Assessment of the potential environmental and ecological risks associated with traffic induced heavy metal contamination in country parks of Hong Kong

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Abstract. Hong Kong is a densely populated area with a limited area, so most country parks are adjacent to busy traffic roads and town activities. The soil in country parks may be contaminated by heavy metals emitted by traffic activities. During the holidays, most people go to country parks to play. It is very important to assess the potential risks of residents, especially children. So far, data on pollution in Hong Kong’s country parks is very limited. The heavy metals arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), silver (Ag) and zinc (Zn) were collected in the Kam Shan (KS), Plover Cove (PC), Sai Kung West (SK) and Lion Rock (LR) country parks. The mean Zn concentration in KS Country Park was more than three times higher than the background concentration in Dutch soil standard, while Cu and Pb were more than 1.6 times higher. The average pollution index (PI\textsubscript{env}) of KS Country Parks was classified as high, and the potential ecological risk index (RI) was classified as moderate. Country parks should pay special attention to heavy metal pollution in order to continue further research and remedial measures. **Keywords:** Country Park Soils, Heavy Metals, Ecological Risk, Risk Index

1. Introduction

In Hong Kong, leisure space is scarce, especially in densely populated areas such as the north shore of the Hong Kong Island and Kowloon. There are 24 designated country parks in Hong Kong, covering an area of 43,467 ha [1]. Country parks play an important role in nature protection, recreation, and outdoor education. Every weekend and holiday, thousands of residents and tourists flock to the country parks for recreational activities such as camping and hiking.

The areas of the parks are approved by the Chief Executive of Hong Kong and managed by the Director of Agriculture, Fisheries and Conservation, who is also appointed as the Country and Marine Parks Authority, under Cap. 208 Country Parks Ordinance. New developments are kept out of the parks unless approved by the authority to protect the parks from damages. In recent years, more lands are being developed and more roads are being built closer to the edges of the country parks to accommodate for the rising demand of residential units and the ever-expanding road network. Furthermore, more people get to the country parks on privately owned vehicles, which can be evidenced by the serious illegal parking issues near the barbeque hot spots in the parks on weekends, despite more public transport routes, including buses and minibuses, are licensed to provide easy access to the country parks. Some popular barbeque or camping sites are now within few meters from the roadside with hundreds of
vehicles passing by every hour. Previous studies have confirmed that traffic activity is one of the sources of heavy metal pollution in roadside soils [2-4].

Although the accumulation of heavy metals in agricultural soils indirectly leads to human health problems mainly through the food chain, soil pollution in country park may pose a significant health risk, especially for children, due to oral ingestion, inhalation of particles and direct skin contact [5]. There are rising concerns that some parts of the country parks may be contaminated by traffic induced heavy metal emissions. Majority of the studies on the heavy metal pollution impacts of country park (or forest) soils in Hong Kong were conducted before 2000. The number of licensed motor vehicles in Hong Kong has reached 878,539 units at the end of 2019, which is 70% up from the figure of 2000 [6]. Therefore, it is important to assess the current status of soil pollution by heavy metals in the parks and quantify the level of risk at which the park users are exposed to harmful metals. In addition, past researches on heavy metal pollution in Hong Kong mainly considered Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn). Very few researchers have extended their investigations to cover Mercury (Hg) and Silver (Ag), which can cause serious health risks even at low concentrations [7-8]. This study will also evaluate the risks associated with Hg and Ag.

2. Materials and methods

2.1. Study area

Four country parks in Hong Kong, namely Plover Cove Country Park (PC), Sai Kung West Country Park (SK), Lion Rock Country Park (LR), and Kam Shan Country Park (KS), were selected for this study due to their popularities among visitors and the potential health impacts of soil pollution on the visitors. To evaluate the environmental and health risks posed by metal emissions from road traffic related sources, nine sampling sites scattered across the parks, featuring barbeque areas, camping sites, and assembly points of hiking trails within ten meters of the verge of public access roads, were chosen. Figure 1 shows the locations of the sampling sites in relation to the nearest road sections. The three sampling sites in Plover Cove Country Park were located along Bride’s Pool Road, which had an annual average daily traffic (AADT) of 1,060 in 2019 [9]. For Sai Kung West Country Park, three sampling sites covering Sai Sha Road and Tai Mong Tsai Road, which are the two major roads that provide access to the park, were identified. The AADT of the two roads in 2019 were 11,800 and 2,930, respectively [9]. A section of Tai Po Road cuts though the range of hills that separates New Kowloon from the rest of the New Territories and divides the hills into Kam Shan Country Park (on the east side) and Lion Rock Country Park (on the west side). Some park facilities and hiking trails are in close vicinity to Tai Po Road, where the traffic volume was recorded to be 35,950 AADT in 2019 [9]. The two sampling sites in Lion Rock Country Park and the site in Kam Shan Country Park were located at the tips of the parks where Tai Po Road is only a few meters away.

