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Investigating arsenic impact of ACC treated timbers in compost production (A case study in Christchurch, New Zealand)[☆]

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ABSTRACT

The arsenic concentration is an important issue in compost production. The main inputs of a compost factory, including kerbsides, green wastes, food industry wastes, and river weeds are investigated in this study. Also, this study investigated how treated timbers, ashes, and other contamination can impact arsenic concentration in compost production. The results showed that most treated timbers and all ashes of treated and untreated timbers contained significant amounts of arsenic. These results revealed that the presence of a small amount of treated timber ashes can significantly increase the arsenic concentration in composts. The results of the study show the arsenic concentration in compost increase during cold months, and it dropped during summer, which would be mostly because of high arsenic concentration in ashes of log burners. This study shows ashes of burning timbers can impact arsenic contamination mostly because of using Copper-Chrome-Arsenic wood preservatives (CCA). Also, the lab results show the arsenic level even in ashes of untreated timber is around 96 ppm. The ashes of H3, H4, and H5 treated timbers contain approximately 133,000, 155,000, and 179,000 ppm of arsenic, which one kg of them can increase arsenic concentration around 10 ppm in 13.3, 15.5 and 17.9 tons of dry compost products. The main problem is many people look at ashes and treated timber as organic materials; however, ashes of treated and untreated timbers contained high concentrations of arsenic. Therefore, it was necessary to warn people about the dangers of putting any ashes in organic waste bins.

1. Introduction

Compost is made from the microbial bio-oxidation of raw waste to generate a biologically steady organic component from a great number of components, greens, and agri-food manufacturing wastes (Hartley et al., 2010). Green waste is an affordable low-cost method to improve and rehabilitate soil to restore lands into green places (Beesley et al., 2014). Previous studies reveal that amending polluted soils with compost might increase mobility and the leaking of trace elements, specifically, arsenic (Cao et al., 2003; Clemente et al., 2010; Mench et al., 2003).

Arsenic is a significant chemical substance existing in air, soil, water, and food. This element can occur naturally or after pollution from human activities (Fsanz, 2019, Sodhi et al., 2019). Generally, arsenic is found in a series of sources, such as nature combined with chlorine, Sulphur and oxygen, trace quantities from the breakdown of living components, geological creation, and ores containing silver, nickel, gold, cobalt, and antimony (Lederer and Fensterheim, 1983). The two forms of arsenic, organic and inorganic, can be found in food and beverages, groundwater, and soil. Organic arsenic, for example, is combined with carbon and hydrogen; while inorganic arsenic is combined with iron, sulphur, and oxygen (ATSDR, 2004; Asere et al., 2019; Upadhyay et al., 2019; Sodhi et al., 2019). The organic form of arsenic has a lower level of toxicity, whereas the inorganic form has a substantial level of hazard (Ampiah-Bonney et al., 2007; Chutia et al., 2009; Tangahu et al., 2011; Vaclavikova et al., 2008; Park et al., 2019). When arsenic is combined with hydrogen and carbon, it is categorized as being in the organic form. The inorganic form of arsenic is found naturally in many types of rocks (Epa, 1998).

Arsenic contamination has a crucial effect on human well-being

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[☆] This paper has been recommended for acceptance by Yong Sik Ok.

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(Saha et al., 1999; Upadhyay et al., 2019). It is found that arsenic triggers different types of cancers; namely, skin (Rossman et al., 2004), bladder (Steinmaus et al., 2003), lung (Hopenhayn-Rich et al., 1998) and also other severe neuro-behavioral and neuropathic effects (Tsai et al., 2003), memory and intellectual function (Wasserman et al., 2004), reproductive effects (Chakraborti et al., 2003), steatosis (fatty liver) (Chen et al., 2004; Li et al., 2019), the hormonal system, diabetes mellitus type 2 (Bodwell et al., 2004) as well as serious diseases, such as cardiovascular disease (Lee et al., 2002), ischemic heart diseases (Tseng et al., 2003), carotid atherosclerosis (Wang et al., 2002), and respiratory system diseases (Milton et al., 2003; Milton and Rahman, 2002, Jovanovic and Rasic-Milutinovic, 2017).

