A Project entitled

The relationship between urban trees, PAHs, and infection status of wood decay fungi in Hong Kong

Submitted by

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for the degree of *Bachelor of Education (Honours) (Science)*

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DECLARATION

I, *Sung Ka Chun* , declare that this research report represents my own work under the supervision of *Dr. Li Wai Chin*, and that it has not been submitted previously for examination to any tertiary institution.

Signed _____

Sung Ka Chun

7/4/2023

ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) are one of the most abundant and potentially harmful pollutants found in most urban soils, while wood decaying fungi are one of the major threats to the urban trees grown on the polluted soils. The aims of this research study are to investigate the distribution and concentration of PAHs in the soil and the distribution of wood decay fungi grown in tree species grown in Hong Kong urban parks via field study and figure out the relationship between the chemical parameters of soil and the extent of infection of wood decaying fungi grown in different types of tree species located in Hong Kong urban parks.

Soil samples were collected from the 18 urban parks in Hong Kong, and significant differences ($p<0.05$) were found in fungal infection rate of urban trees species (0.78-24.3%) and other chemical parameters including electrical conductivity (EC) (334.6-1641.8 ms/cm), redox potential (2-61.2 V), pH (6.12-7.15), TOC (2.40-7.08%), nitrate (2.70-52.42 mg/kg, dry weight), total carbon (C) (0.85-4.51%), total hydrogen (H) (0.36-1.81%), total nitrogen (N) (0.14-1.33%) and total sulphur (S) (0.05-0.46%) and total PAHs (0.47-3.33 mg/kg). By referring to the Dutch guideline (Esdat, 2000), 13 out of the 18 sampling sites were found to exceed the Dutch Target Values (DTVs) (i.e., 1 mg/kg, dry weight) in PAHs. Three principal components are found to be responsible for fungal infection rate of tree species grown in the studied

sites in general. The first and second components included EC (PC1: 99.7%), redox potential and the concentration of nitrate (PC2: 0.2%), respectively. However, other parameters (e.g., Total PAHs, low molecular weight [LMW] PAHs, etc.) were found to be responsible for tree species (e.g., *S campanulata*, *F macrocarpa*, *A confusa*, *C camphora*, *L speciosa*). This study provides baseline information on the most dominant soil characteristics in altering the infection rate of urban trees species by wood-decaying fungi and the relationship between certain soil characteristics and fungal infection rates. This information can aid in the development of effective management strategies for urban trees in Hong Kong by prioritizing management efforts to improve soil characteristics that are significantly correlated with fungal infection rates.

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1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) as a class of organic compounds consisting of two or more aromatic rings derived from the incomplete combustion and pyrolysis of organic substances (Bamforth & Singleton, 2005; Kravić, et al., 2005; Lau, Gan & Ng, 2012). PAHs are ubiquitous in both the natural environment and urban areas as they are recalcitrant and poor degradable molecules that can exist in the environment for a long time due to their tight absorption to organic matter and low water solubility in soil, leading to its wide distribution in soils, ground water and atmosphere substances (Bamforth & Singleton, 2005; Kravić, et al., 2005; Lau, Gan & Ng, 2012). PAHs originate from both natural and anthropogenic sources, and the latter sources contribute to the major portion of the total release of PAHs to the environment (Bamforth & Singleton, 2005). With PAHs mutagenic and carcinogenic and teratogenic properties, 16 congeners of PAHs including naphthalene (Nap), acenaphthylene (A), acenaphthene (Ace), fluorine (F), phenanthrene (Phe), anthracene (Ant), fluoranthene (Flu), pyrene (Pyr), benz[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), indeno[1,2,3-cd]pyrene (IP), dibenz [a,h]anthracene (DA) and benzo[g,h,i]perylene (BP) have been classified as "priority pollutants" by United States Environmental

Protection Agency (USEPA), causing their presence becomes a serious health issue (USEPA, 1982).

Among different natural repositories of PAHs, it is estimated that the largest proportion of PAHs released to the environment are eventually deposited in soils through atmospheric deposition. Wild and Jones (1995) found that 90% of PAHs is estimated to be stored in soil. Yet, the distributions and concentrations of PAHs varied remarkably in different areas due to the climate, soil microbial activity and emissions from different sources (Bandowe, et al., 2021; Zhong, et al., 2006). Therefore, Edwards (1983) concluded that the endogenous concentrations of PAHs in soil is around 1 to 10 μg/kg, dry weight in natural environment due to the plant synthesis and wildfire. Besides, the endogenous concentrations of PAHs in Hong Kong soils are around 7.0 to 69.3, dry weight in soils of rural areas, and 42.9 to 410, dry weight in soils of urban areas (Zhong et al., 2006). Based on the above data, it is obvious that the concentrations of PAHs in urban soils is 4 to 400 times higher than the natural concentrations, which is deemed by Zhang and his colleagues (2006) to be mainly caused by the vehicular exhaust due to heavy traffic. Moreover, certain type of the land use in Hong Kong (i.e., car dismantling workshop) are found to have extraordinarily high concentrations of PAHs in soil, which is 93492 μg/kg, which possess serious carcinogenic risk to human (Man et al., 2013). However, effective

bioremediation of soil PAHs in practice is still considered immature due to the environmental disruption and considerable cost required (De Boer & Wagelmans, 2016).

Fortunately, research has been done to report that wood-decaying fungi (e.g., white-rot fungi) are capable of a series of POPs by transformation (e.g., phenanthrene, fluoranthene, pyrene and benzo[a]pyrene) (Mao & Guan, 2016; Mineki, et al., 2015; Arun et al., 2008; Sack et al., 1997; Brodkorb & Legge, 1992). It was found that the metabolism includes two types of ligninolytic enzymes that are excreted extracellularly by the wood decaying fungi which are responsible for oxidizing the POPs to give O_2 and uncharacterized polar metabolites that are more readily to be naturally degraded by other creatures (Brodkorb & Legge, 1992; Hammel, 1995; Bamforth & Singleton, 2005). Mo and Guan (2016) explained that the use of wood decaying fungi for bioremediation of POPs is more advantageous when compared with the use of bacteria, as the extracellular enzymes and mycelia of the fungi provide a deeper penetration in soil, and hence a larger surface area of absorption of PAHs.

However, wood decay fungi exhibited pros and cons to the tree health. The ability of wood decay fungi to break down complex and recalcitrant lignified cell walls improves material cycling in the ecosystem as the decomposed materials can be made available as nutrients for other species in the soil (Newbound, 2010; Blanchette,

1991). On the contrary, some wood decay fungi are pathogenic, which can infect living trees by causing rot or decay on the stems and roots (e.g., brown root rot disease) (Ing, Hu & Gu, 2020; Development Bureau, 2020). Recently, Hong Kong government tried to classify the risk level of wood decay fungi accordingly in four risk-based categories with specific colour code for each one (i.e., high risk [red], moderate risk [orange], low risk [yellow] and insignificant risk [green]) (Development Bureau, 2020).

Intensified anthropogenic disturbances due to the urban expansion, the urban environment is highly deteriorated by various toxic pollutants in the atmosphere and soil (Fung et al., 2021), heat and drought, scarcity of growing space (Ing, Hu & Gu, 2020), causing urban trees to be attacked readily by different pathogens and pests (Lüttge & Buckeridge, 2020). The trees that are seriously infected by wood decaying fungi are likely to fall, which can pose disastrous effects to the public in Hong Kong where strong and unpredictable typhoons occur annually (Ing, Hu & Gu, 2020; Development Bureau, 2020).

Based on the previous findings, it was hypothesized that PAHs in soil is related to the presence of wood decay fungi, which may ultimately affect the health and survival rate of the urban trees in the polluted soil. However, limited information on the relationship between PAH concentrations and the presence of wood decay fungi in

the field is available, as most studies in Hong Kong have focused on the identification and pathogenicity of highly pathogenic fungi, such as *P noxius*. Nonetheless, it is important to examine the relationship between PAHs and other wood decay fungi species to improve the management of urban trees in Hong Kong for public safety and ecological benefits. As a result, 18 urban parks were selected randomly as the primary sites for investigation. The following research questions will be addressed in this project:

1. What is the distribution and concentration of PAHs in the soil of Hong Kong's urban parks?

2. What is the distribution of wood decay fungi found in tree species grown in Hong Kong's urban parks?

3. What is the relationship between the physical and chemical parameters of soil and the extent of infection of wood decay fungi grown in different types of tree species located in Hong Kong's urban park?

To address the research questions, this proposed project has the following objectives to narrow down the scope of the study and provide a more standardized framework to report the relationship between the concentration of PAHs and growth of wood decay fungi:

1. To study the PAHs concentration and other major physical and chemical parameters of the soil sampled near tree roots.

2. To explore the correlation between the physical and chemical parameters of the soil samples and the occurrence of wood decay fungi found in different types of tree species from the sampling sites.

2. Methodology

2.1 Preliminary test

A preliminary field visit was done in July 2022 in Kowloon Park (KLP) in order to examine the current situation of fungal infection in urban trees. As reported by Ing, Hu and Gu (2020), KLP was identified as one of the urban parks where wood-decay fungi was a major problem in tree management. During the field visit, fungi were found and identified according to the guideline proposed by the Development Bureau (2020), and they were suspected to belong to the moderate risk category (ORANGE) (i.e., *Ganoderma applanatum*) and low risk category (YELLOW) (i.e., *Schizophyllum commune*) (Fig. 1&2). Hence, it further supports hypothesis that PAHs concentration in urban soils may possibly be related to the presence of wood decay fungi.

Fig. 1. Fungal fruiting body of *Ganoderma applanatum* which belongs to the moderate risk category (orange) was found during the preliminary visit in the Kowloon Park (KLP)

Fig. 2. Fungal fruiting body of *Schizophyllum commune* which belongs to the low risk category (yellow) was found during the preliminary visit in the KLP

2.2 Study sites

18 urban parks were randomly chosen as the study sites for investigation in this proposed project (Fig.3 & Table 1).

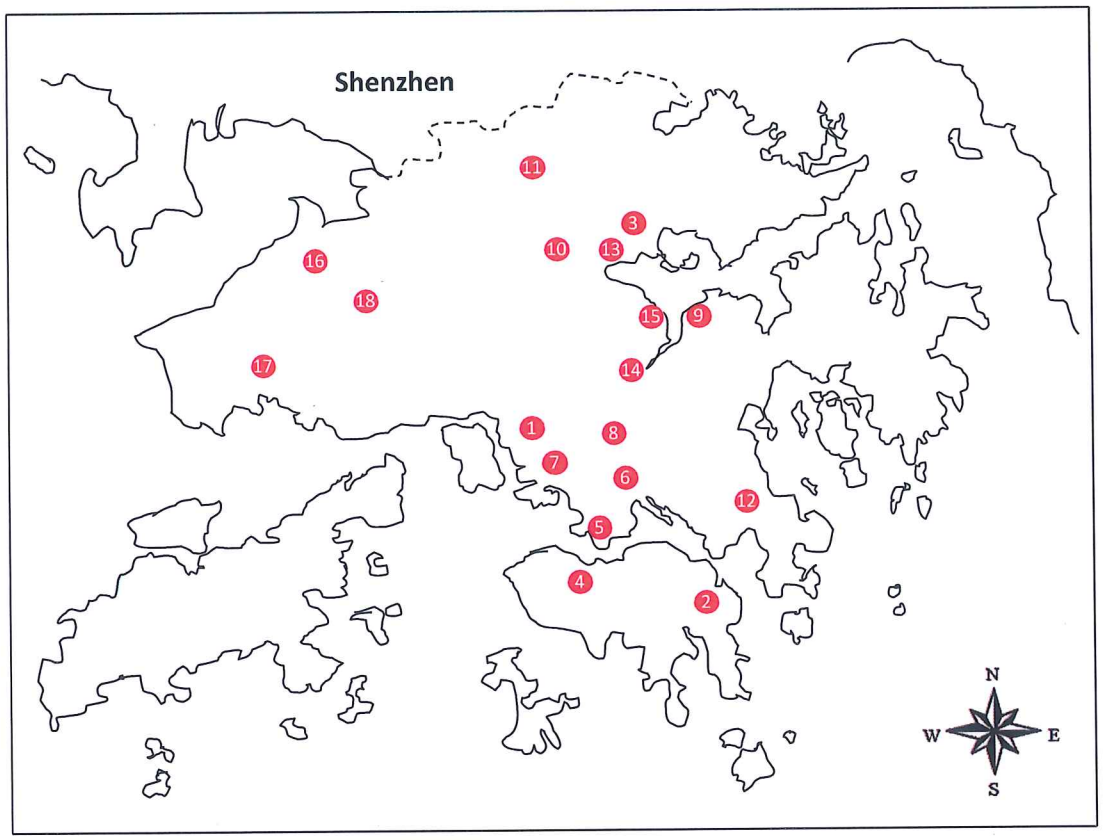

Fig. 3. Locations of the 18 study sites

Table 1. Information of the 18 study sites (Leisure and Cultural Services Department [LCSD], 2018; Hong Kong Science and Technology Park, 2023).

No.	Abbreviation	English name of Parks	Chinese name of Parks	District	Area (ha)	Opening Year (Since)
1	CKCP/KCP	Central Kwai Chung Park	中葵涌公園	葵青	10.56	1986
2	CWP	Chai Wan Park	柴灣公園	東區	7.13	1993
3	EDU	Green spaces in the Education University of Hong Kong	香港教育大學	大埔	12.5 (Total area)	1994
4	HKP	Hong Kong Park	香港公園	中西區	8	1991
5	KLP/KWP	Kowloon Park	九龍公園	油尖旺	13.3	1970
6	KWCP	Kowloon Walled City Park	九龍寨城公園	九龍城	3.1	1994
7	LCKP	Lai Chi Kok Park	荔枝角公園	深水埗	17.65	1989
8	LRP	Lion Rock Park	獅子山公園	黃大仙	5.07	1966
9	MOSP	Ma On Shan Park	馬鞍山公園	沙田	5.5	1998
10	MSHP	Mui Shue Hang Playground	梅樹坑遊樂場	大埔	2.25	1991
11	NDP	North District Park	北區公園	北區	8.605	1990
12	PHP	Po Hong Park	寶康公園	西貢	4.13	1997
13	SP	Green spaces in the Hong Kong Science and Technology Park	香港科學園	沙田	22 (Total area)	2001
14	STP	Sha Tin Park	沙田公園	沙田	8.05	1988
15	TPWP	Tai Po Waterfront Park	大埔海濱公園	大埔	22	1994
16	TSWP	Tin Shui Wai Park	天水圍公園	元朗	14.86	1997
17	TMP	Tuen Mun Park	屯門公園	屯門	12.5	1985
18	YLP	Yuen Long Park	元朗公園	元朗	7.5	1991

2.3 Soil sampling

In each study site, surface soils were collected as the samples randomly in each site from the October 2022 to November 2022, while each composite sample was consisted of 3 sub-samples collected from the surrounding of each site (within 1 m^2). All the soil samples were stored in kraft paper zip lock bags and transported to the laboratory at the Education University of Hong Kong (EdU) as soon as possible.

2.4 Field measurements and fungi identification

The infected trees were visually identified in the study sites based on the presence of fruiting bodies and mycelia. The basic information of the infected trees were recorded and measured including (1) the species name, (2) dates of record, (3) locations, (4) presence of wood decay fungi, (5) height, (6) crown spread, (7) DBH. Fungal fruiting bodies or fungal mycelium, if present, were photographed for further identification according to the morphological characters (Development Bureau, 2020). Species names were identified by referring to the tree labels with QR codes established by Development Bureau (2020). The tree height was measured by using the tangent method developed by Korning and Thomsen (1994), while the DBH was measured in align with the rules suggested by the Agriculture, Fisheries and Conservation Department (AFCD) (2006). Some basic information of the infected trees measured, and methods used were summarized in table 2.

Table 2. Basic information of the infected trees obtained in field and methods used

Basic information of the infected trees obtained in field	**Methods**
Infection status	Visual identification (Development Bureau, 2020)
Species Name	Tree Labels with QR Codes (Development Bureau, 2021)
Height	Tangent method (Korning and Thomsen, 1994)
DBH	Standard Practice (AFCD, 2006)

2.5 Soil samples treatment

All the soil samples were air-dried, homogenized and composited into 5 replicates, and then sieved to 2 mm so as to remove invertebrates, stones and residual roots. The treated samples were eventually be stored in desiccators prior to further analysis.