2.2. Soil sample collection and analysis

During the wet and dry seasons from 2019 and 2021, a total of 48 topsoil samples were collected from four country parks. Based on the monthly total rainfall data extracted from the Hong Kong Observatory Climatological Database, the wet season in Hong Kong stretches from June to August and the dry season covers November to January (Hong Kong Observatory). At each location, a stainless-steel soil sample probe was used to collect soil samples from the top soil in 0–10 cm. The samples were sent to a HOKLAS accredited laboratory, where As, Ag, Cd, Cr, Cu, Hg, Ni, Pb, and Zn in the sample were analysed by inductively coupled plasma mass spectrometry (ICP-MS) and/or inductively coupled plasma atomic emission (ICP-AES) according to the laboratory’s in-house methods. The in-house method refers to ASTM D3976-92 [10] and USEPA 6010B [11]. The standard solution is a high-purity standard product (a mixed standard of the elements of As, Ag, Cd, Cr, Cu, Ni and Pb, with concentration of 100 ppm each). The dry weight reporting limit for As is 0.01 mg/kg; Cd, Cr, Cu, Pb, Hg, Ni, Ag are 0.05 mg/kg, and Zn is 0.2 mg/kg.
2.3. Traffic survey
During the monitoring period, traffic surveys were conducted between 7:30 AM and 7:30 PM at each sampling point on random weekdays and random weekends to quantify the number of light vehicles (e.g., passenger cars, taxis, motorcycles, light-duty vans, and minibuses) and heavy vehicles (e.g., lorries, coaches, buses, cement mixers, and tankers). The information was useful for explaining the different composition of trace elements in soil samples from different locations.

3. Pollution and ecological risk assessment
Different indices have been developed over the years for systematic assessment of heavy metal contamination and the associated risks. Caiero et al. [12] reviewed the popular indices and suggested that they can be divided into three categories, namely contamination indices, background enrichment indices, and ecological risk indices, based on their service purpose [12]. These indices can be further divided into single indice and total complexity indice, including composite indices and ecological risk indice [13]. A single indice can be used to show the influence of a single factor, while a composite indice (which may be composed of a corresponding single indice), aims to show the collective influence of multiple factors [14]. The indices used in the present study were selected based on the availability of input data and their applications in evaluation of the impacts of individual metals and the overall site quality.

The geo-accumulation index ($I_{geo}$) can be used to evaluate the accumulation level of various heavy metals in soil based on the metal concentration in the topsoil sample and the metal’s geochemical background. The $I_{geo}$ value of a specific metal at a specific location can be calculated according to Equation (1), where $C_i$ is the concentration of the metal in the field sample (mg kg$^{-1}$) and $B_i$ is the background value of the metal (mg kg$^{-1}$). The coefficient of 1.5 is to illustrate the possible changes in the background value due to changes in lithology. $I_{geo}$ includes 7 classes: Class 0 - unpolluted ($I_{geo} \leq 0$); Class 1 - unpolluted to moderately polluted ($0 < I_{geo} \leq 1$); Class 2 - moderately polluted ($1 < I_{geo} \leq 2$); Class 3 - moderately to strongly polluted ($2 < I_{geo} \leq 3$); Class 4 - strongly polluted ($3 < I_{geo} \leq 4$); Class 5 - strongly to extremely polluted ($4 < I_{geo} \leq 5$); and Class 6 - extremely polluted ($I_{geo} > 5$).
\[ I_{geo} = \log_2 \left( \frac{C_i}{1.5 B_i} \right) \] (1)

The pollution load index (PLI) calculated from the available contamination factors (CF) is used to assess the soil quality of a site caused by the presence of different heavy metals. It can be calculated by Equation (2), where \( C_i \) is the contamination factor of an individual metal \( i \), and \( n \) is the number of metals considered \((n = 9 \text{ in this study})\). Hakanson [15] defined the CF of a single substance as the ratio of the mean content of the substance to the preindustrial reference level of that substance. In more recent studies, CF is derived from dividing the mean concentration of a metal by the background reference value of the metal [16-18]. The latter approach was adopted in this study as the preindustrial reference level for Hong Kong is not available. The overall quality of a site can be classified based on the PLI value as followed: \( \text{PLI} < 1 \), perfection; \( \text{PLI} = 1 \), only baseline levels of pollutants present; and \( \text{PLI} > 1 \), deterioration of site quality [19].

\[ \text{PLI} = \sqrt[n]{\text{CF}_1 \times \text{CF}_2 \times \text{CF}_3 \times \ldots \times \text{CF}_n} \] (2)

The pollution index (PI) is used to quantify the pollution impact of each heavy metal in each park. As shown in Equation (3), it can be defined as the ratio of the content of a metal in the inspected environment \((C_i)\) to the corresponding background value \((B_i)\). Hu et al. [20] used the geometric mean concentration of heavy metals in the control area as the background concentration. The PI values are divided into three classes: \( \text{PI} \leq 1 \), low level of pollution impact; \( 1 < \text{PI} \leq 3 \), moderate pollution impact; and \( \text{PI} > 3 \), high level of pollution impact [21].