The primary source of commercial arsenic is a by-product obtained from the treatment of gold ore, copper, and lead. Commercial use of arsenic is found from various sources, such as wood preservatives, pesticides, animal feed additives, nonferrous alloys, electronics, printing, ceramics, dyeing, glassmaking, desiccants, glass, and botanical and medicinal products (Epa, 1998).

High arsenic concentrations in water and soil have been of significant concern in New Zealand, where anthropogenic and natural sources are responsible. These include: arsenic-based pesticides, volcanic rocks, and CCA treated timber (Robinson et al., 2004). Arsenic can also be released from volcanic rocks to groundwater from two primary processes, the decay of organic sediment layers and geothermal heating (Robinson et al., 2006). Arsenic is found in various sources that might hurt human lives and the environment.

Arsenic contamination is one of the important concerns on compost production. Therefore, the inputs of a compost factory and the main possible sources of arsenic in New Zealand were investigated separately. Some studies show there is high arsenic concentration in treated timbers especially if they are treated by Copper-Chrome-Arsenic (CCA) (Paltseva et al., 2018; Babaee et al., 2018; Jones et al., 2019; Scott-Richardson et al., 2019), therefore the central question of this study is how arsenic concentration in treated timbers and wood ashes can influence total arsenic concentration compost product.

In New Zealand, residential contractors have declined to take working with treated timber into consideration. Construction workers when building houses use more than one grade of CCA treated timber. Dust produced from silk saw spreads around the workers and the residential neighborhood posing a potential health hazard. Unlike building safety, there is a lack of information about working with CCA treated timber and its harmful effects. Safety equipment, such as gloves and masks, is also not used by construction workers to avoid potential hazard impacts of CCA treated timber. Plywood, which is made in New Zealand, contains CCA as well. In New Zealand houses, plywood is widely used for reconstructing and repairing purposes (Mcdonald, 2013).

Groundwater from coastal, marshy sediment has low concentrations of oxygen because of oxygen consumption by bacteria. This results in the release of arsenic and other substances, such as iron and manganese, into groundwater (Abraham and Hanson, 2009; Dodson et al., 2012; Dolamore, 2016). Also, the use of CCA treated timber has a significant role in elevating arsenic concentrations and resulting in groundwater pollution (Robinson et al., 2004; South et al., 2007). Copper, Chromium, and Arsenic (CCA).

Copper-Chrome-Arsenic wood preservatives are a combination of several substances; arsenic oxides or salts, copper, and chromium. They are mainly used in the vacuum-pressure treatment of timber, which is sold to the general public and commercial consumers. The primary role of CCA is to protect the wood from pests, including wood-boring insects, marine borers, or decay fungi that pose a threat to wood products (Read, 2003; Paltseva et al., 2018). In 1933, the preservation of wood by CCA treatment was created and became the most extensively used waterborne preservative worldwide by the 1960s. Before the 1980s, the production of CCA treated wood was a worldwide industry; however, residential use of CCA treated wood became extensive (Read, 2003). There are a significant number of CCA formulations practiced globally. Various formulations of CCA have been established based on the relative significance attached to their monitoring of fungi or insects. In New Zealand, variations in the relative percentage of active components have been made to increase resistance to leaching and increase efficiency (Orozco, 2010).

Since 1955, in New Zealand, CCA has been used extensively as a common method for preserving wood (Branz, 2013). In New Zealand, the three main components of CCA are in different forms; for instance, copper is in the form of copper oxide, and chromium is in the soluble hexavalent form as chromic acid, and arsenic, which is used for timber treatment, is in its soluble pentavalent form (Mfe, 1997). Among 13 registered CCA formulations in New Zealand, three of them are used most (Read, 2003).