2.6 Soil chemical analysis

Electrical conductivity (EC), pH and redox potential were measured using a pH meter, conductivity meter and redox tester respectively on soil extracts obtained by mixing with distilled water at 1:5 (w/v) sample to water ratio (Page, Miller & Keeney, 1982). Total carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) measurements were tested with a Perkin Elmer 2400 series II CHNS/O analyser (Page, Miller & Keeney, 1982). Total organic matter (TOM) was measured by dry combustion under 550°C in furnace (Page, Miller & Keeney, 1982) and total organic carbon was estimated by dividing the factor of 1.724 (Chaney and Swift, 1984). Nitrite-N were determined colorimetrically in accordance with procedures described by Anderson and Ingram (1989) at absorbance readings of 517 nm.

PAHs was extracted by using Soxhlet extraction according to the USEPA method (USEPA, 1996a). Soil samples (0.5g dry weight) were placed into a thimble. Then 90ml of extraction solvents: acetone/hexane/DCM (1:1:1) and 1 to 2 anti-bumping

granules were added into the round bottom flask which was then be attached to the Soxhlet extractor on the heat plates inside the fume hood. The samples were extracted for 16 to 24 hours at 4 to 6 cycle per hour at 250°C on hot plates. The extracts were concentrated into about 5ml at 250°C on hot plates. The concentrated extracts were cleaned up using a column consisting of 10cm of glass wool and 1g of silica gel, and then were eluted with 5ml of extraction solvents: DCM/hexane (3:7). The solution was finally be concentrated to around 2 ml at 250°C on hot plates and was transferred to a glass of vial for gas chromatography (GC) injection.

The concentrations and profiles of PAH compounds were analysed according to the USEPA method based on the Hewlett Packard 6890 Gas Chromatography system equipped with a mass selective detector (GC/MS) (USEPA, 1996b) and 2 mg/kg, dry weight of PAHs was spiked in all clean extracts to check the recovery of the extraction method for quality control. 16 congeners of PAHs were included in this proposed project: naphthalene (Nap), acenaphthylene (A), acenaphthene (Ace), fluorene (F), phenanthrene (Phe), anthracene (Ant), fluoranthene (Flu), pyrene (Pyr), benz[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), indeno[1,2,3-cd]pyrene (IP), dibenz [a,h]anthracene (DA) and benzo[g,h,i]perylene (BP). The detection limit for all

congeners of PAHs was 0.05 ng/kg, dry weight. To ensure the instruments are free of contamination, analytical blanks was run with samples following the same procedure.

2.7 Statistical Analysis

Means and standard errors were calculated based on the tested parameters. All data obtained was subjected to One Way ANOVA Duncan multiple range test and Pearson correlation test at 0.05 significant level using SPSS 28.0 software and principal component analysis (PCA) via Primer 6.0 for further analysis. Hierarchical cluster analysis was also carried out for identifying homogeneous groups of individual PAHs in soils using SPSS 28.0 software (Zhang et al., 2006).

3. Result and discussion

3.1 Fungal infection rate of study sites

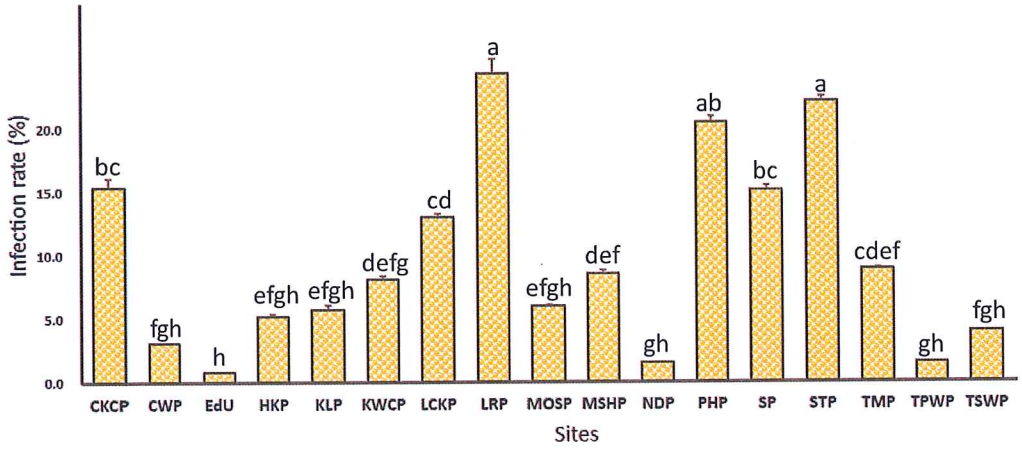

Fig. 4. The fungal infection rate (%) in the various types of trees in the 18 sites. Different letters for each site indicate significant difference between sampling sites at the level of $P < 0.05$ according to Duncan multiple range test.

One-Way ANOVA was done to compare the means of two or more variables to determine if there is statistical difference between them. The result is used to identify which variables are significant in explaining the variation in fungal infection rates between different sampling sites. Fig. 4 shows the summary of fungal infection rate recorded in the sampling sites which ranged from 0.78 - 24.3%. The highest percentage of 24.3% was detected in the LRP, while the lowest percentage of 0.78% was detected in the EDU. The variation of infection rates in different sites were suspected to result from the susceptibility of the host tree species and the environment conditions. For example, old trees were found to be more susceptible to wood-decay

fungi than young trees under same environmental stresses (Wardlaw et al., 2009; Ing, Hu & Gu, 2020). Host specificity of the wood decaying fungi may also explain the variation, since Ing, Hu and Gu (2020) observed that *F macrocarpa* was likely to be infected by a variety of wood decaying fungi, especially those that were identified as old and valuable trees (OVTs). Furthermore, such unfavourable growing conditions for the urban trees was found to be reduce trees' resistance towards wood-decay fungi infection (Lüttge & Buckeridge, 2020).

3.2 Chemical parameters of soil samples

3.2.1 pH value

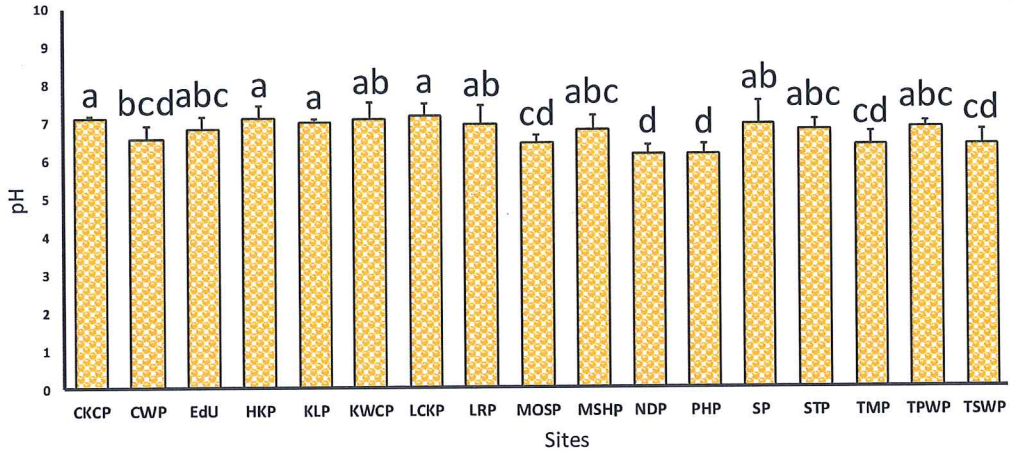

Fig. 5. The pH value in the soils in 18 sites (n = 5). Different letters for each site indicate significant difference between sampling sites at the level of $P < 0.05$ according to Duncan multiple range test.

Fig. 5 showed that the pH values of all soils in the sampling sites varied from 6.12 to 7.15 which fell into the range of pH 5.5 to 8.0 in which most plants will grow favourably (Development Bureau, 2022).

3.2.2 EC value

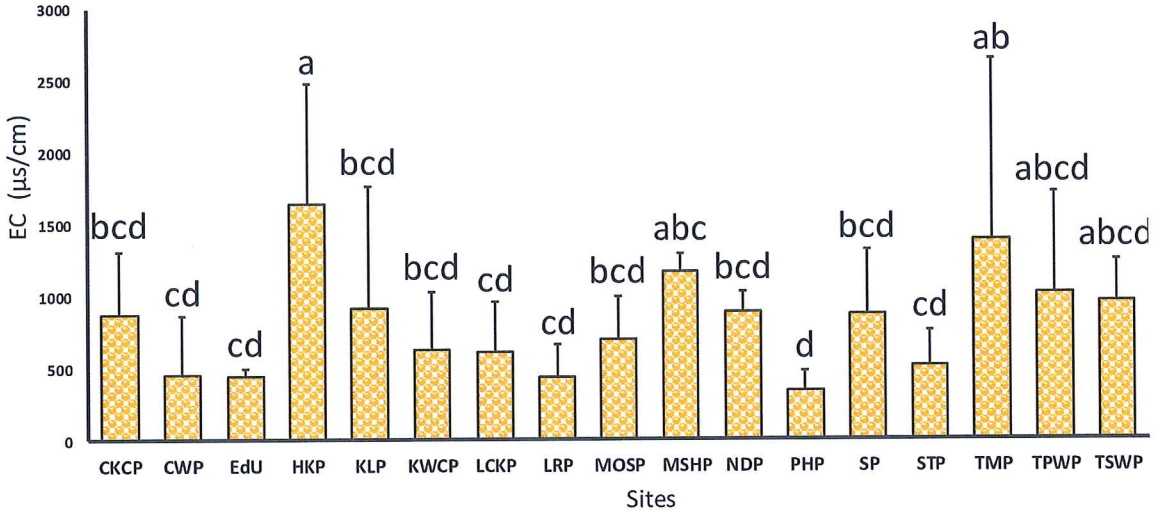

Fig. 6. EC value (µs/cm) in the soils of the 18 sites (n = 5). Different letters for each site indicate significant difference between sampling sites at the level of $P < 0.05$ according to Duncan multiple range test.

According to Fig. 6, EC value of the soil samples varied significantly in 18 urban parks fell into the range of 334.6-1641.8µs/cm. The highest EC value of 1641.8µs/cm was detected in the HKP, while the lowest EC value of 334.6µs/cm was detected in the PHP. As EC is an index of salt concentration and an indicator of electrolyte concentration of the solution, which can be used to estimate the concentration of cations like calcium (Ca^{2+}), potassium (K^{+}) and sodium (Na^{+}), and anions like chloride (Cl^{-}), sulphate (SO_4^{2-}) and carbonate (CO_3^{2-}) (Ding et al., 2018; Development Bureau, 2022). Thus, the significant variations of EC values over the 18 study sites implying the number of ions available to plants in the root zone are different which

can be due to the natural climatic conditions (e.g., precipitation, temperature, etc.) and human activities (e.g., irrigation, drainage, etc.) (Ryšan & Šařec, 2008; Ding et al., 2018; Kaya et al., 2022).

3.2.3 Redox potential

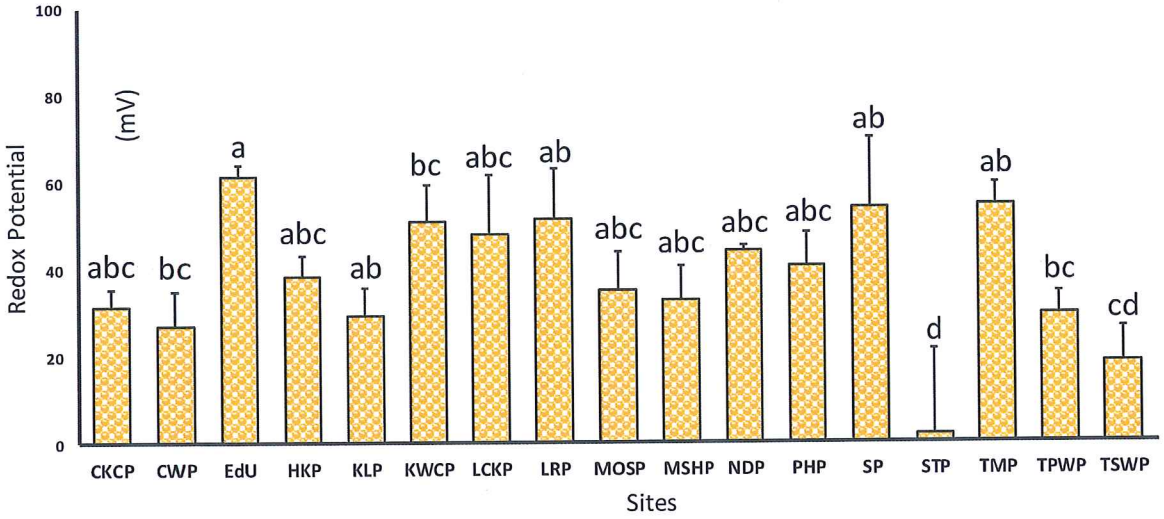

Fig. 7. Redox potential (mV) in the soils of the 18 sites (n = 5). Different letters for each site indicate significant difference between sampling sites at the level of $P < 0.05$ according to Duncan multiple range test

Fig. 7 showed that the values of redox potential in all soil samples ranged from +2 to +61.2 mV. The highest redox potential of +61.2 mV was detected in the EdU, while the lowest redox potential of +2 was detected in the STP. Redox potential determines the speed and the amplitude of the response of soil to the input of electrons (Husson, 2013). According to Fig. 7, the values of redox potential varied over the 18 study sites, meaning that the factors which govern redox potential (e.g., soil microorganisms' communities, supply of oxygen, availability of organic matter, etc.) may be different in the study sites (Pezeshki, 2001; Husson, 2013). Although redox potential of all sites fell on the normal range of −300 to +900 mV, they were

lower than 350 mV which are particularly limiting for many plants (Husson, 2013). Studies also found that survival rates of young trees were found lower in study zones with lower redox potential may lead to photosynthesis reduction (Pezeshki, 2001; Pennington & Walters, 2006).

3.2.4 TOC

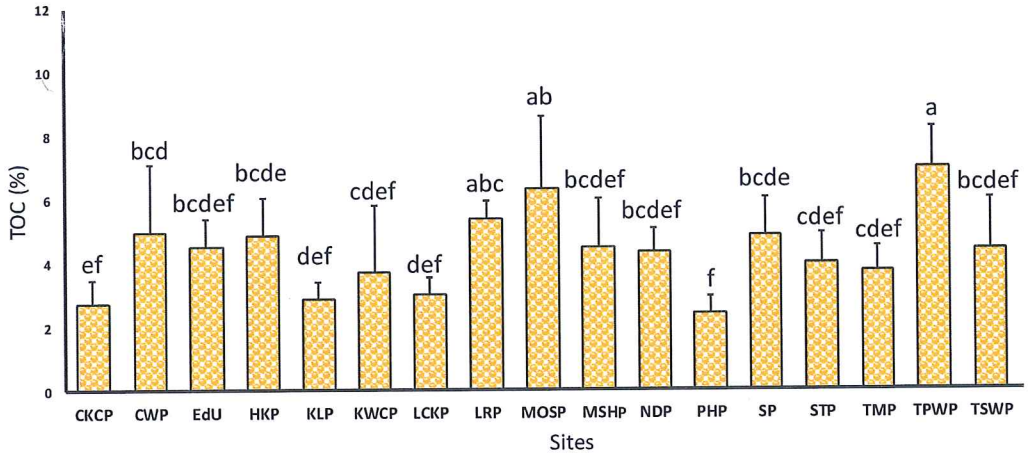

Fig. 8. TOC (%) in the soils of the 18 sites (n = 5). Different letters for each site indicate significant difference between sampling sites at the level of $P < 0.05$ according to Duncan multiple range test

With reference to Fig. 8, the content of TOC ranged from 2.40 to 7.08%. The highest percentage of 7.08% was detected in the YLP, while the lowest percentage of 2.40% was detected in the PHP. Total organic carbon in soil is the main component of soil organic matter consisting of plant residues and microbial biomass which largely contributes to the soil fertility serving as the major soil nutrient pool (Development Bureau, 2022). Referring to the Fig. 8, significant differences of the TOC are found in the 18 study sites, which may result from various abiotic factors (e.g., soil porosity, water drainage, etc.) and biotic factors (e.g., diversity and activity of soil microorganisms) over the study sites (Bot & Benites, 2005; Development Bureau, 2022).