\[ \text{PI}_i = \frac{C_i}{B_i} \] (3)

The average value of the pollution index (\( \text{PI}_{ave} \)) (or integrated pollution index, IPI) is used to assess the level of soil pollution of each study area due to the presence of all the heavy metals of concern [21]. It is defined as the average value of the PI of all the investigated metals described in Equation (4) \((n = 9 \text{ in this study})\). According to the calculated IPI value, the pollution level of the site can be classified as low \((\text{PI}_{ave} \leq 1.0)\), moderate \((1.0 < \text{PI}_{ave} \leq 2.0)\), high \((2.0 < \text{PI}_{ave} \leq 5.0)\), or extremely high \((\text{PI}_{ave} > 5)\).

\[ \text{PI}_{ave} = \frac{1}{n} \sum_{i=1}^{n} \text{PI}_i \] (4)

The Nemerow (integrated) pollution index \((\text{PI}_{\text{Nemerow}} \text{ or NIP})\) is used by several research groups to assess the quality of soil in the environment [22-23]. The index formula shown in Equation (5) includes the term \( \text{PI}_{\text{max}} \), which is the maximum value of the single pollution index of all metals considered [24]. The purpose of the term is to demonstrate the impact of the most polluting elements on the overall environmental quality. A site can be classified as one of the five domains of the index: the safety domain \((\text{PI}_{\text{Nemerow}} < 0.7)\); the precaution domain \((0.7 \leq \text{PI}_{\text{Nemerow}} < 1)\); the slightly polluted domain \((1 \leq \text{PI}_{\text{Nemerow}} < 2)\); the moderately polluted domain \((2 \leq \text{PI}_{\text{Nemerow}} < 3)\); and the seriously polluted domain \((3 < \text{PI}_{\text{Nemerow}})\) as proposed by [23].
The single potential ecological risk factors \((E_i)\) and potential ecological risk index \((RI)\) or \((PERI)\) are based on the \(E_i\) of all measured elements, and are widely used to jointly consider synergy, toxicity level, heavy metal concentration and ecological sensitivity to heavy metals [25]. \(E_i\) and \(RI\) can be calculated by Equation (6) and Equation (7), respectively, where \(T_r^i\) is the toxic response factor of substance \(i\); and \(n\) is the total number of metals measured \((n = 9\) in this study). The \(T_r\) of some metals is determined by [15]: \(As = 10\), \(Cd = 30\), \(Cr = 2\), \(Cu = Pb = 5\), and \(Zn = 1\).

The terms used to explain risk factors proposed by Hakanson [15] are: low potential ecological risk \((E_i < 40)\), moderate ecological risk \((40 \leq E_i < 80)\), considerable ecological risk \((80 \leq E_i < 160)\), high eco-logical risk \((160 \leq E_i < 320)\), and very high ecological risk \((320 \leq E_i)\). When the \(T_r\) proposed by Hakanson [15] is used to determine the \(E_i\) of a single metal, \(RI\) uses the following classification: low ecological risk \((RI < 150)\); moderate ecological risk \((150 \leq RI < 300)\); considerable ecological risk \((300 \leq RI < 600)\); and very high ecological risk \((600 < RI)\).

\[
E_r^i = CF_i \times T_r^i
\]  

\[
RI = \sum_{i=1}^{n} E_r^i
\]

### 4. Results and discussions

#### 4.1. Reference level

Regarding the different comments on the commonly used pollution indices to assess heavy metal pollution, it is agreed that the choice of reference level and fluctuations within the reference level are critical to the accuracy of most indices [12, 26-27]. In different journal papers, the terms “natural geological background”, “background level (or value)”, “geochemical baseline”, and “baseline value” were used to refer to the reference level for calculation of pollutant indices. It is, therefore, essential to distinguish the differences between some of the terms.

The background value provides an estimation of the natural concentrations of trace elements. It is often used to differentiate between anthropogenic and naturally occurring trace element enrichment [28]. The mineralogical composition of the parent materials, weathering intensity, diagenesis processes, organic carbon and clay contents are some of the factors that affect the natural concentration of trace elements in the soil [29]. The background concentration of each element changes in space, reflecting the changes in the earth’s surface materials and the diagenesis processes. In contrast, the geochemical baselines is essential for assessing the current status of the environment, because humans have already had certain impact on the environment [30] and it should be used to define legal limits. Based on the comparison between the metal content in the field samples and the background level in the study area, many pollution indices have been derived [27]. Several methods including statistical methods (indirect, theoretical), empirical methods (direct, geochemical), and integrated methods (combination of statistical and empirical methods) have been proposed for establishing the geochemical background [26].