CCA treated timber is known as potentially being hazardous globally, and it is not allowed to be used in regions, such as Germany, Ireland, the United Kingdom, France, Italy, the United States, and Spain (Love, 2007). Hazard is categorized into six categories (H1–H6) in which timber falls under the risk of biodegradation. In New Zealand, CCA preservatives are permitted to be practiced in some hazard classes. Timber is mostly used for residential purposes, such as decks, playground equipment, and garden furniture are included in the hazard categories from their exposure to weather, above and in the ground, or freshwater. The arsenic portion in treated timber for the above-mentioned purpose is 0.11–0.22%. The CCA treatment process consists of several phases. The first phase is to put untreated wood into a cylindrical treatment vessel and a vacuum to eliminate air existing in the dry wood. In the next stage, CCA treatment is loaded completely with a CCA solution, and pressure is used to force the preservative into the cells of the wood. To obtain the required preservative treatment, 45–60 min of pressure is required. Following this, more vacuum is used to extract the extra solution and reduce post-treatment drips. A steam process is applied at the end of the treatment process to raise the concentration of fixation in large treatment plants. In the last stage, the wood is detached and kept for one to two weeks before being discharged to the market (Read, 2003).

Two countries, Australia and New Zealand are the greatest consumers of CCA treated wood in the world (Read, 2003). The primary treated wood in New Zealand is *Pinus radiata* (Connell et al., 1995). Regardless of the type of wood preservative used, it is compulsory in New Zeeland to register the hazard classification as well as several treatment plants. Packet planning is permitted for insignificant sizes of timber, such as fence palings (Häggman et al., 2013). In New Zealand, there is no restriction in the regulations for the use of CCA treated wood by specific consumers. The general restrictions on the use of treated timber also state that it should not be practiced for various purposes; namely, domestic fires, barbecues, toys, smoking fish or meat, and food containers. In addition, sawdust from treated timber is not permitted to be applied under playground equipment (Read, 2003). Generally, CCA treated wood is used in outdoor locations. Various uses of CCA treated wood are listed below.

- Domestic usage of CCA treated wood includes:

Garden furniture, picnic tables, play area equipment, decks, fences, gazebos, patios, and landscape timbers.

- Common usage of CCA treated wood includes:

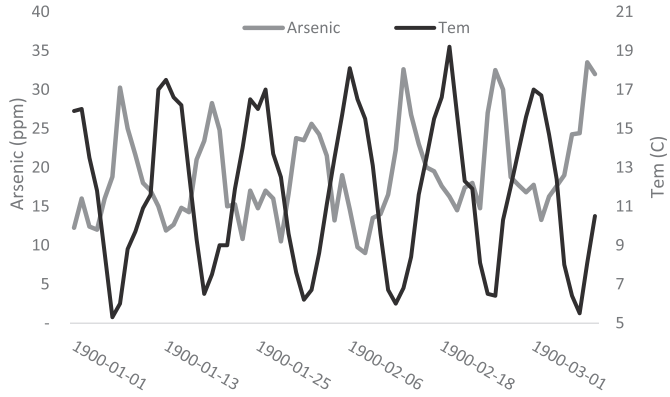

Fig. 1. Arsenic Concentration and monthly temperature ©

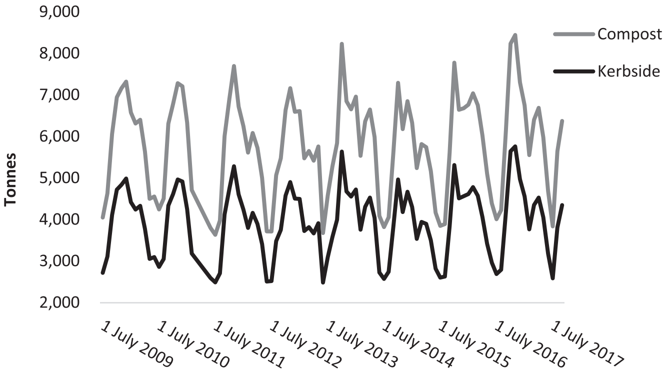

Fig. 2. Kerbside input and Compost production.