3.2.5 Nitrate-N

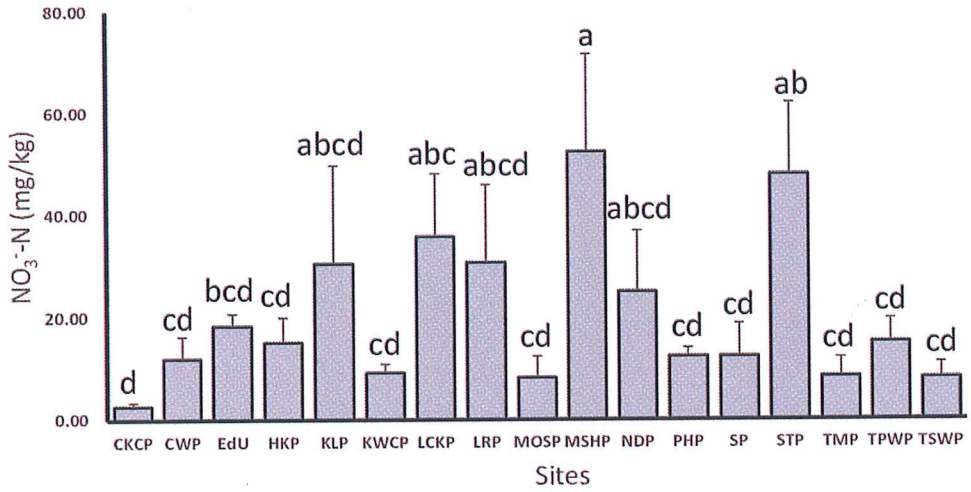

Fig. 9. Nitrate-N concentration (mg/kg, dry weight) in the soils of the 18 sites (n = 5). Different letters for each site indicate significant difference between sampling sites at the level of $P < 0.05$ according to Duncan multiple range test.

According to the Fig. 9, the concentration of nitrate-N ranged from 2.70 to 52.42 mg/kg, dry weight. The highest percentage of 2.70 mg/kg, dry weight was detected in the MSHP, while the lowest percentage of 52.42 mg/kg, dry weight was detected in the CKCP. Soil nitrate (NO_3^-) is a form of essential inorganic nitrogen that is readily available to the plants for robust growth by making chlorophyll, amino acids, and proteins (Bagshaw, Moody & Pattison, 2010). According to Bagshaw and his colleagues (2010), the concentration of nitrate required in soil in general should not fall below 10 mg/kg and should not exceed 50 mg/kg (Fig. 10), whereas only 4 of the study sites (i.e., KLP, LCKP, LRP & NDP) fell into the optimal concentration of

nitrate level ranged from 20 to 40 mg/kg, whereas 1 of the sampling sites were higher than 60 mg/kg, dry weight (i.e., MSHP) and 5 of the sampling sites were lower than 10 mg/kg (i.e., CKCP, KWCP, MOSP, TMP & TSWP).

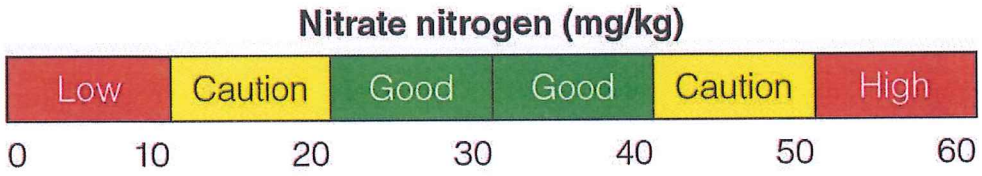

Fig. 10. Guide to the interpretation of nitrate-N values for soils (Bagshaw, Moody & Pattison, 2010)

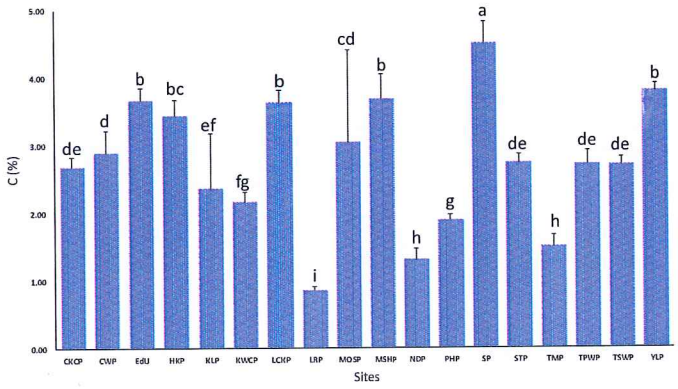

Fig. 11. Total C concentration (%) in the soils of the 18 sites (n = 5) Different letters for each site indicate significant difference between sampling sites at the level of P < 0.05 according to Duncan multiple range test.

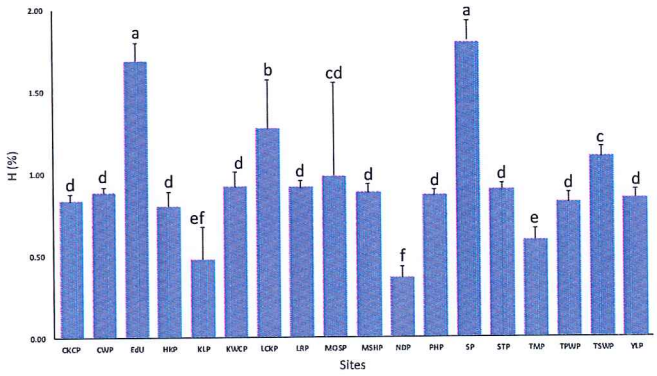

Fig. 12. Total H concentration (%) in the soils of the 18 sites (n = 5) Different letters for each site indicate significant difference between sampling sites at the level of P < 0.05 according to Duncan multiple range test.

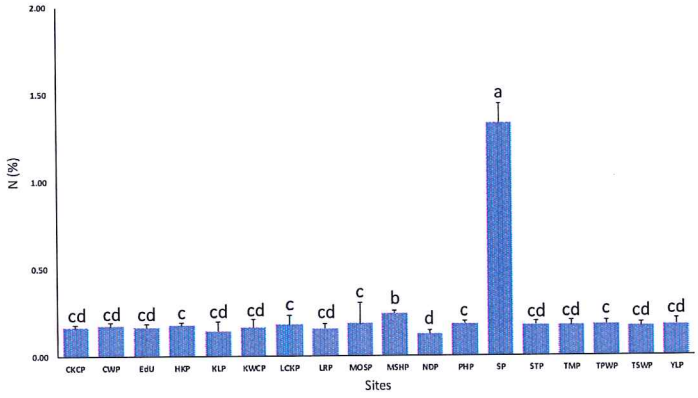

Fig. 13. Total N concentration (%) in the soils of the 18 sites (n = 5) Different letters for each site indicate significant difference between sampling sites at the level of P < 0.05 according to Duncan multiple range test.

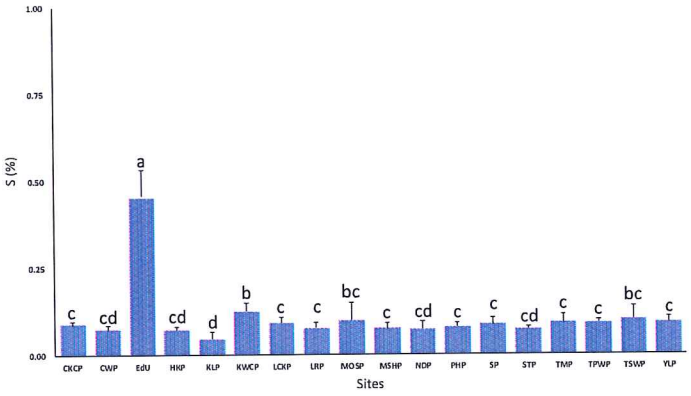

Fig. 14. Total S concentration (%) in the soils of the 18 sites (n = 5) Different letters for each site indicate significant difference between sampling sites at the level of P < 0.05 according to Duncan multiple range test.

3.2.6 Total C, H, N & S

Figures 11 to 14 showed that the concentration of total C, H, N and S of all sediment samples ranged from 0.85-4.51%, 0.36-1.81%, 0.14-1.33% and 0.05-0.46% respectively. For total C, the highest percentage of 4.51% was detected in the SP, while the lowest percentage of 0.85% was detected in the LRP. While for total H, highest percentage of 1.81 was detected in the SP, while the lowest percentage of 0.36 was detected in the NDP. For total N, the highest percentage of 1.33 was detected in the SP, while the lowest percentage of 0.14 was detected in the NDP. For total S, the highest percentage of 0.46 was detected in the EdU, while the lowest percentage of 0.05 was detected in the KLP.

3.3 Concentration of PAHs in soil samples

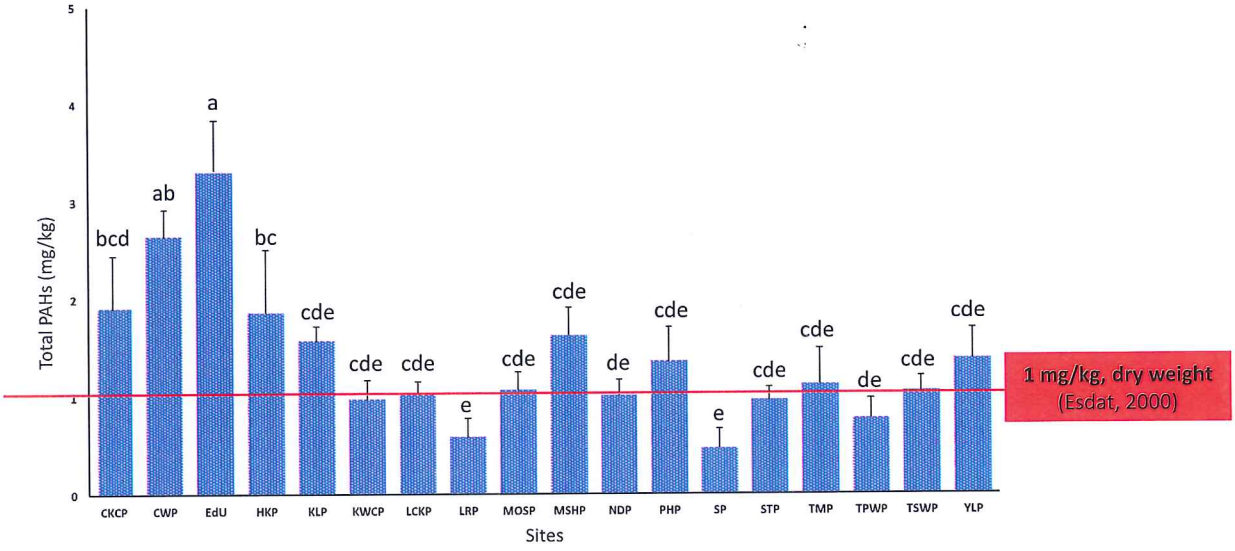

Fig. 15. Total concentrations of PAHs (mg/kg) in the soil of the 18 sites (n=5). Different letters for each site indicate significant difference between sampling sites at the level of $P < 0.05$ according to Duncan multiple range test.

According to figure 15, total PAHs (mg/kg) in soil samples ranged from 0.47 to 3.33. By referring to the Dutch guideline (Esdat, 2000), 13 out of the 18 sampling sites were found to exceed the Dutch Target Values (DTVs) (i.e., 1 mg/kg). DTVs for soils were established by Ministry of Housing, Spatial Planning, and the Environment, which was used in evaluating "uncontaminated" land in order to protect sustainable soil quality and ecological health (Chan et al., 2017). In particular, the maximum concentration of 3.98 mg/kg was detected in the EdU, while the minimum concentration of 0.74 mg/kg was detected in the SP.

The limit of detection (LOD) for all congeners of PAHs was 5 ng/kg. Table 3 indicated that the concentrations of each PAHs showed that only the concentration of Acenaphthene (Ace) and Benzo[g,h,i]perylene (BP) were below the detection limit in over half of the samples.

Table 3. Total PAHs concentration (mg/kg, dry weight) in 18 urban parks in Hong Kong.

