031                   | 0.763   |
|                      | Soil lead (<180 μm)| 0.035                   | 0.730   |
| IER                  | Soil lead (<63 μm) | −0.066                  | 0.312   |
|                      | Soil lead (<180 μm)| −0.051                  | 0.611   |
| IEO                  | Soil lead (<63 μm) | 0.032                   | 0.756   |
|                      | Soil lead (<180 μm)| 0.024                   | 0.816   |
| Percent year 12      | Soil lead (<63 μm) | 0.151                   | 0.127   |
|                      | Soil lead (<180 μm)| 0.171                   | 0.085   |
| Percent year 10      | Soil lead (<63 μm) | −0.106                  | 0.285   |
|                      | Soil lead (<180 μm)| −0.097                  | 0.330   |
| Percent diploma      | Soil lead (<63 μm) | 0.173                   | 0.082*  |
|                      | Soil lead (<180 μm)| 0.182                   | 0.066   |
| Percent unemployed   | Soil lead (<63 μm) | 0.006                   | 0.959   |
|                      | Soil lead (<180 μm)| 0.010                   | 0.924   |
| Percent not labour   | Soil lead (<63 μm) | −0.015                  | 0.883   |
|                      | Soil lead (<180 μm)| −0.025                  | 0.809   |
| Percent blue collar  | Soil lead (<63 μm) | −0.115                  | 0.248   |
|                      | Soil lead (<180 μm)| −0.116                  | 0.245   |
| Percent white collar | Soil lead (<63 μm) | 0.020                   | 0.830   |
|                      | Soil lead (<180 μm)| 0.032                   | 0.750   |
| Personal income      | Soil lead (<63 μm) | −0.014                  | 0.910   |
|                      | Soil lead (<180 μm)| −0.029                  | 0.800   |
| Equivalised household income | Soil lead (<63 μm) | −0.066 | 0.554 |
|                      | Soil lead (<180 μm)| −0.060                  | 0.591   |

*p-value <0.1, **p-value <0.05, p-values are in parentheses.

The soil lead concentration values were log-transformed for all regressions.

| Variable | Dependent variable | Correlation coefficient | P-value |
|----------|--------------------|-------------------------|---------|
| IRSAD    | Smelter distance   | 0.145                   | 0.141   |
|          | Mine distance      | −0.032                  | 0.751   |
| IRSD     | Smelter distance   | 0.097                   | 0.328   |
|          | Mine distance      | −0.099                  | 0.362   |
| IER      | Smelter distance   | 0.235                   | 0.017** |
|          | Mine distance      | 0.037                   | 0.713   |
| IEO      | Smelter distance   | 0.075                   | 0.451   |
|          | Mine distance      | 0.062                   | 0.536   |
| Percent year 12 | Smelter distance | −0.185 | 0.06* |
|           | Mine distance      | −0.199                  | 0.042** |
| Percent year 10 | Smelter distance | 0.079 | 0.422 |
|           | Mine distance      | 0.012                   | 0.907   |
| Percent diploma   | Smelter distance   | −0.270                  | 0.006   |
|           | Mine distance      | −0.223                  | 0.023** |
| Percent unemployed | Smelter distance | −0.122 | 0.215 |
|           | Mine distance      | 0.101                   | 0.307   |
| Percent blue collar | Smelter distance | 0.025 | 0.802 |
|           | Mine distance      | −0.104                  | 0.292   |
| Percent white collar | Smelter distance | −0.058 | 0.558 |
|           | Mine distance      | −0.122                  | 0.216   |
| Personal income   | Smelter distance   | 0.091                   | 0.409   |
|           | Mine distance      | −0.101                  | 0.360   |
| Equivalised household income | Smelter distance | 0.166 | 0.125 |
|           | Mine distance      | −0.028                  | 0.805   |

*p-value <0.1.
**p-value <0.05.
***p-value <0.01; p-values are in parentheses.
environmental hazards and where communities are located as a measure of exposure to pollution. Instead, current theories for causes of distributive studies need to account for other factors which may disproportionately increase the risk of exposure to disadvantaged communities.

It is likely that Indigenous residents in Mount Isa are not more likely to live in areas with elevated levels of lead pollution because, contrary to theories for causes of distributive injustice, concerns about the mining and smelting facilities did not significantly influence the location of Indigenous and non-Indigenous housing. Explanations for distributive injustice based on forms of disadvantage typically assume that privileged populations seek housing away from polluting sources for various reasons, including noise, health concerns and decreased property values (Mohai et al. 2009, Mohai and Saha 2015). Consequently, disadvantaged populations become disproportionately located in more heavily polluted areas as they do not have the economic, political or social resources to object to polluting sources being sited near them, or seek housing away from industrial facilities.