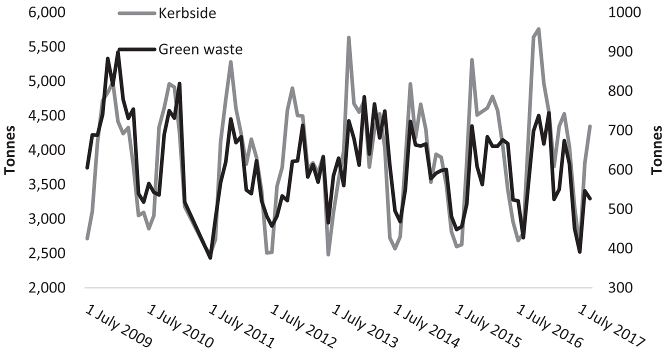

Fig. 3. Kerbside and green waste inputs.

Horticultural and agricultural posts, signboards, ports, and utility poles

2. Research method

The first observation shows arsenic concentration is increased in winters and it dropped in summer (Fig. 1). To find the main sources of arsenic contamination in compost, the factory inputs are investigated carefully.

2.1. *Main inputs in compost production in New Zealand*

The main inputs in compost production can be categorized into four categories: kerbsides, green wastes, food wastes, and river wastes, which are explained below.

2.1.1. *Kerbsides*

Organic wastes in Christchurch are collected weekly. These mostly comprise the contents of kitchen and garden waste. In addition, it contains soil, clothes, and papers. All the materials mentioned here have arsenic contents of less than the maximum standard concentration in NZS4544.[1] As shown in Fig. 2, the volume of kerbside waste reduces in winter and reaches a maximum in the first warm month of the year (mostly September and October) when plants start to grow, and people start mowing and weeding again. Kerbside inputs are around 80%–90% of total inputs in LE.

2.1.2. *Green wastes*

Green wastes are defined as the green wastes of the council and its contractors' activities and garden waste, which people bring directly to the compost factory. Also, some forestry and construction companies send their wastes to LE. For several reasons, it is too difficult to analyze them, but the arsenic concentration is estimated at being around 10–14 ppm. Similar to kerbside wastes (Fig. 3), Green wastes peaks in summer when different industries and residents are producing maximum amounts of organic wastes. Temperature and construction activities by Christchurch City Council (CCC) and its contractors would be the main factors for the changes in the volume of green wastes.

2.1.3. *Food wastes*

Arsenic may be present in many foods, including grains, fruits, and vegetables, where it is present due to absorption through soil and water. While most crops do not readily take up much arsenic from the ground, rice is different, because it takes up arsenic from soil and water more readily than other grains. In addition, some seafood has high levels of less toxic organic arsenic. No limit exists for arsenic in most foods, but the standard for drinking water is ten parts per billion (ppb). Food waste consumption in Compost companies in Christchurch has continuously increased over the last five years. However, the volume of food waste inputs is still much lower than kerbsides and green wastes; however, it reached 23% of total inputs in August 2016 (Fig. 4). Most food wastes come from factories and restaurants; therefore, it is too difficult to design an appropriate sampling method; however, it is not expected to find high concentrations of arsenic in food wastes.

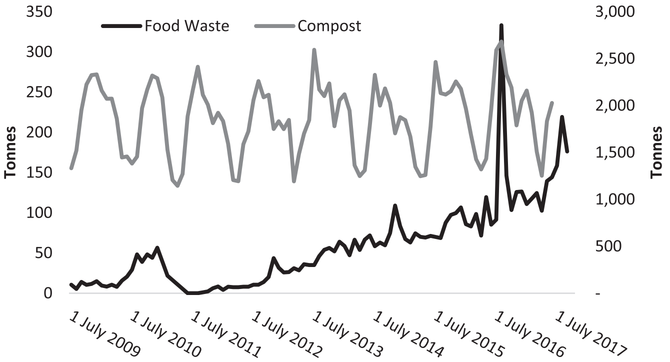

Fig. 4. Food Waste input and compost production.