PAHs congener	Nap†		Ace		Phe	Ant	Flu	Pyr	BaA	Chr	B(b)F	B(k)F	BaP	IP	DA	BP	Total PAHs
CKCP	0.977 ±0.171bcde	0.010 ±0.007c	0.037 ±0.011c	0.017 ±0.017efg	0.108 ±0.036ab	LOD	0.002 ±0.002b	0.017 ±0.017b	0.178 ±0.089abcd	0.205 ±0.083abcd	0.258 ±0.088abc	0.261 ±0.088abc	0.117 ±0.060abcd	0.042 ±0.013ab	0.003 ±0.003ab	0.021 ±0.021a	.253 ±0.242
CWP	1.410 ±0.207b	0.009 ±0.002c	0.043 ±0.011c	0.091 ±0.030bcd	0.120 ±0.014a	LOD	0.014 ±0.008b	0.019 ±0.019b	0.193 ±0.099abc	0.296 ±0.092a	0.344 ±0.099ab	0.342 ±0.096ab	0.189 ±0.055a	0.052 ±0.020a	LOD	0.032 ±0.032a	3.153 ±0.346
EdU	3.083 ±0.452a	0.146 ±0.021a	0.439 ±0.051a	0.009 ±0.002fg	0.017 ±0.002cd	0.023 ±0.004b	0.012 ±0.007b	LOD	0.037 ±0.013cde	0.034 ±0.012e	0.043 ±0.020cd	0.044 ±0.021cd	0.074 ±0.035abcd	0.001 ±0.001d	0.009 ±0.007ab	0.001 ±0.001a	3.971 ±0.764
HKP	0.642 ±0.143cdef	0.011 ±0.005c	0.017 ±0.007c	0.064 ±0.028bcdefg	0.070 ±0.035abcd	LOD	0.005 ±0.005b	LOD	0.254 ±0.123a	0.256 ±0.124ab	0.467 ±0.274a	0.465 ±0.277a	0.115 ±0.071abcd	0.031 ±0.012abc	0.001 ±0.001b	0.024 ±0.015a	2.421 ±0.206
KLP	0.749 ±0.085cdef	0.004 ±0.002c	LOD	0.023 ±0.008cdefg	0.028 ±0.006bcd	LOD	0.008 ±0.008b	LOD	0.211 ±0.032ab	0.220 ±0.034abc	0.203 ±0.027bcd	0.204 ±0.027bcd	0.133 ±0.017abc	0.023 ±0.003bcd	LOD	LOD	.807 ±0.192
KWCP	0.570 ±0.085cdef	0.003 ±0.002c	LOD	0.092 ±0.033bcd	0.085 ±0.030abc	0.036 ±0.036b	0.009 ±0.004b	0.008 ±0.008b	0.066 ±0.036bcde	0.072 ±0.049cde	0.150 ±0.047bcd	0.120 ±0.041bcd	0.014 ±0.01cd4	0.004 ±0.001d	0.004 ±0.002ab	LOD	1.234 ±0.140
LCKP	0.616 ±0.082cdef	0.005 ±0.002c	LOD	0.020 ±0.009defg	LOD	0.056 ±0.029b	0.002 ±0.002b	0.002 ±0.002b	0.051 ±0.018cde	0.060 ±0.021de	0.144 ±0.026bcd	0.148 ±0.025bcd	0.084 ±0.020abcd	0.014 ±0.002cd	LOD	LOD	1.199 ±0.152
LRP	0.330 ±0.059ef	LOD	LOD	0.084 ±0.016bcde	0.093 ±0.024abc	0.099 ±0.026b	LOD	0.002 ±0.002b	0.046 ±0.019cde	0.046 ±0.019e	0.076 ±0.031cd	0.084 ±0.036cd	0.003 ±0.003d	0.006 ±0.002d	LOD	LOD	0.868 ±0.083
MOSP	0.590 ±0.104cdef	0.006 ±0.004c	LOD	0.168 ±0.015a	0.115 ±0.010a	LOD	0.009 ±0.006b	0.001 ±0.001b	0.077 ±0.032bcde	0.076 ±0.030cde	0.161 ±0.031bcd	0.136 ±0.041bcd	0.054 ±0.032bcd	0.013 ±0.004cd	0.011 ±0.005ab	LOD	1.416 ±0.147
MSHP	1.213 ±0.288bc	0.004 ±0.002c	0.057 ±0.016c	0.093 ±0.026bc	0.094 ±0.035abc	0.024 ±0.024b	0.019 ±0.003ab	0.001 ±0.001b	0.077 ±0.007bcde	0.065 ±0.015de	0.094 ±0.011cd	0.069 ±0.024cd	0.053 ±0.009bcd	0.011 ±0.002cd	0.004 ±0.002ab	LOD	1.878 ±0.294
NDP	0.681 ±0.142cdef	LOD	LOD	0.079 ±0.035bcdef	0.066 ±0.030abcd	0.065 ±0.028b	0.010 ±0.007b	0.002 ±0.002b	0.021 ±0.013de	0.032 ±0.014e	LOD	LOD	0.125 ±0.024abcd	0.010 ±0.001cd	0.003 ±0.003ab	LOD	1.094 ±0.168
PHP	1.006 ±0.304bcd	0.003 ±0.002c	LOD	0.135 ±0.030ab	0.064 ±0.030abcd	0.065 ±0.052b	0.016 ±0.007ab	0.005 ±0.005b	0.044 ±0.019cde	0.040 ±0.017e	0.091 ±0.010cd	0.072 ±0.020cd	0.044 ±0.011bcd	0.010 ±0.002cd	0.004 ±0.002ab	LOD	1.597 ±0.245
SP	0.292 ±0.184f	0.080 ±0.017b	0.110 ±0.049b	0.0030 ±0.0012g	0.025 ±0.008bcd	0.033 ±0.011b	0.021 ±0.006ab	0.049 ±0.008a	0.005 ±0.002e	0.005 ±0.001e	0.029 ±0.018cd	0.029 ±0.019cd	0.049 ±0.031bcd	0.006 ±0.002d	0.005 ±0.005ab	LOD	0.741 ±0.072
STP	0.738 ±0.092cdef	0.001 ±0.001c	0.027 ±0.011c	0.079 ±0.021bcdef	0.062 ±0.028abcd	LOD	0.007 ±0.003b	0.001 ±0.001b	0.033 ±0.016cde	0.049 ±0.016de	0.111 ±0.027bcd	0.048 ±0.024cd	0.019 ±0.017cd	0.007 ±0.004cd	0.003 ±0.002ab	LOD	185 ±0.180
TMP	0.919 ±0.317bcdef	0.003 ±0.001c	0.030 ±0.014c	0.103 ±0.022b	0.072 ±0.029abcd	LOD	0.003 ±0.0020b	LOD	0.024 ±0.012de	0.018 ±0.013	0.064 ±0.015cd	0.065 ±0.015cd	0.018 ±0.008cd	0.005 ±0.001d	0.002 ±0.002b	LOD	1.324 ±0.225
TPWP	0.366 ±0.076def	LOD	LOD	0.062 ±0.018bcdefg	0.077 ±0.023abcd	0.020 ±0.020b	0.003 ±0.003b	LOD	0.065 ±0.029bcde	0.051 ±0.031de	0.120 ±0.039bcd	0.118 ±0.041bcd	0.060 ±0.029bcd	0.011 ±0.003cd	LOD	LOD	0.954 ±0.092
TSWP	0.355 ±0.051def	LOD	LOD	0.094 ±0.025bc	0.137 ±0.029a	0.282 ±0.136a	0.044 ±0.038a	LOD	0.014 ±0.009e	0.013 ±0.009e	0.120 ±0.039bcd	0.122 ±0.040bcd	0.061 ±0.017bcd	0.016 ±0.013cd	0.019 ±0.019a	0.008 ±0.008a	1.286 ±0.105
YLP	0.496 ±0.184def	0.001 ±0.001c	0.026 ±0.013c	0.084 ±0.019bcde	0.109 ±0.025ab	0.086 ±0.030b	0.012 ±0.006b	0.019 ±0.019b	0.142 ±0.049abcde	0.126 ±0.056bcde	0.212 ±0.064bcd	0.209 ±0.067bcd	0.164 ±0.069ab	0.025 ±0.008bcd	0.003 ±0.001ab	0.017 ±0.017a	1.729 ±0.126

† Nap: naphthalene, A: acenaphthylene, Ace: acenaphthene, F: fluorine, Phe: phenanthrene, Ant: anthracene, Flu: fluoranthene, Pyr: pyrene, BaA: benz[a]anthracene, Chr: chrysene, B(b)F: benzo[b]fluoranthene, B(k)F: benzo[k]fluoranthene, BaP: benzo[a]-pyrene, IP: indeno[1,2,3-cd]pyrene, DA: dibenz[a,h]anthracene, BP: benzo[g,h,i]perylene.

Within each PAHs congener, means with the same letter are not significantly different according to Duncan's Multiple Range Test at 5% level. The bolded column indicated the concentration between the 18 urban parks is significant.

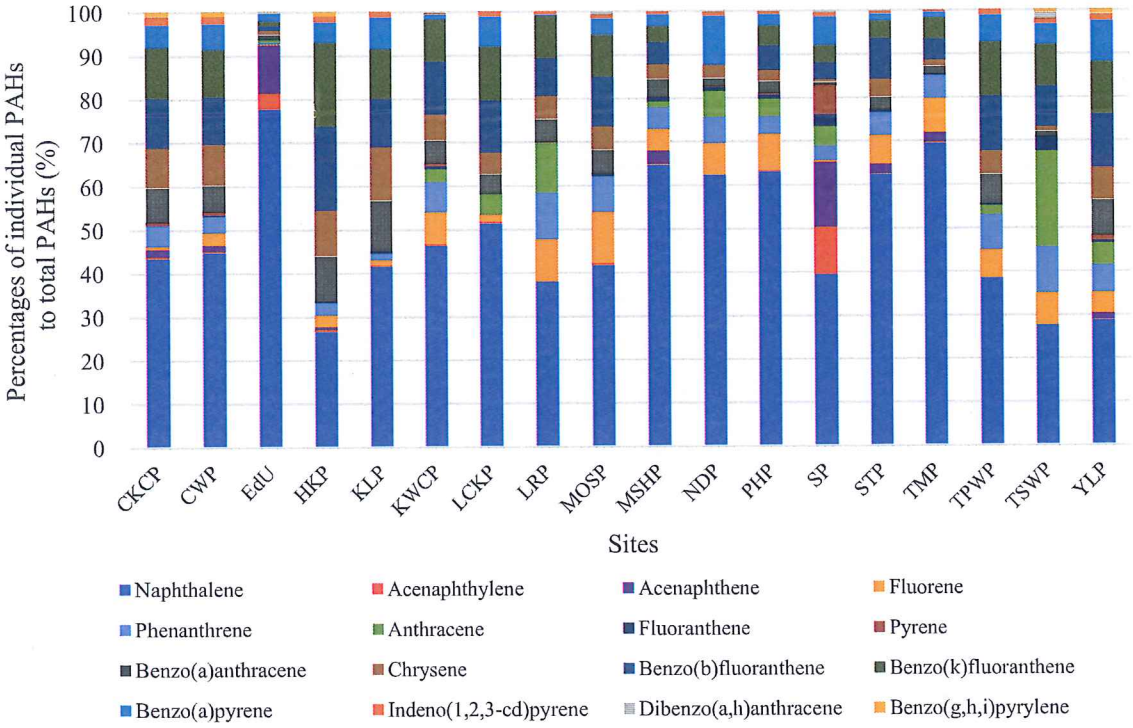

Fig. 16. A relative concentration in percentage of individual PAHs to total PAHs in the soil of the 18 sites.

The PAHs profile of sampling soils is presented in Fig. 16. Naphthalene (two-ring PAH) were dominated over all study sites, accounting 27.6% to 77.6% of the total concentrations. As naphthalene (Nap) mainly exists in gaseous phase and can be transported to a long distance which may explain the dominance over 18 sites (Zhang et al., 2006). Compared the sources of PAHs in United States (US), it was also suspected that the largest emission source of atmospheric naphthalene in Hong Kong was mainly combustion of fossil fuel in electricity generation, vehicles, followed by the use as a moth repellent (ATSDR, 2005; Jia & Batterman, 2010)

3.4 Statistical relationship between the soil samples properties and trees grown in study sites by using bivariate Pearson correlation analysis

The correlation analyses between the fungal infection rate, chemical parameters of soil samples with PAHs concentration in soil samples over all study sites was shown in Table 4. The result shows that TOC and pH had a negative correlation with the fungal infection rate, whereas the IP and BP had a positive correlation with the fungal infection rate. Both congeners belong to high molecular weight PAHs which have 6 aromatic rings in their structure, and BP is one of the PAHs that was proved to be utilized by one kind of wood decaying fungi in laboratory study (Wolter et al., 1997).

Table 4. Correlation coefficients (r) between fungal infection rate and chemical parameters of soil samples over all study sites.

	pH	EC	Redox	C	H	N	S	Nitrate	TOC
Infection rate	-0.240*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.293

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 5. Correlation coefficients (r) between fungal infection rate and the concentration of total PAHs and 16 congeners in soil samples over all study sites.

	Nap	A	Ace	F	Phe	Ant	Flu	Pyr	BaA	Chr	BbF	BkF	BaP	IP	DA	BP	Total PAHs
Infection rate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.285**	n.s.	-0.211*	n.s.

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

3.5 Statistical relationship between the soil samples properties and trees grown in study sites by using principal component analysis (PCA)

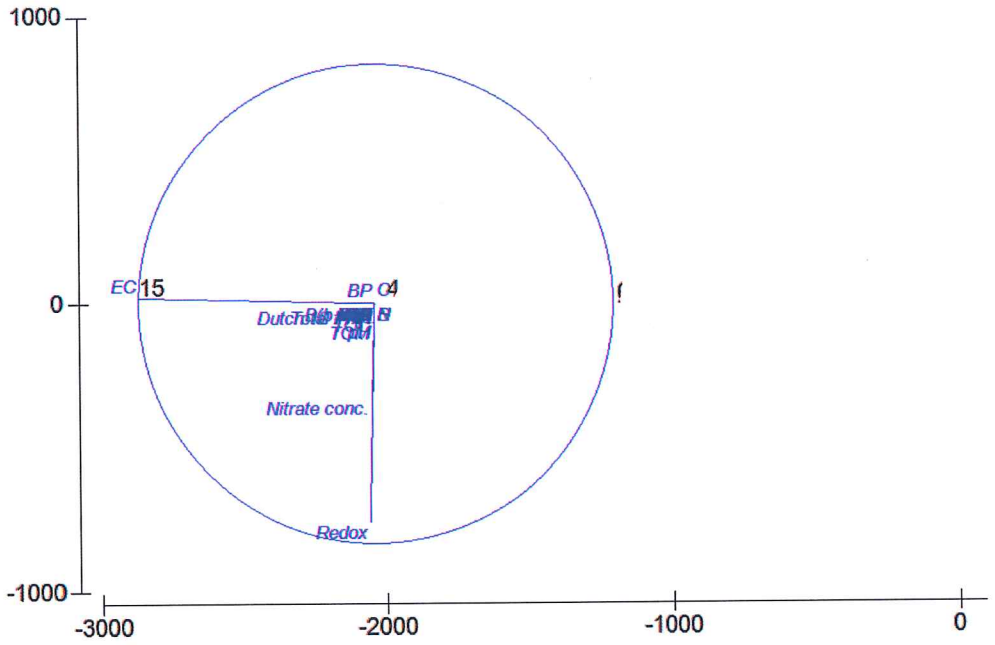

Fig. 17. PCA analysis of the fungal infection rate and chemical parameters of soil samples taken in the study sites.

Table 6. Rotated component matrix

Component	Eigenvalues	
	1	2
pH	-0.004	-0.075
EC	-1.000	0.025
Redox potential	-0.022	-0.910
C	0.000	0.003
H	0.000	-0.002
N	0.000	0.000
S	0.000	0.000
TOC	-0.003	-0.047
Nitrate-N	-0.011	-0.394
Total PAHs	-0.001	-0.016
Nap	0.000	-0.011
A	0.000	0.000
Ace	0.000	-0.001
F	0.000	0.000
Phe	0.000	0.000
Ant	0.000	0.000
Flu	0.000	0.000
Pyr	0.000	0.000
BaA	0.000	0.000
Chr	0.000	-0.001
BbF	0.000	0.000
BkF	0.000	-0.001
BaP	0.000	0.000
IP	0.000	0.000
DA	0.000	0.000
BP	0.000	0.000

PCA is performed on the fungal infection rate and chemical parameters of the soil samples obtained in all study sites. Sites of greater similarities are plotted closer together, while sites of low similarity are further apart. The PCA figure showed there is one majority of grouped sites similar in composition of soil (Fig. 16). The contribution of each principal component and its eigenvalue after rotation are presented in Table 5. Two principal components (eigenvalue >1) control 99.9% of variations in the fungal infection rate over 18 urban parks. The first component is the most significant principal, which represents 99.7% of the variance in the fungal infection rate, and is largely influenced by EC. According to Fig. 6, Only 4 of the sampling sites (i.e., HKP, MSHP, TMP and TPWP) had the optimal EC values in soil ranges from 1000 to 5000 μs/cm, where plants have sufficient nutrients in the form of free ions for healthy growth (Development Bureau, 2022). Studies have been done on the effects of different EC values on vegetable growth and found out that too low EC values would limit plant growth by inhibiting plant leaf development and lowering photosynthetic rates due to nutrient deficiency (Ding et al., 2018), which may further cause the trees susceptible to the infection of fungi.

The second component explains 0.2% of variance in the fungal infection rate and are moderately influenced by redox potential and the concentration of nitrate. The relatively low redox potential (i.e., <350 mV) in all the study sites may further cause

the trees being more susceptible to the infection of wood-decaying fungi by leading to photosynthesis reduction (Pezeshki, 2001; Pennington & Walters, 2006). Furthermore, as unfavourable concentration of nitrate is found in most of the study sites (Fig. 9 & 10), tree growth may also be severely restricted due to nitrogen deficiency and reduction of beneficial soil organisms that can suppress soil diseases (Bagshaw, Moody & Pattison, 2010), and hence may cause the trees being more susceptible to the infection of fungi.

3.6 Statistical relationship between the soil samples properties and trees grown in study sites by using hierarchical cluster analysis

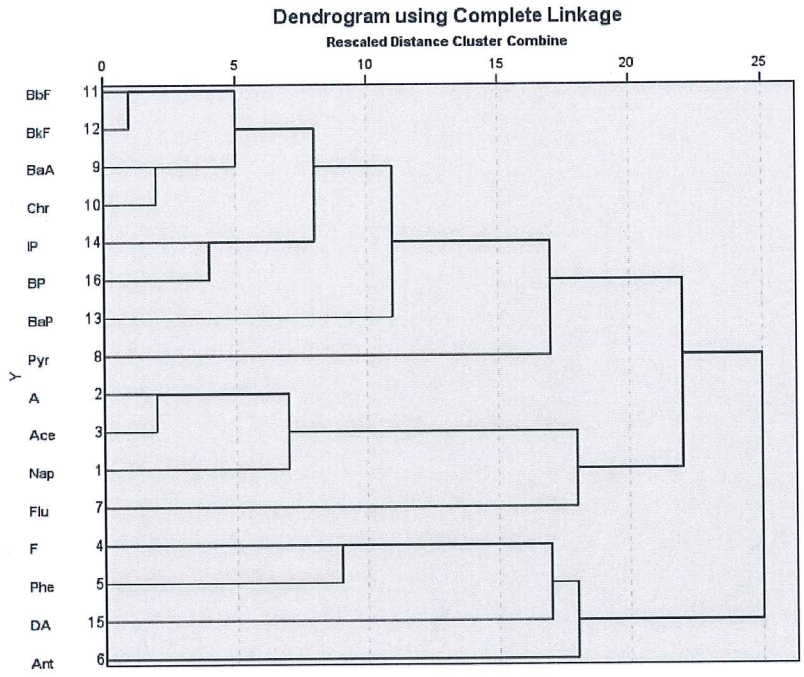

Fig. 18. Hierarchical dendrogram for 16 individual PAHs in soils samples using average linkage between groups and Pearson correlation as measure interval.