In the case of Mount Isa, there is evidence that Mount Isa’s establishment as a mining city caused the distribution of housing initially to be more affected by attempts to attract mine workers into the city as well as restrictions on Indigenous work. The outcome of these factors was that relatively well-maintained company housing was built next to the mines to attract permanent workers and their families, while crude and neglected housing for transitory workers in the government-surveyed township was built further away (White 2007, Eklund 2012). The Indigenous community in Mount Isa was predominately employed by the pastoral industry, and so were even more likely to be living away from the mines when they were being established. This was due to legislation passed in 1897 by the Queensland Government which heavily regulated the work and movement of Indigenous people at the time (Eklund 2012, Memmott et al. 2012). A later compounding factor was that as a large influx of Indigenous families moved to Mount Isa in the 1960s and 1970s, government policies to assimilate Indigenous residents into accepted ‘Anglo-European’ lifestyles led to these families being deliberately dispersed into housing located away from each other to break up their cultural practices and identities (Eklund 2012, Memmott et al. 2012, Habibis et al. 2013, Memmott and Nash 2016). These factors are likely to be significant as they occurred during pivotal times in the city’s development.

By contrast, concerns about mining emissions did not become prominent until the 1990s, when a number of children were found to have BLLs above Australian standards at the time (Taylor et al. 2010) and which have been heavily downplayed by governing bodies and the mines since then (Forbes and Taylor 2015). Overall, we believe that it is this combination of factors that has caused Indigenous families to not be concentrated near the mining and smelting facilities.

While there are plausible explanations for why Indigenous and low-SES residents are not more likely to live in polluted census areas, the results of multiple studies on children’s BLLs in Mount Isa suggest that Indigenous children and their families are disproportionately exposed to lead (QH 2008, 2010, Green et al 2017). The results of this study indicate that this is unlikely to be due to living in areas with disproportionately high concentrations of lead, and that other causes are responsible. The most significant causes are likely to be those that increase exposure to lead in the home environment, both inside and outside, as this is the location where the risk of exposure is highest due to the amount of time spent there, particularly for children (Lanphear et al. 2003, Taylor et al. 2011). Previous explanations for disparities in BLLs in Mount Isa have included non-mine sources of lead such as leaded paint, historical motor vehicle emissions and ‘natural’ geological sources (Taylor et al. 2010, Forbes and Taylor 2015, Kristensen and Taylor 2016). However, the magnitude and spread of historic and contemporary mining and smelting emissions in soil and air relative to these other sources means that non-mine sources are insignificant by comparison (Parry 2000, Taylor et al. 2010, Mackay et al. 2013, Kristensen and Taylor 2016, Department of Environment and Energy 2018). For this reason, lead from mining and smelting emissions are likely to be the primary source of lead in the home environment of most residents of Mount Isa and therefore the primary source of lead exposure (Taylor et al. 2010, Mackay et al. 2013). Consequently, Indigenous residents in Mount Isa are still likely to be disproportionately exposed to lead pollution from the mines, even though they do not live in areas with disproportionately elevated concentrations of lead.

The results of this study, the BLL studies and previous research on lead pollution from the mines in Mount Isa suggest that the distribution of health outcomes for lead pollution does not match the distribution of lead pollution across Mount Isa. This finding is significant because unequal proximity to pollution is typically assumed to cause unequal health outcomes between communities for most distributive justice studies—and consequently is the basis of current theories of the causes of distributive injustice. Concerns about this assumption have been raised before, as researchers have noted that disparities in health outcomes between groups may occur even when there is an equal level of exposure to environmental hazards, due to a variety of physical factors including age, gender and physical health (Walker 2009). It has also been noted that the risk of exposure to pollution may not be correctly represented by measurements of the concentration of pollution, due to additional factors increasing residents risk of exposure to pollution. Authors have noted that factors influenced by the SES of residents including housing...
quality (Rauh et al 2008) may increase residents risk of exposure to pollution as well as decrease their means of averting exposure. Distributive justice studies which have examined the distribution of health outcomes from pollution have found that health outcomes from exposure to pollution are often not equivalent to the level of pollution measured between populations (Pearce et al 2010, 2011, Grineski et al 2013, 2015, Richardson et al 2013). Unlike those studies, our study has not directly assessed the correlation between soil lead concentration and BLLs between Indigenous and non-Indigenous children. Nonetheless, due to differences in BLLs and the likelihood of living in areas with high levels of soil lead experienced between Indigenous and non-Indigenous families, it can be inferred that there are additional factors increasing the risk of exposure to Indigenous families beyond the distribution of lead pollution.