In order to determine the reference level of heavy metals in this study, eight background soil samples were collected from two locations in Tsing Yi and Sai Kung that range from 200 to 500m from anthropogenic pollution sources. Table 1 tabulates the mean metal contents of the samples and compares them to the trace metal concentrations in natural bedrocks found in Hong Kong [31] and the predicted geochemical baseline of Hong Kong soil proposed by Zhang et al. [32] derived from the statistical method. It can be seen that the mean concentrations of Cr, Ni, and Zn in the background samples
collected in this study are close to the mean values reported by Lee et al. [31] and Zhang et al. [32]. The concentrations of Cu and Cd of the background samples are within the range of the data sets used by Zhang et al. [32] but are nearly 2 and over 3 times of those found in bedrocks in Hong Kong, respectively. These suggest serious man-made accumulations of Cd and Cu in Hong Kong. The levels of Pb and Hg found in the background samples are also alarming as they are 1.7 and 2.5 times above the predicted concentrations, suggesting noticeable anthropogenic enrichment of these metals in the last fourteen years. The As concentration of the background soil is on the high side of the historical data range and the mean As level in Sai Kung (n = 3) is three times that of Tsing Yi (n = 5). This could be due to the difference between the bedrock materials of the two sampling sites. From the geological map of Hong Kong, the site in Sai Kung features volcanic rocks, mainly ash tuff, while the site in Tsing Yi features intrusive rocks, mainly granite [33]. Tabelin et al. [34] mentioned that volcanic rocks typically contain more As compared to other igneous rocks, which could be the reason for the higher As concentrations in the samples collected from Sai Kung.

Table 1. Comparison of the concentrations (mg/kg) of trace elements in the background samples to published data.

| Source                  | Type of sample | As  | Cd  | Cr  | Cu  | Pb   | Hg   | Ni  | Ag  | Zn |
|-------------------------|----------------|-----|-----|-----|-----|------|------|-----|-----|----|
| Present study           | Soil sample (n = 8) | Mean | 8.7 | 0.1 | 15.7 | 5.1  | 46.1 | 0.1 | 4.7 | 0.1 | 63.3 |
|                         |                | SD  | 7.59| 0.02 | 10.82| 4.00 | 20.70| 0.02| 3.45| 0.01 | 42.02 |
| Lee et al. (2006)       | Rock sample    | Mean | -  | <0.03 | 13.00| 2.04 | 7.41 | -   | 5.82| -  | 27.30 |
|                         | (Granite, n = 3) | SD  | -  | -   | 2.80 | 2.64 | 3.94 | -   | 6.14| -  | 9.34  |
|                         | Rock sample    | Mean | -  | <0.03 | 32.80| 2.87 | 15.40| -   | 13.40| -  | 92.90 |
|                         | (Granodiorite, n = 3) | SD  | -  | -   | 11.30| 3.58 | 4.03 | -   | 13.90| -  | 28.80 |
|                         | Rock sample    | Mean | -  | <0.03 | 26.50| 2.79 | 16.10| -   | 5.08| -  | 55.10 |
|                         | (Tuff, n = 3)  | SD  | -  | -   | 8.44 | 3.36 | 10.10| -   | 2.16| -  | 31.40 |
| Zhang et al. (2007)     | Estimated by the method of relative cumulative frequency (n = 217) | Mean | 4.69| 0.37| 15.70| 10.20| 26.70| 0.04| 4.86| -  | 63.40 |
|                         | Range          | 0.83-9.58| 0.01-0.49 | 6.14-24.3 | 2.69-16.9 | 10.2-36.6 | 0.013-0.07 | 0.19-9.07 | -  | 22-103.2 |