Hierarchical Cluster analysis was performed to identify the homogeneous groups of individual PAHs in Hong Kong soils. The results presented in the dendrogram (Fig. 17) distinguished the 14 individual PAHs into two major groups. The first major group was subdivided into two subgroups. The first subgroup consisted of BbF, BkF, BaA, Chr, IP, BP, BaP and Pyr; while the second subgroup consisted of A, Ace, Nap and Flu. The second major group also contained two subgroups. The first one consisted of F, Phe and DA, and the second comprised of Ant.

3.7 Statistical analysis of relationship between the soil samples properties and individual infected tree species in corresponding study sites

Table 7. Top 5 most tree species that were found with the highest fungal infection rates by wood decay fungi

	Scientific name of the tree species	**Infection rate (%)**
1	*S campanulata*	10.98 ± 0.15 (highest)
2	*F microcarpa*	7.45 ± 0.20
3	*A confusa*	6.67± 0.25
4	*C camphora*	6.67 ± 0.17
5	*L speciosa*	5.88 ±0.10 (lowest)

Due to variations in genetics of different species, growth stage, and external environment in different study sites, bivariate Pearson correlation analysis and PCA was conducted using data from the top five tree species with the highest infection rates (listed in table 6) to elucidate the relationship between certain species with the chemical parameters.

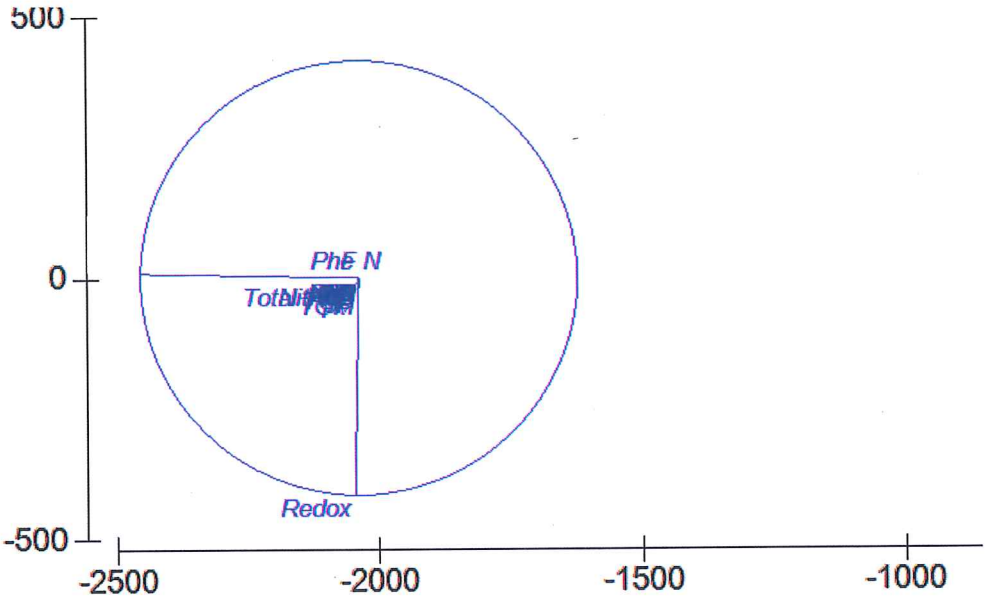

Fig. 19. PCA analysis of the fungal infection rate of *S. campanulata* and chemical parameters of soil samples taken in the study sites

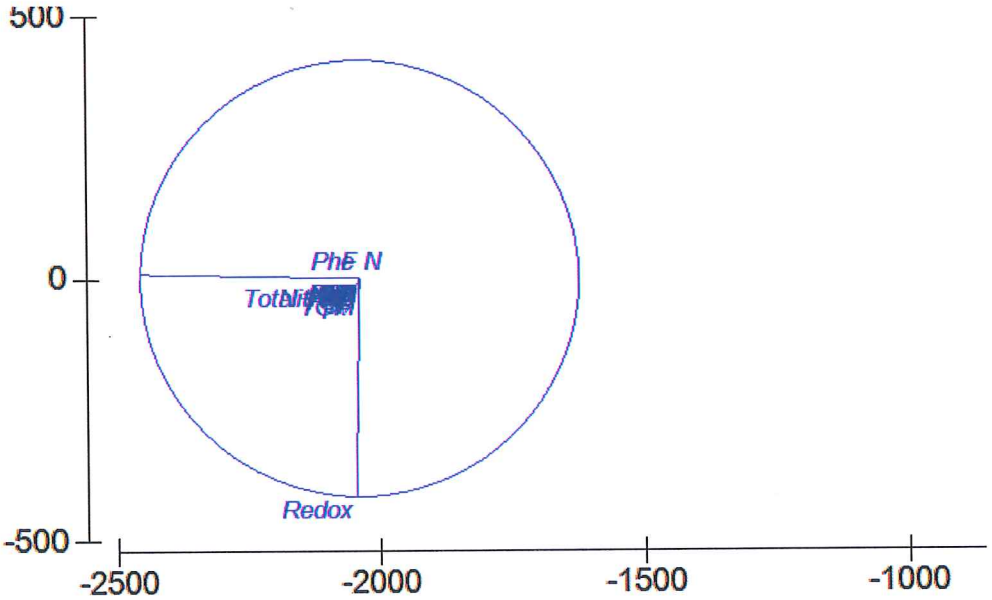

Fig. 20. PCA analysis of the fungal infection rate of *F. microcarpa* and chemical parameters of soil samples taken in the study sites

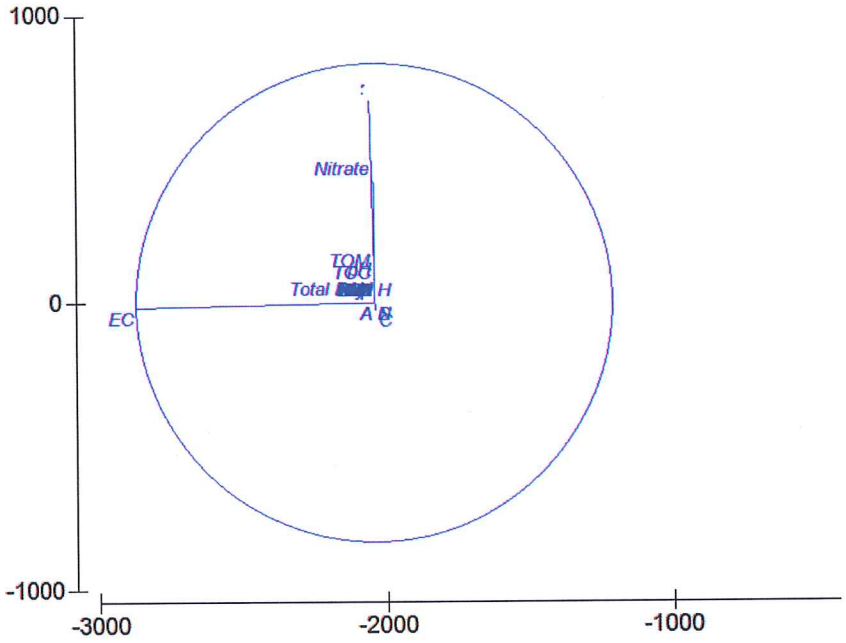

Fig. 21. PCA analysis of the fungal infection rate of F. microcarpa and chemical parameters of soil samples taken in the study sites.

3.7.1. Statistical relationship between the soil samples properties and S. campanulata, F. microcarpa and A. confusa grown in study sites by using principal component analysis (PCA)

For *S. campanulata*, the contribution of each principal component and its eigenvalue after rotation are presented in Fig 19 and appendix 1. Two principal components (eigenvalue >1) control 99.9% of variations in the fungal infection rate. The first component is the most significant principal, which represents 99.7% of the variance in the fungal infection rate, and is largely influenced by EC. The second and

third component explains 0.2% of variance in the fungal infection rate and is moderately influenced by redox potential.

For *F. microcarpa*, the contribution of each principal component and its eigenvalue after rotation are presented in Fig 20 and appendix 2. Two principal components (eigenvalue >1) control 99.9% of variations in the fungal infection rate. The first component is the most significant principal, which represents 99.7% of the variance in the fungal infection rate, and is largely influenced by EC. The second component explains 0.2% of variance in the fungal infection rate and is moderately influenced by the concentration of nitrate and redox potential.

For *A. confusa*, the contribution of each principal component and its eigenvalue after rotation are presented in Fig 21 and appendix 3. Two principal components (eigenvalue >1) control 99.9% of variations in the fungal infection rate. The first component is the most significant principal, which represents 99.9% of the variance in the fungal infection rate, and is largely influenced by EC. The second component explains 0.1% of variance in the fungal infection rate and is slightly influenced by the concentration of nitrate and redox potential.

According to the PCA result of the top three tree species with the highest fungal infection rate, EC and redox potential were found to be the most influential factors in controlling the fungal infection rate of *S. campanulata*, while EC, the concentration of

nitrate and redox potential were found to be the most influential factors in controlling the fungal infection rate of *F. macrocarpa* and *A. confusa*. The results of these three tree species were found in alignment of the general PCA result covering all species and study sites.

Generally, low EC value found in all study sites (Fig. 6) may limit the tree growth by inhibiting plant leaf development and lowering photosynthetic rates due to nutrient deficiency (Ding et al., 2018). Low redox potential found in all sites (Fig. 7) may lead to photosynthesis reduction of the tree species (Pezeshki, 2001; Pennington & Walters, 2006). Unfavourable concentration of nitrate is found in most of the study sites (Fig. 9 & 10), tree growth may also be severely restricted due to nitrogen deficiency and reduction of beneficial soil organisms that can suppress soil diseases (Bagshaw, Moody & Pattison, 2010). In this sense, above studies may also apply in *S. campanulata* in this study as low EC, redox potential and the concentration of nitrate may be the reasons explaining why *S. campanulata*, *F. macrocarpa* and *A. confusa* to be more readily infected by wood decay fungi when compared to other species.

Table 8. Correlation coefficients (r) between fungal infection rate and chemical parameters of soil samples from the study sites where *S. campanulata* was found infected

	pH	EC	Redox	C	H	N	S	Nitrate	TOC
Infection rate	n.s.	-0.342	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 9. Correlation coefficients (r) between fungal infection rate and the concentration of total PAHs and 16 congeners in soil samples from the study sites where *S. campanulata* was found infected

	Nap	A	Ace	F	Phe	Ant	Flu	Pyr	BaA	Chr	BbF	BkF	BaP	IP	DA	BP	Total PAHs
Infection rate	0.760**	0.581	0.630*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.676

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 10. Correlation coefficients (r) between fungal infection rate and chemical parameters of soil samples from the study sites where *F. microcarpa* was found infected

	pH	EC	Redox	C	H	N	S	Nitrate	TOC
Infection rate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 11. Correlation coefficients (r) between fungal infection rate and the concentration of total PAHs and 16 congeners in soil samples from the study sites where *F. microcarpa* was found infected

	Nap	A	Ace	F	Phe	Ant	Flu	Pyr	BaA	Chr	BbF	BkF	BaP	IP	DA	BP	Total PAHs
Infection rate	0.544	0.442**	0.490	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.317**	n.s.	0.463

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 12. Correlation coefficients (r) between fungal infection rate and chemical parameters of soil samples from the study sites where *A. confusa* was found infected

	pH	EC	Redox	C	H	N	S	Nitrate	TOC
Infection rate	n.s.	n.s.	0.467*	-0.358*	0.469**	n.s.	n.s.	n.s.	-0.474*

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 13. Correlation coefficients (r) between fungal infection rate and the concentration of total PAHs and 16 congeners in soil samples from the study sites where *A. confusa* was found infected

	Nap	A	Ace	F	Phe	Ant	Flu	Pyr	BaA	Chr	BbF	BkF	BaP	IP	DA	BP	Total PAHs
Infection rate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.426*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

3.7.2. Statistical relationship between the soil samples properties and S. campanulata, F. microcarpa and A. confusa grown in study sites by using bivariate Pearson correlation analysis

In particular, the bivariate Pearson correlation analyses between the fungal infection rate of *S. campanulata* and chemical parameters of soil samples was shown in Table 7. The result shows that EC had a negative correlation with the fungal infection rate, meaning that when the EC value decreases, the fungal infection rate of *S. campanulata* increases. This further corroborates that low EC values may particularly inhibit the growth of *S. campanulata* and hence increasing its fungal infection rate. Conversely, the result also showed that Total PAHs, Nap, A and Ace and BP had a positive correlation with the fungal infection rate, meaning that two variables tend to increase together.

The bivariate Pearson correlation analyses between the fungal infection rate of *F. macrocarpa* and chemical parameters of soil samples was shown in Table 8. The result shows that the total PAHs, Nap and Ace had a positive correlation with the fungal infection rate, meaning that two variables tend to increase together. According to a study conducted by Azhari, Dalimin and Wee (2011) in Malaysia, accumulation pattern of PAHs compounds in leaves samples of *F. macrocarpa* was detected, as they pointed out that this species has one of the waxiest surfaces of leaves and hence

greater ability to accumulate the highest amount of PAHs in the leaves. The absorption of low molecular weight (LMW) PAHs (e.g., Nap, Ace) in the atmosphere may be more possible to be absorbed into the inner tissues of the leaf through by passive diffusion through the hydrophobic cuticle and the stomata (Molina & Segura, 2021). Furthermore, the presence of PAHs above particular doses can pose detrimental effects on plant growth and biomass yield which may cause *F. macrocarpa* to be more susceptible to the fungal infection (Molina & Segura, 2021).

Lastly, the bivariate Pearson correlation analyses between the fungal infection rate of *A. confusa* and chemical parameters of soil samples was shown in Table 9. The result shows that total C, TOC and Flu had a negative correlation with the fungal infection rate, meaning when total C, TOC and Flu decreases, fungal infection rate increases. This pinpoint that *A. confusa* may be particularly sensitive to the soil organic matter which largely contributes to the soil fertility by reducing the soil bulk density and increasing the amount of plant-available water storage in soil. In contrary, the redox potential and total H had a positive correlation with the fungal infection rate, meaning that when redox potential and total H increases, fungal infection rate also tends to increase. Focusing on redox potential which is generally more dominant in controlling the fungal infection rage among all study sites according to the PCA result, a study conducted in Côte d'Ivoire by Emile and his colleagues (2020) aimed at

investigating the adaptation of *Acacia* seedlings (i.e., *mangium*, *auriculiformis* and *crassicarpa*) in polluted soils in laboratory conditions. In addition, it was found the tested *Acacia* species had growth rates and biomass production rates in redox potential from -96.34 mV to -63.31 mV and concluded that the lower is the redox potential, the higher is the content of metals being absorbed (Emile et al., 2020). Thus, it may explain the positive correlation between redox potential and fungal infection rate as lower redox potential in urban soils may create a more advantageous environment for certain *Acacia* species to grow.