Risk factors that can affect exposure to pollution from soil and air include lifestyle factors and structural factors which are beyond the agency of residents. Attempts by governing bodies and the mines to address elevated BLLs have been aimed at changing personal behaviours that can increase exposure to lead (Forbes and Taylor 2015, Sullivan and Green 2016). These have focused on the regular washing of hands and table surfaces in homes, growing lawns and regularly eating fresh fruit to reduce uptake of lead (Sullivan and Green 2016). However, these efforts fail to account for the influence of structural factors such as SES on the risk of exposure around the home environment and the ability for individuals to reduce their risk of exposure. This criticism has been raised in Mount Isa (ABC 2017a) and has been found to be a significant issue in other Australian mining cities such as Broken Hill (Thomas et al 2012). Recent studies in Mount Isa have documented the ongoing neglect of Indigenous housing stock, including doors and windows, and the lack of regular inside and outside cleaning which are caused in significant part by the lack of economic resources of many Indigenous families, particularly those in public housing (Memmott and Nash 2016). Evidence also suggests that Indigenous residents, including those in public housing, are less able to maintain lawns due to a lack of financial resources, which can be exacerbated by water restrictions (Memmott and Nash 2016, ABC 2017a). All of these factors significantly increase the risk of exposure to lead in soil or air by influencing the likelihood that lead is deposited indoors or is more likely to come into contact with skin and be ingested by children (QH 2008, Laidlaw and Filippelli 2008, Csavina et al 2012). Furthermore, these factors also decrease the ability of residents to change behaviours to reduce their risk of exposure through measures such as growing lawns and regular washing. For these reasons, although our analysis found that Indigenous residents are not disproportionately likely to live in areas with elevated concentrations of lead in soil, it is likely that Indigenous residents in Mount Isa are disproportionately exposed to lead pollution due to their poorer quality housing and lawn facilities resulting from lower SES.

It is possible that a significant relationship between the geospatial distribution of Indigenous residents or SES and soil lead concentration may exist at the household scale, however this would be almost impossible to measure with any certainty due to the possibility of violating the confidentiality of individuals. In addition, the risk factors described here may increase the concentration of soil and air around particular households rather than simply increasing the risk of exposure. This indicates that these risk factors could be the cause of disproportionate exposure even when a relationship between population indicators and soil lead concentration is measured at the household scale. For these reasons, the disproportionate risk of exposure experienced by Indigenous families in Mount Isa would constitute a novel case of distributive environmental injustice, as it cannot be measured through a standard geospatial analysis.

The possible influence of housing quality and other risk factors relating to SES increasing Indigenous families’ exposure to lead has significant implications for actions to address elevated BLLs in Mount Isa, as well as informing and developing existing theories on the causes of distributive environmental justice. In terms of addressing disparities in BLLs in Mount Isa, our findings indicate that actions by the mines and government bodies must consider and address the increased risk of exposure caused by structural factors such as SES and give less emphasis to personal behaviours.

In regard to distributive environmental justice research, this study demonstrates the need to consider the existence of distributive injustice that cannot be mapped geospatially. Researchers have previously noted that disadvantaged subpopulations may be disproportionately affected by environmental hazards that are distributed evenly in a geospatial sense, due to increased vulnerability to health outcomes or increased risk of exposure due to a lack of ability to avert exposure. Although measures of exacerbated health outcomes from equal exposure are important, as most distributive justice research investigates the distribution of pollutants rather than health outcomes it is important for distributive justice studies to account for factors that may increase the risk of exposure. These factors are likely to be caused by the social and cultural context of a subpopulation, such as housing quality which is strongly influenced by the SES of residents. The influence of SES on housing and lawn quality in Mount Isa, which in turn affects Indigenous residents’ risk of lead exposure, demonstrates that structural factors can significantly influence the level of exposure beyond what is expected from measurements of pollution alone. This in turn may hide disparities in exposure to pollution. It is therefore important that theories and research about distributive environmental justice pay attention to sim-
ilar structural factors which can increase disadvantaged residents’ risk of exposure, potentially causing disparities in exposure which are not captured by measures of proximity to hazards.

Conclusion

Our study measured the statistical relationship between the concentration of lead in soil and the percentage of residents of Indigenous status in each census area in Mount Isa. Our analysis found insufficient evidence that Indigenous residents and residents of low-SES were disproportionately likely to live in areas with high concentrations of soil lead. Despite this, studies on BLLs strongly suggest that Indigenous residents in Mount Isa are disproportionately exposed to lead pollution from the mines. Research indicates that the relatively low SES of Mount Isa’s Indigenous population may be increasing their exposure to lead pollution due to lower quality housing facilities, similar to other mining cities in Australia. Actions by the mines and government bodies to address disparities in BLLs should give greater attention to risk factors increasing Indigenous residents risk of exposure to lead pollution. The current theoretical framework of explanations for distributive injustice would do well to consider and account for additional risk factors increasing disadvantaged communities’ risk of exposure to environmental hazards.

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