4.2 concentrations of trace metals in country park soils

Figures 2–4 show the concentrations of nine heavy metals measured in different country parks. It can be noted that the mean concentration of arsenic detected in PC was over 10 times higher than that of other country parks covered in this study. Arsenic is a minor terrestrial element, mainly related to sulphur-containing minerals. Gomez-Caminero et al. [35] reported that the mean concentration of arsenic in the soil was 5 mg kg⁻¹. Other studies on trace elements in the upper crust have shown that As abundance of the crust ranges from 1.5 to 5.7 mg kg⁻¹ [36]. The As concentrations detected in SK, KS, LR agreed reasonably well with the values from Gomez-Caminero et al. [35] and Hu & Gao [36], while the average As concentration in PC is way above the average values. The average As level of the samples collected from PC even exceeds the Hong Kong’s Risk-Based Remediation Goals (RBRGs) for public park soil (i.e., 7.35 mg kg⁻¹). Chen et al. [37] reported that the average As concentration in forest soil collected in Hong Kong was 9.53 ± 2.25 mg kg⁻¹, and the average As concentration in orchard soil was 17.4 ± 9.44 mg kg⁻¹. Due to the use of arsenical pesticides, Arsenic was found to be concentrated in agricultural soils [38]. The Pearson correlation analysis of PC (Table 2) showed that As was positively correlated with Cr (p ≤ 0.01) and Hg (p ≤ 0.05), but not significant correlated with Pb, which was also found in As-containing pesticides [37]. Prior to the construction of the Plover Cove Reservoir (began in 1960) and the designation of the Plover Cove Country Park (in 1978), land use records in the area were limited. More thorough soil surveys are needed to confirm possible sources of As in the area.
Figure 2. Concentrations of As, Cr and Cd at nine sampling sites. 1 – 3: Plover Cove Country Park, 4 – 6: Sai Kung West Country Park, 7 – 8: Lion Rock Country Park, 9: Kam Shan Country Park.
Figure 3. Concentrations of Cu, Pb and Hg at nine sampling sites. 1 – 3: Plover Cove Country Park, 4 – 6: Sai Kung West Country Park, 7 – 8: Lion Rock Country Park, 9: Kam Shan Country Park.
Figure 4. Concentrations of Ni, Ag and Zn at nine sampling sites. 1 – 3: Plover Cove Country Park, 4 – 6: Sai Kung West Country Park, 7 – 8: Lion Rock Country Park, 9: Kam Shan Country Park.
Among the country parks covered in this study, KS had the highest mean concentrations of Cr, Cu, and Zn. The contents of Cr, Cu, and Zn in KS soil were 5.94, 6.21, and 7.8 times higher than the average of PC, LR, and SK, respectively. Cu and Zn enrichment in roadside soils are often attributed to brake and tyre wear [39, 13] as these elements are found in high compositions in the materials of the parts [40]. KS is also found to be enriched in Pb to a greater extent (i.e., 3.22 time higher) compared with other parks. Although the sampling points of KS and LR were located on the same road within 500 m apart from each other, KS is apparently more polluted than LR. This may be due to the fact that the sampling point of KS is located on a declining slope only 2 m away from the kerb while the sampling point of LR is located on an inclining slope 5 to 10 m away from the kerb.

Since Hong Kong does not have its own regulatory guidelines or regional background values to assess trace metal pollution, it usually uses the background concentrations recommended by the Netherlands Soil Contamination Guidelines (commonly referred to as the Dutch Soil Standard) as reference values and thresholds for investigating soil in Hong Kong [41]. By comparing the mean trace metal concentrations observed at the four country parks to the target value (T values) adopted from the Dutch guideline updated in 2000 (Table 3), a few points have been noticed. First, all Cd, Cr (except two measurements from KS), and Ni measurements were well below the Dutch T values. The two exceptionally high Cr measurements (i.e., 1.2 – 3 times over the Dutch T value) were from two consecutive months, which suggested that the anomalies could be due to a one-off event that led to excessive Cr deposition in the topsoil. Secondly, nearly all the monthly and average Pb concentrations in PC, SK, and LR were below the target value with two values slightly over the target. Pb is a concern only for KS as the Pb contents of 92% the KS samples were up to 2.35 time over the target. Similar to Pb, Cu was found to be problematic only in KS with 83% of the samples up to 2.26 times the Dutch standard. Last but not least, urban soils of Hong Kong have been found enriched with Zn to a much greater extent in comparison to other cities [42-44]. The concentration of zinc in Polish National Parks is 0.4-11.8 mg/kg, which is much lower than this study. Their heavy metal concentration from road transportation is about 3% or less of the emission source. The urban soil in Hong Kong can be attributed to the relatively high traffic flow observed on Hong Kong roads. All the KS samples exceeded the Dutch Zn target value by up to 6.29 times while less than 20% of the LR and SK samples were slightly above the target and none of the PC sample exceed the target. The noticeable difference in the percentage of Zn measurements exceeding the threshold value between KS and PC can be explained by the difference in traffic volumes recorded in those areas. The AADT of KS was nearly 34 times higher than that of PC as of 2019.

The mean concentrations of all the measurement obtained from this study are compared with the data published in three previous studies that had analysed soil samples collected from country parks or forest land in Hong Kong [31, 37, 44-45]. Table 2 summarizes the means, medians, and ranges for each metal from all the aforementioned studies except Ag as silver has not been investigated by any of the previous

| As  | -   | 0.69 | -   | 0.05 | -0.16 | 0.65 | -0.54 | -0.04 | 0.42 |
| Cd  | -   | 0.21 | 0.70 | -0.33 | -0.27 | 0.42 | 0.63 | 0.60 |
| Cr  | -   | 0.15 | -0.04 | 0.70 | -0.01 | 0.23 | 0.30 |
| Cu  | -   | 0.00 | 0.72 | -0.37 | 0.43 | 0.60 | 0.61 |
| Pb  | -   | | | -0.28 | 0.41 | 0.37 | 0.37 |
| Hg  | -   | | | -0.50 | 0.20 | 0.20 |
| Ni  | -   | | | -0.20 | 0.20 |
| Ag  | -   | | | -0.20 | 0.20 |
| Zn  | -   | | | 0.00 | 0.00 |

Table 2. Results of Pearson correlation analysis for Plover Cove Country Park.
studies. It is worth noting that As, Cu, and Zn contents in country park soils have increased noticeably in the past two decades. Pb has also increased despite the ban on sale and dispensing of leaded petrol and fuel additives containing lead that took effect from April 1, 1999. Similar lead-free fuel policies have been implemented in many major cities such as Guangzhou and Shanghai in the late 1990s. The studies of Pb isotopes in urban park soils show that high concentration of Pb from past vehicular emissions remain in the soil decade after the discontinuation of leaded fuels [41, 46-48]. Given that Pb-emitting industrial activities in Hong Kong are limited and the Pb contents in road surface/roadside environments are frequently elevated, the lead enrichment observed in recent years could be due to other traffic related sources.