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[1] NZS4454: 2005, (The New Zealand standard for Composts, Soil Conditioners and Mulches) applies to organic products and mixtures of organic products that are to be used to amend the physical, biological and chemical properties of natural or artificial soils and growing media.

2.1.4. *River weeds*

Some studies show that river weeds can absorb arsenic from contaminated waters. The amount of river weed depends on the activities of CCC contractors. River weed inputs fluctuate from 5% of total inputs in summer to zero in winter. The arsenic contents of river weeds were investigated to find its effects on arsenic concentrations in the final compost products. As expected, the volume of river weeds increases in summer, but Fig. 5 shows it is too difficult to find any link between river weed inputs and compost production. The river weeds were collected from different sites and they contained several different plants, so it was recommended to monitor them frequently.

2.2. *Sampling and Lab Analysis*

The high concentration of arsenic of compost in winters would be because of the constant arsenic inputs, which were diluted in summer or because of specific contaminated inputs in winter or both. The first tests show arsenic in food wastes and river weeds are not very high. Also, due to high volume of kerbsides and green wastes, it was decided to focus on their components. We found some people are burning treated timber in winter and put ashes in organic waste bins, however, due to the high arsenic concentration in summer it was expected to find another source (or sources) of arsenic. Therefore, various contamination factors were investigated carefully to find input materials that contained arsenic-containing.

In the first step, 3–7 samples of each timber hazard categories and untreated timber were collected to estimate the arsenic concentration in the timbers and ashes from the different timber hazard categories. The timber samples were collected randomly from the main timber suppliers. A few H2 and H3 timber samples were also collected directly from under construction building sites. The possible arsenic contamination in river weeds and water consumed in compost production process also investigated using three river weed samples and 6 water samples were collected from the compost factory. Due to high arsenic concentration in some samples it was decided to test all results again but we couldn't find significant differences.

Samples of timbers and ashes were investigated to find the concentrations of arsenic or other heavy metals using the digest technique. The CEM MARS Xpress has an operator selectable output of 0–1600 W ± 15% (by IEC (International Electrical Conference) method). Microwave energy was used to heat samples in a closed vessel microwave system. A sample was placed inside a Teflon PFA® and Kevlar-shielded vessel, usually with concentrated nitric acid. Once in the MARS Xpress, the samples were subjected to rapid heating and elevated pressure, causing the sample to digest or dissolve in a short time. The concentration of a specific element in a sample was related to the intensity of lines in its optical spectrum. The sample, in an aerosol form, was introduced into a high energy plasma that dissociated the sample into atoms and ions which emitted electromagnetic radiation. The emitted light was spectrally resolved by diffractive optics, and the intensity of light measured with a detector.

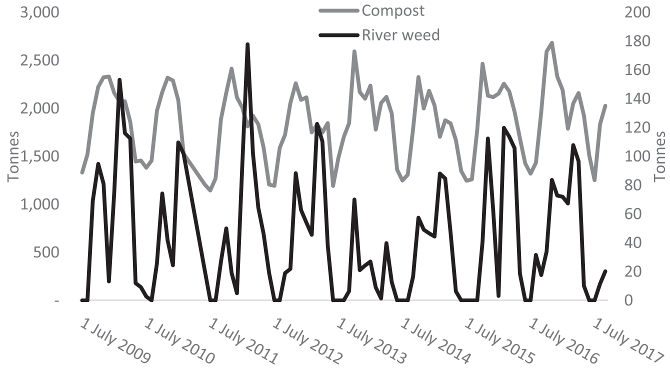

Fig. 5. River weed inputs and compost production.

3. Results

In the results of this study show, H3, H4, H5 timbers have the highest arsenic, and other heavy metal contents, which were very low in H1 timbers and untreated timbers (Table 1). The arsenic concentration in H5 ranged from 1% (10,313 ppm) to 1.2% (11,868 ppm) of total weight. This meant, 1 kg of H5 timber was enough to increase the arsenic rate of 844 kg dry compost around 10 ppm (Table 2). The arsenic concentrations in H3 and H4 samples were between 1100 ppm and 2700 ppm in different samples. This meant that one kg of H3 and H4 timber on average was enough to contaminate 396 kg and 210 kg of dry compost respectively around 10 ppm.