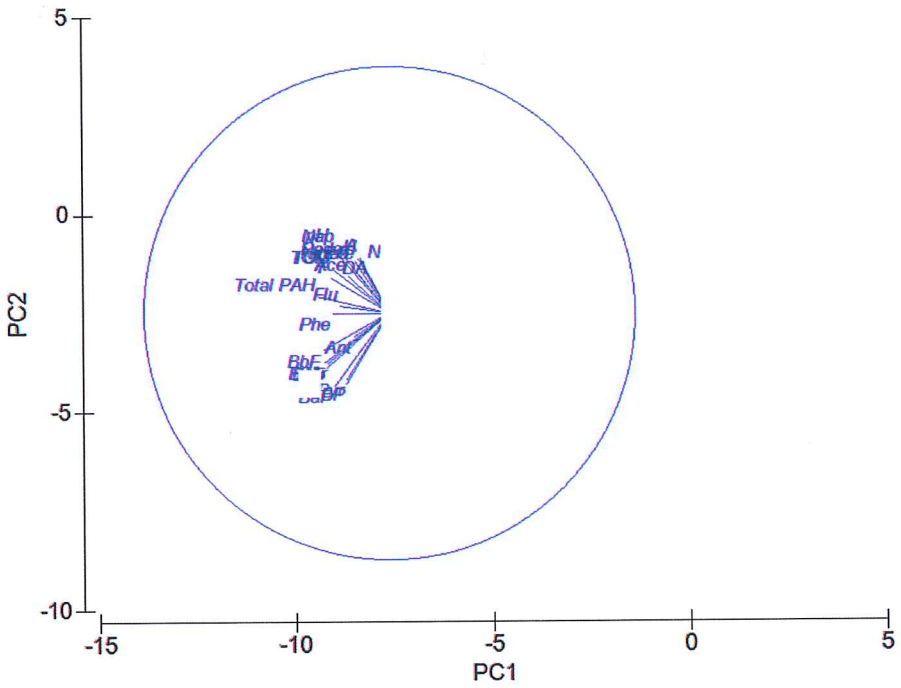

Fig. 21. PCA analysis of the fungal infection rate of C. camphora and chemical parameters of soil samples taken in the study sites

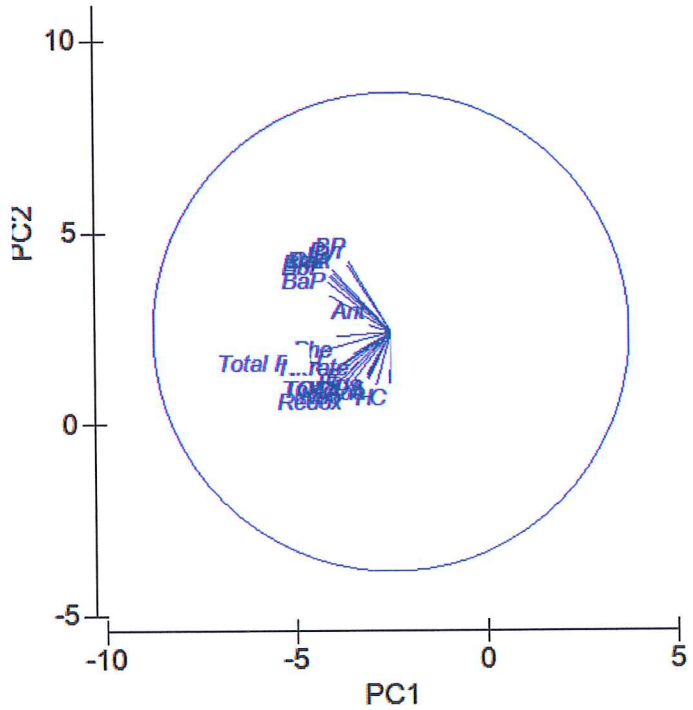

Fig. 22. PCA analysis of the fungal infection rate of *L. speciosa* and chemical parameters of soil samples taken in the study sites

3.7.3. Statistical relationship between the soil samples properties and C. camphora and L. speciosa grown in study sites by using principal component analysis (PCA)

For *C. camphora*, the contribution of each principal component and its eigenvalue after rotation are presented in Fig. 21 and appendix 4. Three principal components (eigenvalue >1) control 62% of variations in the fungal infection rate. The first component is the most significant principal, which represents 38.8% of the variance in the fungal infection rate, and is largely influenced by total PAHs, BbF, BaA and IP. The second component explains 15.4% of variance in the fungal infection rate, and is moderately influenced by BaP, BP and Pyr. The third component explains 7.8% of variance in the fungal infection rate, and is slightly influenced by C and EC.

For *L. speciosa*, the contribution of each principal component and its eigenvalue after rotation are presented in Fig. 22 and appendix 5. Three principal components (eigenvalue >1) control 66.1% of variations in the fungal infection rate. The first component is the most significant principal, which represents 36.1% of the variance in the fungal infection rate and is largely influenced by total PAHs and pH. The second component explains 18.5% of variance in the fungal infection rate, and is moderately influenced by BP, Pyr and IP. The third component explains 11.5% of variance in the fungal infection rate, and is also moderately influenced by Ace and A.

As the fungal infection rate of both *C. camphora* and *L. speciosa* are found to largely influenced by total PAHs. According to Fig. 17, 13 out of the 18 sampling sites were found to exceed the DTVs (i.e., 1 mg/kg, dry weight) in PAHs (Esdat, 2000), meaning that most soil samples were contaminated by PAHs. It was suspected that there are two absorption mechanisms of PAHs by plants, which are by 1) passive diffusion of atmospheric PAHs through the cuticle and stomata of the leaf and by 2) root uptake and subsequently transferred between the whole plant via transpiration (Molina & Segura, 2021). Although LMW-PAHs can probably be taken up by both absorption mechanism, whereas root uptake is the main entrance pathway for high molecular weight (HMW) PAHs (Molina & Segura, 2021). However, the presence of PAHs above certain doses has detrimental effects on plant germination and growth and biomass yield, especially lead to shorter roots and lower root weight (Molina & Segura, 2021). The PCA result may point out that these two species are more sensitive to the presence of PAHs which is found to largely influence their fungal infection rate.

Particularly, some HMW-PAHs (i.e., Pyr, BaA, BbF, IP, BaP and BP) were found to play an important role in controlling the fungal infection rate of *C. camphora*. A study conducted in Shang Hai found that 16 individual PAHs were observed in the *C. camphora* leaves, and the total PAHs were found to significantly positively correlated with the industry, road, business, and residential areas due to traffic and

industrial emissions (Yin et al., 2020). The study further found that the PAHs profile observed in the *C. camphora* leaves was dominated by the medium molecular weight and HMW-PAHs as they are more difficult to degrade in the environment (Yin et al., 2020). Hence, the PCA result in this study may further indicate that the accumulation of PAHs in *C. camphora* may also be an important factor determining its fungal infection rate.

By looking at the PCA result, the fungal infection rate of *L. speciosa* was also found to largely influenced by pH, meaning that changes in soil pH may possibly affect its susceptibility to wood decay fungi. Although all soils obtained in this study fell into the range of pH 5.5 to 8.0 in which most plants will grow favourably, soil pH value can fluctuate daily due to various environmental conditions and anthropogenic activities. As soil pH affects soil micro-environment such as its chemistry, microbiology and enzyme activities, nutrient availability, and dissolution and mineralization of organic matter, pH value that goes beyond 8.0 or below 5.5 may lead to nutrient deficiencies, especially for those species which are sensitive to soil pH (Development Bureau, 2022).

Table 14. Correlation coefficients (r) between fungal infection rate and chemical parameters of soil samples from the study sites where *C. camphora* was found infected

	pH	EC	Redox	C	H	N	S	Nitrate	TOC
Infection rate	n.s.	n.s.	0.467*	n.s.	0.469**	n.s.	n.s.	n.s.	-0.474*

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 15. Correlation coefficients (r) between fungal infection rate and the concentration of total PAHs and 16 congeners in soil samples from the study sites where *C. camphora* was found infected

	Nap	A	Ace	F	Phe	Ant	Flu	Pyr	BaA	Chr	BbF	BkF	BaP	IP	DA	BP	Total PAHs
Infection rate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.426*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 16. Correlation coefficients (r) between fungal infection rate and chemical parameters of soil samples from the study sites where *L. speciosa* was found infected

	pH	EC	Redox	C	H	N	S	Nitrate	TOC
Infection rate	n.s.	n.s.	0.467*	-0.358*	0.469**	n.s.	n.s.	n.s.	-0.474*

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

Table 17. Correlation coefficients (r) between fungal infection rate and the concentration of total PAHs and 16 congeners in soil samples from the study sites where *L. speciosa* was found infected

	Nap	A	Ace	F	Phe	Ant	Flu	Pyr	BaA	Chr	BbF	BkF	BaP	IP	DA	BP	Total PAHs
Infection rate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.426*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Values that are given asterisks means that the p values are less than 0.05 (*) and 0.01 (**) respectively, whereas n.s. is shown when p values are larger than 0.05.

3.7.4. Statistical relationship between the soil samples properties and C. camphora and L. speciosa grown in study sites by using bivariate Pearson correlation analysis

The Pearson correlation analyses between the fungal infection rate of *C. camphora* and *L. speciosa* and chemical parameters of soil samples was shown in Table 10 and 11. For *C. camphora*, the result shows that C had a negative correlation with its fungal infection rate, whereas the redox potential, pH, H, S and DA had a positive correlation with the fungal infection rate. While for *L. speciosa*, the result shows that F had a negative correlation with its fungal infection rate, whereas the Nap, A, Ace, BkF and total PAHs had a positive correlation with its fungal infection rate.

3.8 Potentials of usiing soil properties as indicators of fungal infected trees

Overall, the general result from PCA indicated that EC, redox potential and the concentration of nitrate are the most important soil parameters that are associated with fungal infection rates in urban trees (Fig. 17 & Table 6). The result of bivariate Pearson correlation between the fungal infection rate of tree species (i..e., *S. campanulata*) and the soil properties further shows that low EC value may be related to high fungal infection rate. It is also noteworthy that low redox potential may create a more favourable environment for certain species (i.e., *A. confus* & *L, speciosa*) which links to a lower fungal infection rate. The above result suggests that aside from conducting visually identification of wood decay fungi based on the signs (e.g.,

fruiting bodies, mycelial net) and symptoms that are usually found in an advanced stage, some soil parameters such as EC, redox potential and the concentration of nitrate can also serve as an indicator to predict the tree health, and hence the fungal infection rate of a particular area in an much earlier stage.

Moreover, as most soil samples were found to be contaminated by PAHs according to the Dutch guideline (Esdat, 2000) (Fig. 15), it is necessary to examine the relationship between the concentration of PAHs and the fungal infection rate. By looking at the result from bivariate Pearson correlation, positive correlation between the concentration of LMW-PAHs (i.e., Nap, A, Ace, etc.) and certain tree species (i.e., *S. campanulata* & *F. macrocarpa*). Since LMW-PAHs was found to be the dominant PAHs in the soil samples, it is highly possible that certain concentration of PAHs is accumulated in the plant through passive diffusion and root uptake which may consequently pose detrimental effects on the tree health when above certain doses ((Molina & Segura, 2021). In this sense, urban trees planted in the soils contaminated with PAHs may be more susceptible to the infection of wood decay fungi. Therefore, remediation of PAHs from contaminated urban soils may be needed as a control and preventive measurements of wood decay fungi colonized in the trees.

4. Conclusion

To conclude, this research project found that PAHs were determined in all sampling sites and the concentration in some sites even exceeded the target values listed in the new Dutch list (Esdat, 2000), while Naphthalene (Nap) was found dominated among all congeners of PAHs in all sampling sites. Then, wood-decaying fungi were found in all sampling sites, and the highest percentage of 24.3 was detected in the Lion Rock Park (LRP), while the lowest percentage of 0.78 was detected in the Education University of Hong Kong (EDU). Various infection rates over different study sites were found to changed accordingly, and it is suspected to be due to the trees' age, host specificity and also the growing conditions. Eventually, by looking at the result of PCA and bivariate Pearson correlation analysis, the most important soil physical and chemical parameters that are associated with fungal infection rates in urban trees species were found to be EC (PC1: 99.7%), redox potential and the concentration of nitrate (PC2: 0.2%). However, tree species (e.g., *S. campanulata*, *F. microcarpa*, *A. confusa*, *C. camphora*, *L. speciosa*, etc.) were found to be affected by different parameters (e.g., Total PAHs, LMW-PAHs, etc.) due to its characteristics. Further study of positive and negative relationship between fungal infection and tree health is recommended.

Based on the present investigations, further analysis focusing on the temporal pattern of the physical and chemical parameters and infection rate should be done to obtain a more comprehensive data. In addition, further in-depth study should be conducted to study the physical and chemical parameters of the bulk soil and rhizosphere soil in order to showcase a more accurate correlation between soil quality and fungal infection. Relationship between the synergistic effects of pest infection and fungal infection to the trees could be done as pest infection was also a serious concern in some of the urban trees in Hong Kong.

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7. Appendices

Appendix 1-1: Rotated component matrix of *S. campanulata*

Component	Eigenvalues	
	1	2
pH	0.005	-0.057
EC	-1.000	0.021
Redox potential	-0.020	-0.994
C	0.000	0.000
H	0.000	0.002
N	0.000	0.000
S	0.000	-0.001
TOC	-0.003	-0.037
Nitrate-N	-0.011	-0.025
Total PAHs	0.001	0.026
Nap	0.000	-0.020
A	0.000	-0.001
Ace	0.000	-0.003
F	0.000	0.000
Phe	0.000	0.000
Ant	0.000	0.000
Flu	0.000	0.000
Pyr	0.000	0.000
BaA	0.000	0.000
Chr	0.000	-0.001
BbF	0.000	-0.001
BkF	0.000	-0.001
BaP	0.000	0.001
IP	0.000	0.000
DA	0.000	0.000
BP	0.000	0.000

Appendix 1-2: Rotated component matrix of *F. macrocarpa*

Component	Eigenvalues	
	1	2
pH	0.001	0.024
EC	1.000	0.001
Redox potential	0.003	-0.307
C	0.000	-0.008
H	0.000	-0.002
N	0.000	0.000
S	0.000	0.000
TOC	-0.001	-0.022
Nitrate-N	0.000	0.950
Total PAHs	0.000	-0.003
Nap	0.000	-0.004
A	0.000	0.000
Ace	0.000	0.000
F	0.000	0.001
Phe	0.000	0.001
Ant	0.000	0.001
Flu	0.000	0.000
Pyr	0.000	0.000
BaA	0.000	-0.001
Chr	0.000	-0.001
BbF	0.000	0.000
BkF	0.000	0.000
BaP	0.000	-0.001
IP	0.000	0.000
DA	0.000	0.000
BP	0.000	0.000

Appendix 1-3: Rotated component matrix of *A. confusa*

Component	Eigenvalues	
	1	2
pH	-0.003	0.089
EC	-1.000	-0.020
BaP	-0.019	0.843
C	0.001	0.031
H	0.000	0.001
N	0.000	0.000
S	0.000	0.000
TOC	-0.002	0.072
Nitrate-N	-0.005	-0.510
Total PAHs	0.001	0.006
Nap	-0.001	0.001
A	0.000	0.000
Ace	0.000	0.000
F	0.000	0.001
Phe	0.000	0.001
Ant	0.000	0.001
Flu	0.000	0.000
Pyr	0.000	0.000
BaA	0.000	0.000
Chr	0.000	0.000
BbF	0.000	0.001
BkF	0.000	0.001
Redox potential	0.000	0.000
IP	0.000	0.000
DA	0.000	0.000
BP	-0.001	0.006