Table 3. Comparison of the concentrations (mg/kg) of trace elements in country park soils to published data

|                | As    | Cd    | Cr    | Cu   | Hg    | Ni   | Pb    | Zn   |
|----------------|-------|-------|-------|------|-------|------|-------|------|
| Li et al. (2001) Table 1 |       |       |       |      |       |      |       |      |
| Range          | 0.02 - 0.37 | 2.57 - 13.8 |       |      |       |      |       |      |
| Mean           | 0.16  | 5.17  |       |      |       |      | 8.66  | 76.6 |
| Lee et al. (2000) Table 2 |       |       |       |      |       |      |       |      |
| Range          | 0.29 - 0.58 | 13.7 - 47.6 | 1.99 - 20.2 | 1.77 - 9.02 | 11.2 - 124 | 25.3 - 130 |       |      |
| Mean           | 0.35  | 21.8  | 6.37  | 5.3  | 39.6  | 46.8 |       |      |
| Chung et al. (2020) Table 1 |       |       |       |      |       |      |       |      |
| Range          | 3.8 - 95 | ND - 2.42 | ND - 23 | ND - 93 | ND - 128 | 56 - 115 | 38 - 110 |       |
| Mean           | 36.1  | 0.36  | 7.18  | 11   | 52    | 75   | 75    |      |
| Staszewski et al. (2012) |       |       |       |      |       |      |       |      |
| Range          | 0.01 - 0.48 | ND - 2.42 | ND - 23 | ND - 93 | ND - 128 | 56 - 115 | 38 - 110 |       |
| Mean           | 0.07  | 0.1   | 0.02 - 0.36 | 0.01 - 2.32 | 0.4 - 11.8 |       |       |      |
| Present study | 1.1 - 4.1 | 3.5 - 0.3 | 2.6 - 79 | ND - 0.4 | ND - 0.4 | 11 - 20 | 20 - 200 | 23 - 000 |       |
| Mean           | 22.98 | 0.19  | 19.48 | 17.99 | 0.113 | 4.73 | 64.48 | 150  |

Table 4. Summary of the single indices calculated for four country parks in Hong Kong

|                | As    | Cd    | Cr    | Cu   | Hg    | Ni   | Pb    | Zn   |
|----------------|-------|-------|-------|------|-------|------|-------|------|
| Plover Cove Country Park |       |       |       |      |       |      |       |      |
| Igeo           | 0.63  | 2.32  | 23.25 | -0.43 | 1.12  | 33.47 | -1.89 | 0.41 |
| PI             |       |       |       |      |       | 46.16 | -0.67 | 0.95 |
| Er             |       |       |       |      |       | 72.77 | -0.93 | 0.79 |
| Plover Cove Country Park |       |       |       |      |       |      |       |      |
| Igeo           | 0.03  | 1.53  | 7.65  | -0.60 | 0.99  | 4.86  | -0.68 | 0.94 |
| PI             |       |       |       |      |       | 45.60 | -0.13 | 1.37 |
| Er             |       |       |       |      |       | 72.77 | -0.93 | 0.79 |
| Sai Kung West Country Park |       |       |       |      |       |      |       |      |
| Igeo           | 0.17  | 1.68  | 8.42  | -0.74 | 0.99  | 4.50  | -0.68 | 0.94 |
| PI             |       |       |       |      |       | 45.60 | -0.13 | 1.37 |
| Er             |       |       |       |      |       | 72.77 | -0.93 | 0.79 |
| Lion Rock Country Park |       |       |       |      |       |      |       |      |
| Igeo           | 0.06  | 2.37  | 11.86 | -0.27 | 1.24  | 6.20  | -0.80 | 0.86 |
| PI             |       |       |       |      |       | 4.86  | -0.68 | 0.94 |
| Er             |       |       |       |      |       | 45.60 | -0.13 | 1.37 |
| Kam Shan Country Park |       |       |       |      |       |      |       |      |
| Igeo           | 2.94  | 11.60 | 57.61 | 1.13  | 3.27  | 16.37 | -0.81 | 0.80 |
| PI             |       |       |       |      |       | 45.60 | -0.13 | 1.37 |
| Er             |       |       |       |      |       | 72.77 | -0.93 | 0.79 |