The first column of Table 2 presents, the volume of compost contaminated around 10 ppm by one kg of the treated timber or ashes. For example one kg piece of H3 timber can increase arsenic concentration of 141 kg around 10 ppm. The second column of Table 2 shows how much of treated timbers or shows will raise the arsenic content of compost by around 10 ppm/month in winter 2017 (June, July, and August), at around 1531 tonnes/month. This shows, again, that ashes from treated timbers are high-risk inputs; however, all the inputs mentioned here can affect the arsenic rate under different conditions. Another study is necessary, however, to investigate the volume of each of these inputs in kerbside wastes.

The main concern was high arsenic concentrations in the ashes, which reached almost 20% of one of the H5 timber sample's weight. However, the chance to access H3 and H4 timber wastes was much higher than in H5. After minor construction activities, many people have a few pieces of treated timber left over. The observations in this study showed some people save this waste of treated timbers that were used in summer for burning in winter. The ash samples of H3 and H4 timbers have high arsenic concentrations of between 10% (100,000 ppm) to 16% (155,921 ppm) and 15% (149,868 ppm) to 16% (164,897 ppm) of total weight, respectively. The high arsenic concentration in the ashes meant that one kg of H3 ash could contaminate seven tonnes of dry compost (if there was no arsenic in other inputs). If average arsenic concentration from other inputs was around 10 ppm, 30 kg/week of H3 timber ash was enough to contaminate total compost at around 20 ppm. It seemed burning treated timber and to put ashes in landfill bins are different topics. It was important to encourage people not to burn any treated timber, but it is more important to encourage them to not put any ash (treated and untreated) in the organic waste bins.

A very brief observation showed that log burners make at least

Table 1
Average arsenic, copper and chromium contents in samples (ppm).

Sample name	Number of Samples	As (ppm)
Untreated	4	2
H1.2	3	2
H3 & H3.2	7	1410
H4	7	2098
H5	3	8435
Untreated Timber Ash	4	96
Ash H1.2	3	160
Ash H3 & H3.2	7	133,175
Ash H4	7	155,456
Ash H5	3	179,496

Table 2
Effect of treated timbers and ashes on compost arsenic concentration (10 ppm).

Sample Name	Volume of compost (kg) contaminated 10 ppm by one kg of sample	Volume of sample (kg) to contaminating average monthly winter 2017 compost production
H3	141	10,707
H4	210	7298
H5	844	1816
Untreated timber Ash	10	158,888
Ash H1.2	16	95,615
Ash H3	13,317	115
Ash H4	15,546	99
Ash H5	17,950	85

1–2 kg of ash weekly in winter. Therefore, around 10–20 residences could be enough to contaminate the whole winter's compost products in Christchurch, if they only burnt treated timbers. Or if 1000 residents put only 0.03 kg of H3 ash into organic waste bins weekly, this was enough to increase arsenic contamination to around 20 ppm in July 2017.

On the other hand, untreated woods were the main sources of fuel in log burners and open chimneys. The results showed that the arsenic concentration, even in H1.2 and untreated timbers ash, was much higher than the limited standard concentration. A brief investigation showed almost all people thought the ashes of untreated timbers were safe and they can put them into organic waste bins; however, the arsenic concentration in ashes of untreated timbers was between 32 ppm and 200 ppm. It means a high volume of untreated timber ashes can change the arsenic concentration in compost significantly. For example, based on Table 2 and average compost production in winter 2017, ashes of 10,000 houses are enough to increase arsenic concentration around 6.3 ppm.