Appendix 1-4: Rotated component matrix of *C. camphora*

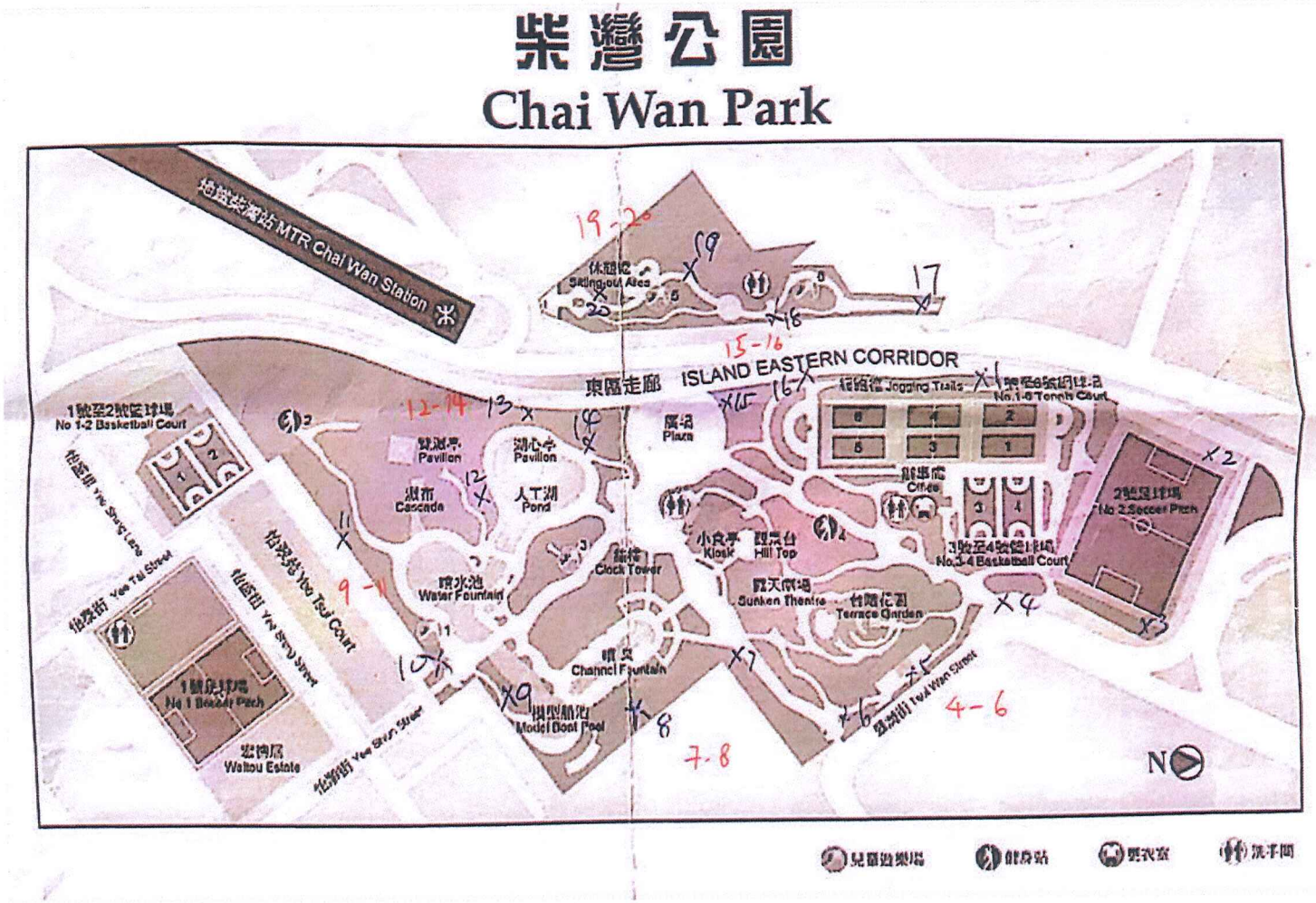
Component	Eigenvalues		
	1	2	3
pH	0.232	0.268	0.092
EC	-0.150	0.194	0.228
Redox potential	-0.137	0.211	0.158
C	0.022	0.155	0.413
H	0.122	0.220	0.167
N	-0.023	-0.198	0.188
S	0.014	0.030	-0.348
TOC	-0.255	0.176	0.212
Total PAHs	-0.128	0.197	-0.079
Nitrate-N	-0.288	0.066	0.118
Nap	-0.207	0.264	-0.148
A	-0.117	0.224	-0.242
Ace	-0.164	0.149	-0.026
F	-0.231	0.140	-0.129
Phe	-0.226	-0.001	-0.185
Ant	-0.143	-0.098	-0.232
Flu	-0.197	0.028	-0.260
Pyr	-0.172	-0.270	0.234
BaA	-0.262	-0.202	-0.103
Chr	-0.243	-0.199	-0.074
BbF	-0.269	-0.151	0.011
BkF	-0.249	-0.204	0.046
BaP	-0.221	-0.296	0.110
IP	-0.253	-0.222	0.060
DA	-0.077	0.136	-0.238
BP	-0.174	-0.288	0.224

Appendix 1-5: Rotated component matrix of *L. speciosa*

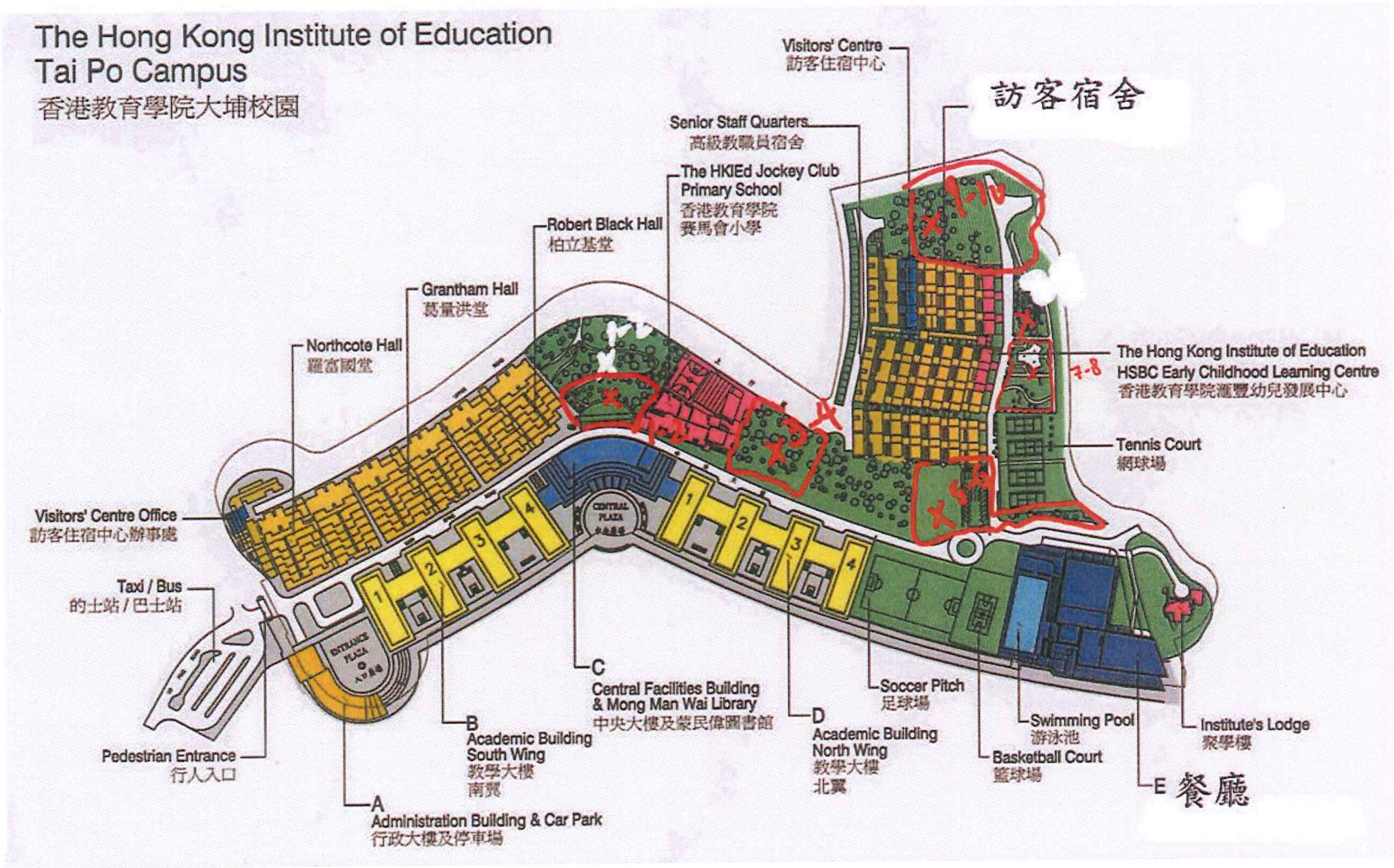
Component	Eigenvalues		
	1	2	3
pH	-0.267	-0.184	0.030
EC	-0.209	-0.200	0.144
Redox potential	-0.181	-0.232	-0.102
H	-0.004	-0.215	0.175
N	-0.061	-0.217	0.307
C	0.026	-0.091	0.098
S	-0.099	-0.176	0.0360
TOM	-0.233	-0.183	0.087
Nitrate-N	-0.161	-0.093	0.061
Total PAHs	-0.274	-0.074	-0.245
Nap	-0.195	-0.212	-0.323
A	-0.093	-0.196	-0.438
Ace	-0.099	-0.192	-0.450
F	-0.199	-0.192	-0.450
Phe	-0.228	-0.018	0.210
Ant	-0.088	0.028	-0.054
Flu	-0.165	-0.154	0.007
Pyr	-0.176	0.277	-0.027
BaA	-0.235	0.240	-0.006
Chr	-0.250	0.240	0.002
BbF	-0.261	0.209	0.026
BkF	-0.254	0.229	0.007
BaP	-0.255	0.154	-0.016
IP	-0.243	0.261	0.039
DA	-0.097	-0.177	-0.064
BP	-0.173	-0.074	-0.245

Appendix 2-1: Site map of Central Kwai Chung Park (CKCP) with sampling points denoted

Appendix 2-2: Site map of Chai Wan Park (CWP) with sampling points denoted

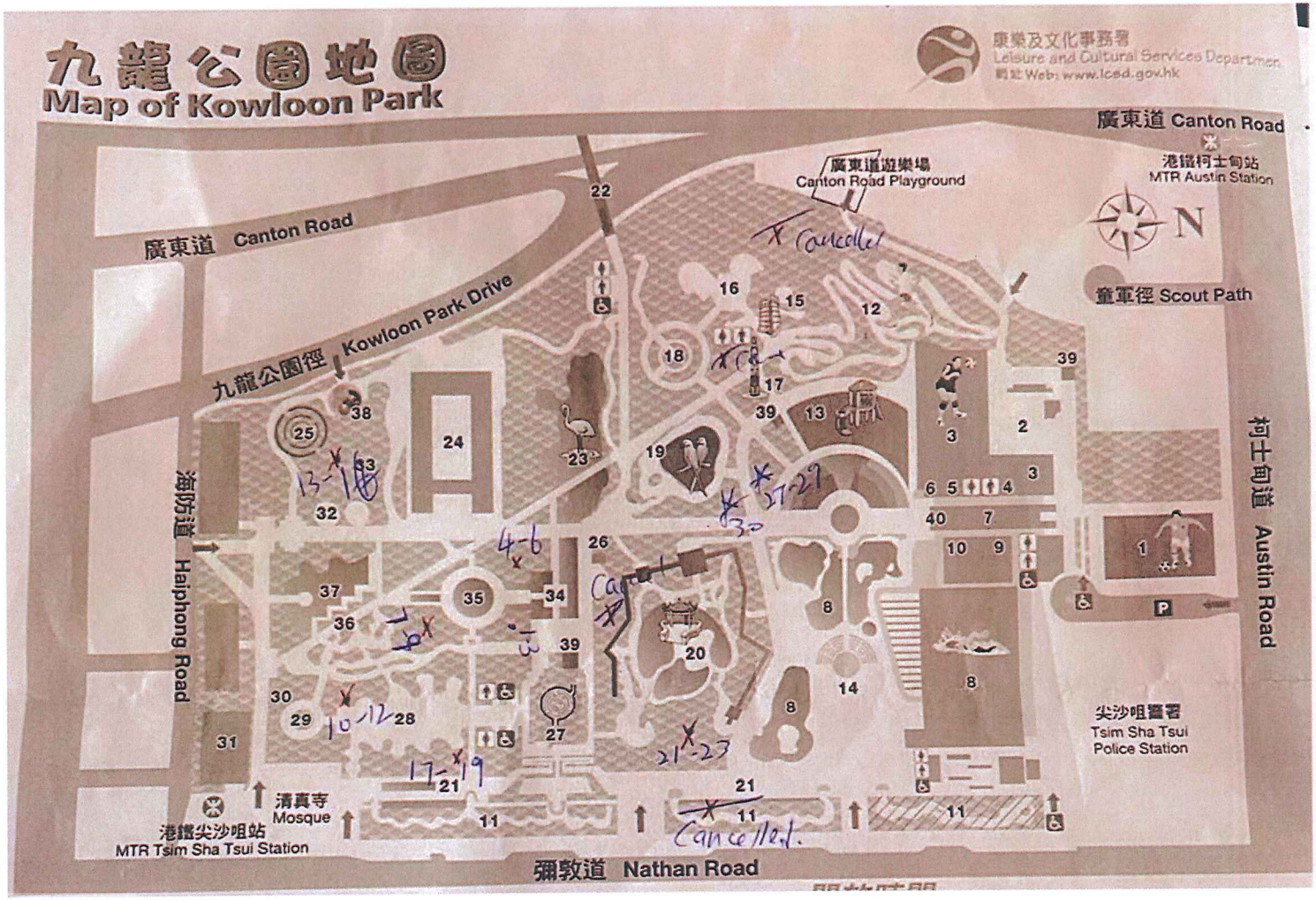


Appendix 2-3: Site map of the Education University of Hong Kong (EdU) with sampling points denoted



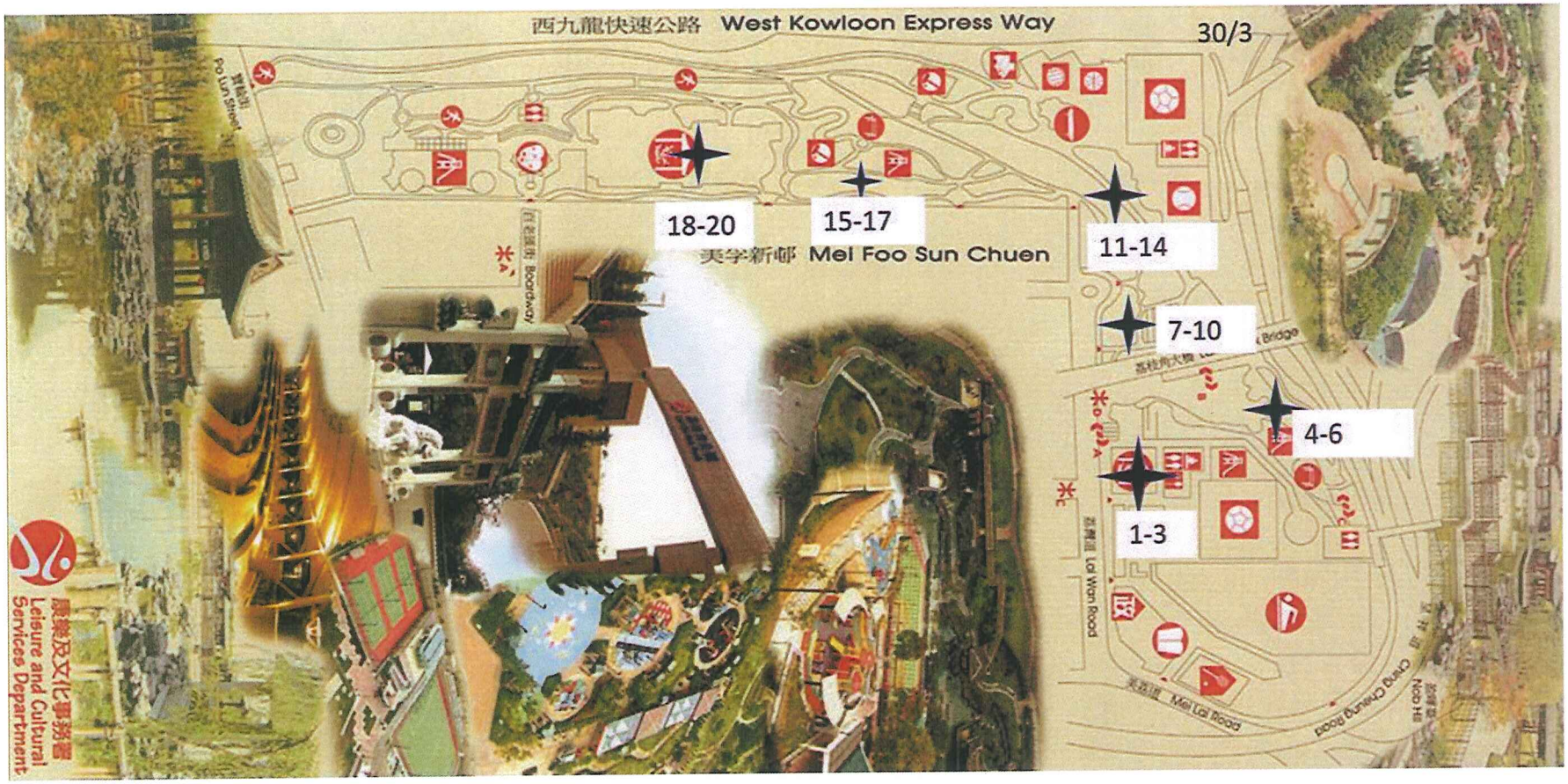
Appendix 2-4: Site map of the Hong Kong Park (HKP) with sampling points denoted