Table 4. Summary of the single indices calculated for four country parks in Hong Kong

|                | Cu    | Pb    | Hg    | Ni   | Ag    | Zn   |
|----------------|-------|-------|-------|------|-------|------|
| Plover Cove Country Park |       |       |       |      |       |      |
| Igeo           | 0.03  | 1.53  | 7.65  | -0.60 | 0.99  | 4.86  |
| PI             |       |       |       |      |       | 45.60 |
| Er             |       |       |       |      |       | 72.77 |
| Plover Cove Country Park |       |       |       |      |       |      |
| Igeo           | 0.17  | 1.68  | 8.42  | -0.74 | 0.99  | 4.50  |
| PI             |       |       |       |      |       | 45.60 |
| Er             |       |       |       |      |       | 72.77 |
| Sai Kung West Country Park |       |       |       |      |       |      |
| Igeo           | 0.06  | 2.37  | 11.86 | -0.27 | 1.24  | 6.20  |
| PI             |       |       |       |      |       | 4.86  |
| Er             |       |       |       |      |       | 45.60 |
| Lion Rock Country Park |       |       |       |      |       |      |
| Igeo           | 2.94  | 11.60 | 57.61 | 1.13  | 3.27  | 16.37 |
| PI             |       |       |       |      |       | 45.60 |
| Er             |       |       |       |      |       | 72.77 |

Table 4. Summary of the single indices calculated for four country parks in Hong Kong

|                | Ni    | Ag    | Zn   |
|----------------|-------|-------|------|
| Plover Cove Country Park |       |       |      |
| Igeo           | -1.40 | 0.57  | -0.29 |
| PI             |       |       | 1.23 |
| Er             |       |       | -1.25 |
| Sai Kung West Country Park |       |       |      |
| Igeo           | -0.17 | 1.34  | 3.74  |
| PI             |       |       | 1.17  |
| Er             |       |       | 1.51  |
| Lion Rock Country Park |       |       |      |
| Igeo           | -0.37 | 1.16  | -0.11 |
| PI             |       |       | 1.39  |
| Er             |       |       | -0.21 |
| Kam Shan Country Park |       |       |      |
| Igeo           | 0.06  | 1.59  | 0.50  |
| PI             |       |       | 2.12  |
| Er             |       |       | 8.54  |

4.3. Levels of contamination

Table 4 summarizes the evaluation results of the pollution and ecological risk indices of each metal. Out of the 36 Igeo values calculated, 21 (~58%) values belong to Class 0 (unpolluted), 9 (25%) to Class 1
(unpolluted to moderately polluted), 3 (8%) to Class 2, 2 (6%) to Class 3 (moderately to strongly polluted), and 1 (3%) to Class 4 (strongly polluted), indicating that the soils in the four country parks are mostly unpolluted to moderately polluted by the metal measured. Silver in SK has the maximum $I_{geo}$ value. Since the deposition of Ag in roadside soil has not been widely studied, there is limited information on the history and trend of Ag enrichment in country park soils. Silver metal and silver compounds have been found in a wide range of applications, including silver-based brazing alloys, batteries, lubrication, window coatings, bactericide, and sanitation products [7]. Some of the applications may have direct linkages to traffic activities and some can be attributed to the recreational activities brought about by transportation. Silver contents in country park soils may enter human bodies via the hand-to-mouth exposure route. Thus, it is recommended to include Ag in future local monitoring programmes to build up the knowledge on Ag enrichment in Hong Kong.

According to the PI values, As and Hg are least concerned as they have moderate impacts only at particular sites, i.e., As at PC and Hg at SK. The PI of all nine metals in PC, SK, and LR are between low to moderate, which indicates that these parks are relatively safe from heavy metal related issues. The pollution impact levels of Cd, Cr, Cu, Pb, and Zn at KS are high, suggesting the area is prone to metal pollution. The Er values for As, Cr, Cu (with one exception), Pb, and Zn in all four park indicate low potential ecological risk. The only exception was Cu in KS, which indicates moderate ecological risk. The risk of Cd is found to be moderate in SK and LR and considerable in KS. The current Cd concentrations of all four parks are lower compared with previous data (shown in Table 2) and no Cd-related problems have been reported in the past, meaning that the Cd is not likely to cause ecological issues in the parks despite the alarming Er values.

The integrated indices provide a platform to compare the overall soil quality of different sites. The PLI values tabulated in Table 5 indicate that the conditions of all the parks considered have deteriorated except PC. The extents of deterioration roughly in line with the traffic volume recorded at the site: the higher the traffic volume, the more the site deteriorated from its baseline condition. The pollution level of KS is high and the levels of the other three parks are moderate based on the PI average values. The PI\textsuperscript{nemerow} values deliver similar message but the difference between the pollution levels of KS and the other parks widen even further. KS is seriously polluted while the PC, SK, and LR are slight polluted on the PI\textsuperscript{nemerow} scale. The overall ecological risks of all the parks are acceptable, ranging from low to moderate.