Table 3 shows that the average arsenic contents in untreated timber are around 2 ppm; this means adding 0.55 tonnes of untreated timber to compost can drop the arsenic content in one tonne of compost from 30 ppm to 20 ppm. Blending compost products with high arsenic (or other heavy metal) concentration with other materials with lower arsenic contents could be part of the solution to reduce arsenic contamination of compost products in winter; however, this would need a high volume of inputs.

Table 3 shows how much of different materials are need to drop 10 ppm arsenic concentration of one tonne of compost. It shows that to reduce the arsenic contained in one tonne of compost, one tonne of material with an arsenic concentration of around 10 ppm would need to be added. The basic equation to estimate the volume of input (tonnes) material to reduce the arsenic contents of one tonne of compost can be presented as:

$$(a_i - 20) / (20 - a_c) = V \qquad (1)$$

Where a_i was the arsenic contents of the inputs, a_c the arsenic-containing compost, and V the volume of inputs.

4. Conclusions

Arsenic contamination is one of the critical concerns of compost production. This study investigated the primary source of arsenic in compost products. Because of different inputs and different production processes, it too challenging to find similar research projects and discuss the results of this study. It found arsenic concentration in compost increase during cold months. Therefore after a few sampling, observation and interviews, it was found arsenic of treated timber and ashes would be one of the important sources of arsenic, especially during winter. However, the study show different type of treated timbers and their ashes affect arsenic contamination in different rates. These results revealed that the presence of a small number of treated timber ashes could significantly increase the arsenic concentration in composts. One of the solutions to drop the arsenic concentration is blending other materials with lower arsenic concentration. However, reducing the volume of ash and treated timbers in the kerbsides would be a more straightforward challenge.

The sampling, observations, and interviews show many people are aware of the danger of burning treated timbers and they know it is not acceptable to put the ashes of treated timbers in organic waste bins. However, for several reasons, some people are still burning treated timbers and, unfortunately, some of them put the ashes in organic waste bins. It appears saving money is not the only reason for burning treated timbers; lack of untreated wood and removing timber wastes are two main important reasons for burning treated woods in houses. It seems part of the problem is a socio-cultural issue and more investigation is necessary to analyze

Table 3
Effect of blended inputs to drop arsenic concentration of compost product.

Sample Name	Arsenic contain (ppm)	Volume (tonne) to drop one-tonne compost arsenic contain from 30 ppm to 20 ppm	Volume (tonne) to drop average monthly winter 2017 compost production from 30 ppm to 20 ppm
Untreated	2.0	0.56	851
H1.2	2.0	0.56	851
Riverweed	12	1.27	1940
Material 3	3	0.59	901
Material 4	4	0.63	957
Material 5	5	0.67	1021
Material 6	6	0.71	1094
Material 7	7	0.77	1178
Material 8	8	0.83	1276
Material 9	9	0.91	1392
Material 10	10	1.00	1531

and solve the problem. Nevertheless, it was found still many people look at treated timbers and the ashes as organic and safe materials.

Most organic waste materials have arsenic and other heavy metals in them, but all lower than the limited concentration mentioned in NZS4454. Understanding the primary sources of arsenic and other heavy metals was the first step in developing a practical plan to reduce them in compost products. Based on the laboratory results and field observations, the most critical contamination was from treated timbers and ashes. Ashes of treated and untreated timbers contained high concentrations of arsenic. Therefore, it was necessary to warn people about the dangers of putting any ashes in organic waste bins. Small amounts of ashes from treated woods can raise arsenic contamination significantly in winter when all inputs were at minimum volumes. It was challenging to find how much-treated timbers were in different inputs. It was possible some people put their timber wastes in organic waste bins, or some treated timbers came in with the wastes from council contractors. Improving awareness of people on arsenic and other heavy metal contamination is long term and removing high-risk inputs from the production process in the short term is the best solution to reduce arsenic and other heavy metal concentration in composts.

It is recommended to develop a linier or none liner models to predict arsenic concentration based on temperature. Also, it is recommended to investigate the arsenic concentration in different areas, which will help compost factory to process wastes with high arsenic concentration separately.

Declaration of competing interest

There is no conflict of interest in this study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2020.114218.

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