4.4. Traffic count
The annual average daily traffic (AADT) estimated from the traffic survey is compared to the 5-year average based on the annual traffic census data from 2015 – 2019 [9]. The survey results and the 5-year averages for PC and SK agreed well with one another while the discrepancy for LR and KS is noticeable (Table 6). The roads in PC and SK chosen for this study primarily provide access to the country parks while the road chosen for LR and KS is a major road connecting Shatin and New Kowloon and is used by non-park users. The work-from-home arrangement adopted by many companies in 2019 due to the Covid-19 outbreak may have contributed to less work-related traffic in 2019. In terms of the percentage of light vehicle, 92-93% of the on-road vehicles counted are light vehicle, meaning that the compositions of heavy metals due to exhaust emissions would be similar at all four parks. The concentrations of Cr, Ni and Zn are noticeably higher in SK, LR, and KS compared with PC, while that of Cu and Pb are relatively high only in LR and KS. Studies on roadside soil contamination often refer traffic activities

| Country Park                          | PLI   | PI(ave) | PI(nemerow) | RI    |
|--------------------------------------|-------|---------|-------------|-------|
| Plover Cove Country Park             | 0.99  | 1.08    | 1.81        | 70.78 |
| Sai Kung West Country Park           | 2.84  | 1.22    | 1.47        | 67.35 |
| Lion Rock Country Park               | 4.11  | 1.34    | 1.96        | 98.84 |
| Kam Shan Country Park                | 813   | 3.95    | 8.60        | 192.08|

Table 5. Summary of the integrated indices calculated for four country parks in Hong Kong
as the source of Cu, Pb, and Zn. The mixed observations of this study suggested that there may be other sources of Cu, Pb, and Zn in the study areas.

**Table 6.** Summary of traffic counts for four sampling sites in country park areas

|                  | PC*  | SK   | LR   | KS   |
|------------------|------|------|------|------|
| AATD - 2019 census| 1,043| 11,880|      | 19,460|
| AATD - 5-yr average (2015 - 2019)| 1,183| 11,222| 22,552|
| Daily traffic volume** | Low  | Medium | Medium |
| % Ligh vehicle***       | 93%  | 92%   |       |

Mean concentration (mg/kg)

| Element | PC*  | SK   | LR   | KS   |
|---------|------|------|------|------|
| As      | 20.28| 5.12 | 4.48 | 4.28 |
| Cd      | 0.09 | 0.12 | 0.20 | 0.26 |
| Cr      | 6.38 | 14.88| 12.38| 63.08|
| Cu      | 7.74 | 8.50 | 11.98| 58.08|
| Pb      | 45.82| 41.56| 57.25| 151  |
| Hg      | 0.08 | 0.11 | 0.07 | 0.07 |
| Ni      | 2.65 | 5.40 | 5.40 | 7.39 |
| Ag      | 0.10 | 0.09 | 0.11 | 0.17 |
| Zn      | 39.91| 81.75| 81.75| 540  |

* The values for PC are averages of three stations located on Bride's Pool Rd.

** Classification of AADT: Low < 10,000; Medium 10,000 - 39,999; High > 40 000 - adopted from Wong et al.(2004)

*** Based on 2019 data, 92.5% of the vehicles in Hong Kong are light vehicles.

5. Conclusion

In the country park studies, Kam Shan country park (KS) has the highest mean concentration of Cr, Cu, Pb and Zn among Plover cove (PC), Sai Kung West (SK) and Lion Rock (LR) country parks. The contents of Cr, Cu, Pb and Zn in KS soil were 5.94, 6.21, 3.22 and 7.8 times higher than the average values derived from PC, LR, and SK, respectively. The soil quality roughly corresponds to the traffic volume recorded on site: the higher the traffic volume, the higher the value in the composite indices. The pollution load index (PLI) indicates that the conditions of all the parks considered have deteriorated except Plove Cove Country Park (perfection). The levels of PLterc and PlNemerow are high in KS whereas the other three parks are moderate. The overall ecological risks of all parks are acceptable, ranging from low to moderate. Consideration should be given to developing better urban planning to avoid high ecological risks in country parks. Increasing the height of roadside green plants may help reduce heavy metal pollution in country parks.

A regulatory guideline and a baseline value for assessing trace metal contamination in soils is yet to be established for Hong Kong. The elements covered in the contamination analyses of a site is largely subjective and practitioners are often required to follow different international practices and standards when conducting contamination assessment, which could be a source of confusion and discrepancy. The existing EPD guideline Contaminated Land Assessment and Remediation was released in 2005 and have not been updated since. The guideline mainly concerns the impacts bring about by industrial facilities such as shipyards and chemical plants/storages but fails to acknowledge the impacts from traffic activities. With the highly polluting industries gradually leaving Hong Kong, vehicular emissions would become a major source of environmental contamination and should be addressed specifically due to its complex and dynamic nature that is distinct from other industrial activities.

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