Appendix 2-5: Site map of the Kowloon Park (KLP) with sampling points denoted



Appendix 2-6: Site map of the Kowloon Walled City Park (KWCP) with sampling points denoted

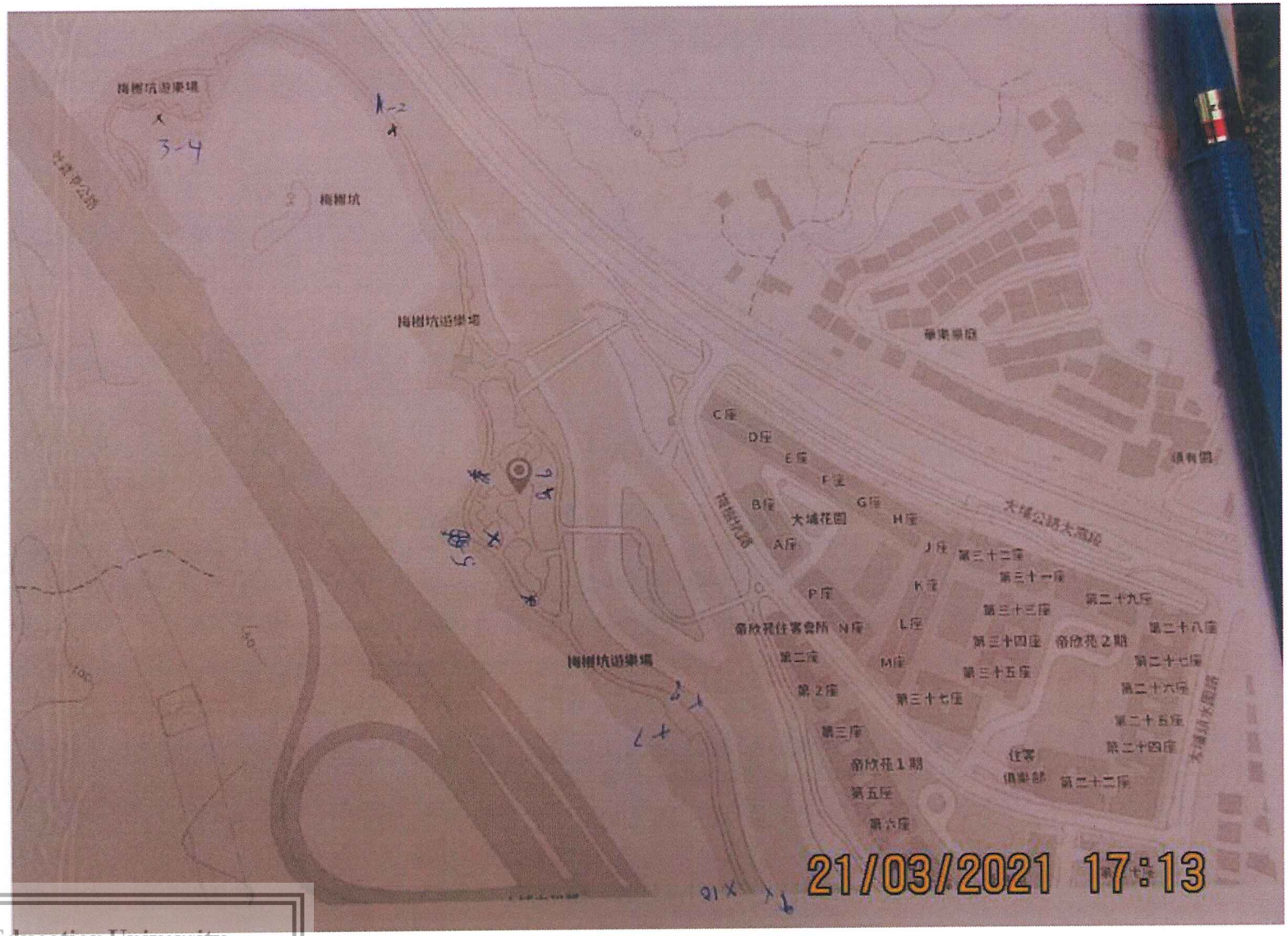
Appendix 2-7: Site map of the Lai Chi Kok Park (LCKP) with sampling points denoted



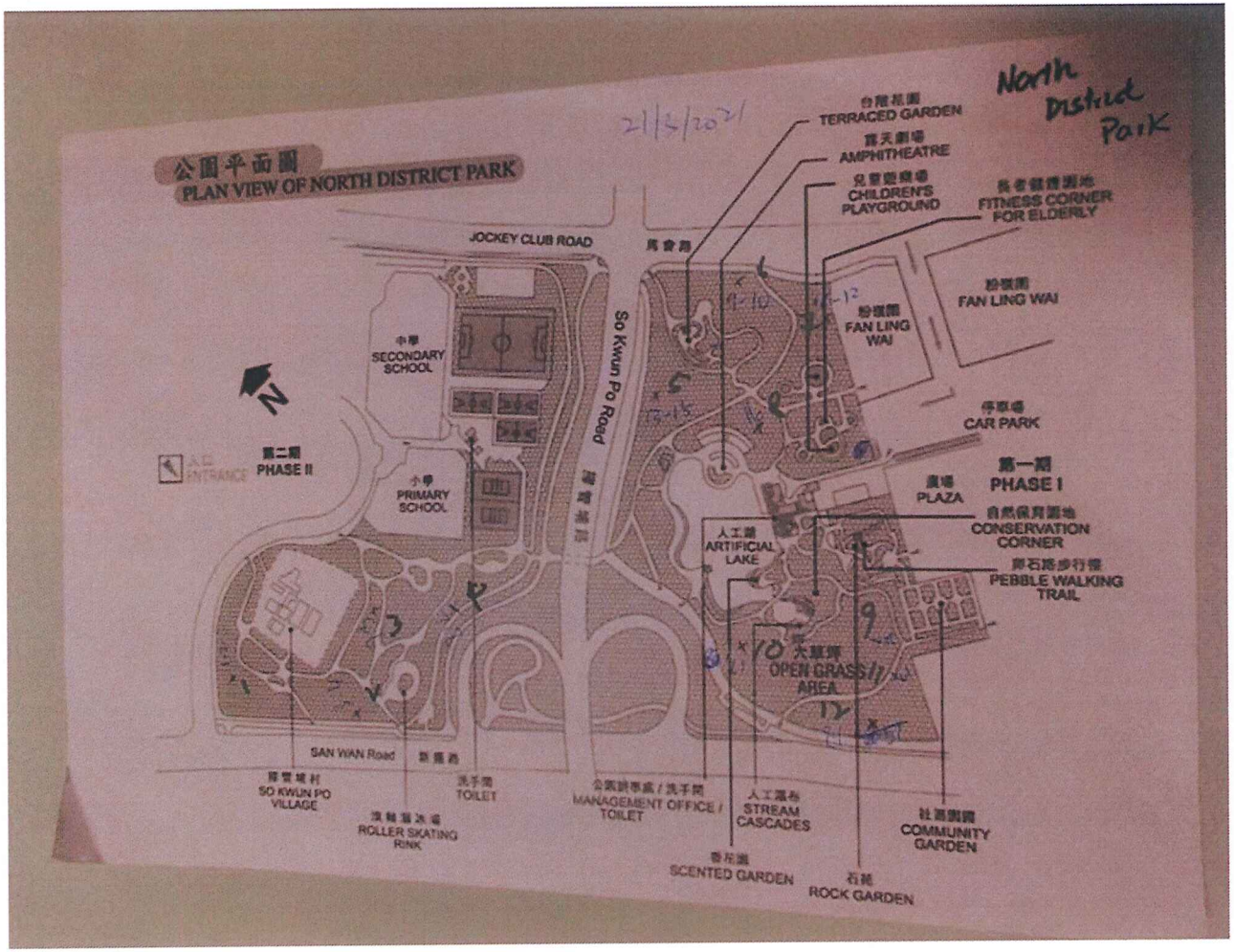
Appendix 2-8: Site map of the Lion Rock Park (LRP) with sampling points denoted

Appendix 2-9: Site map of the Ma On Shan Park (MOSP) with sampling points denoted

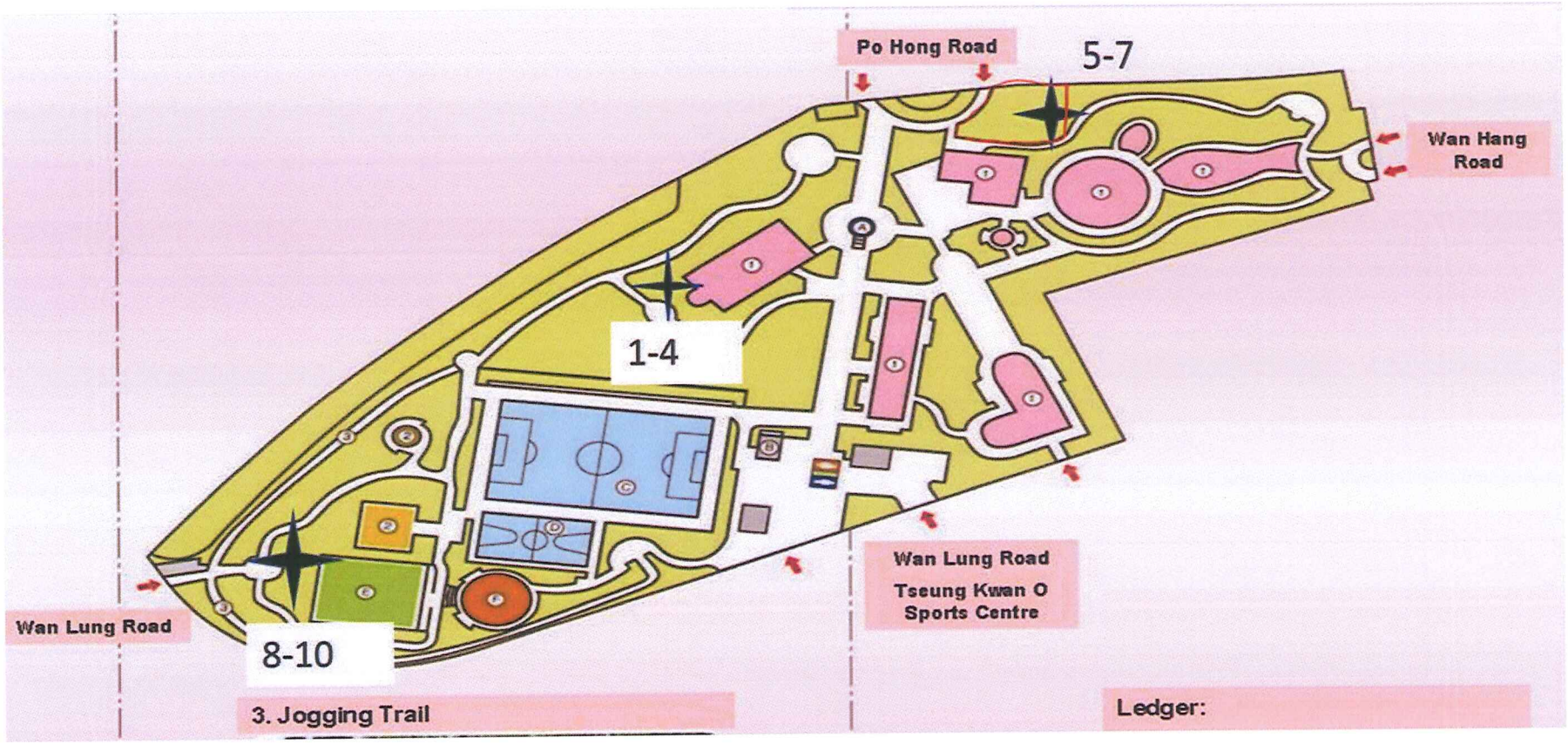
Appendix 2-10: Site map of the Mui Shue Hang Playground (MSHP) with sampling points denoted



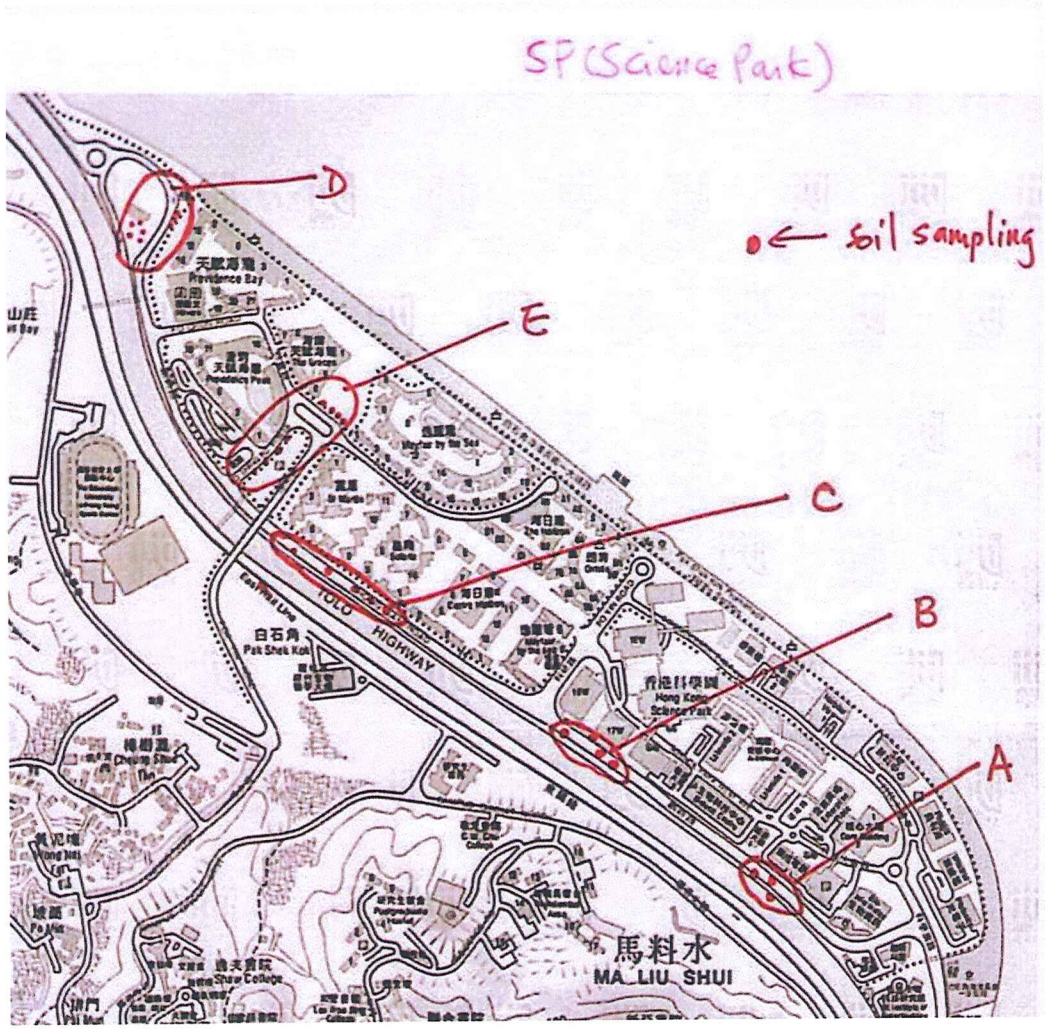
Appendix 2-11: Site map of the North District Park (NDP) with sampling points denoted



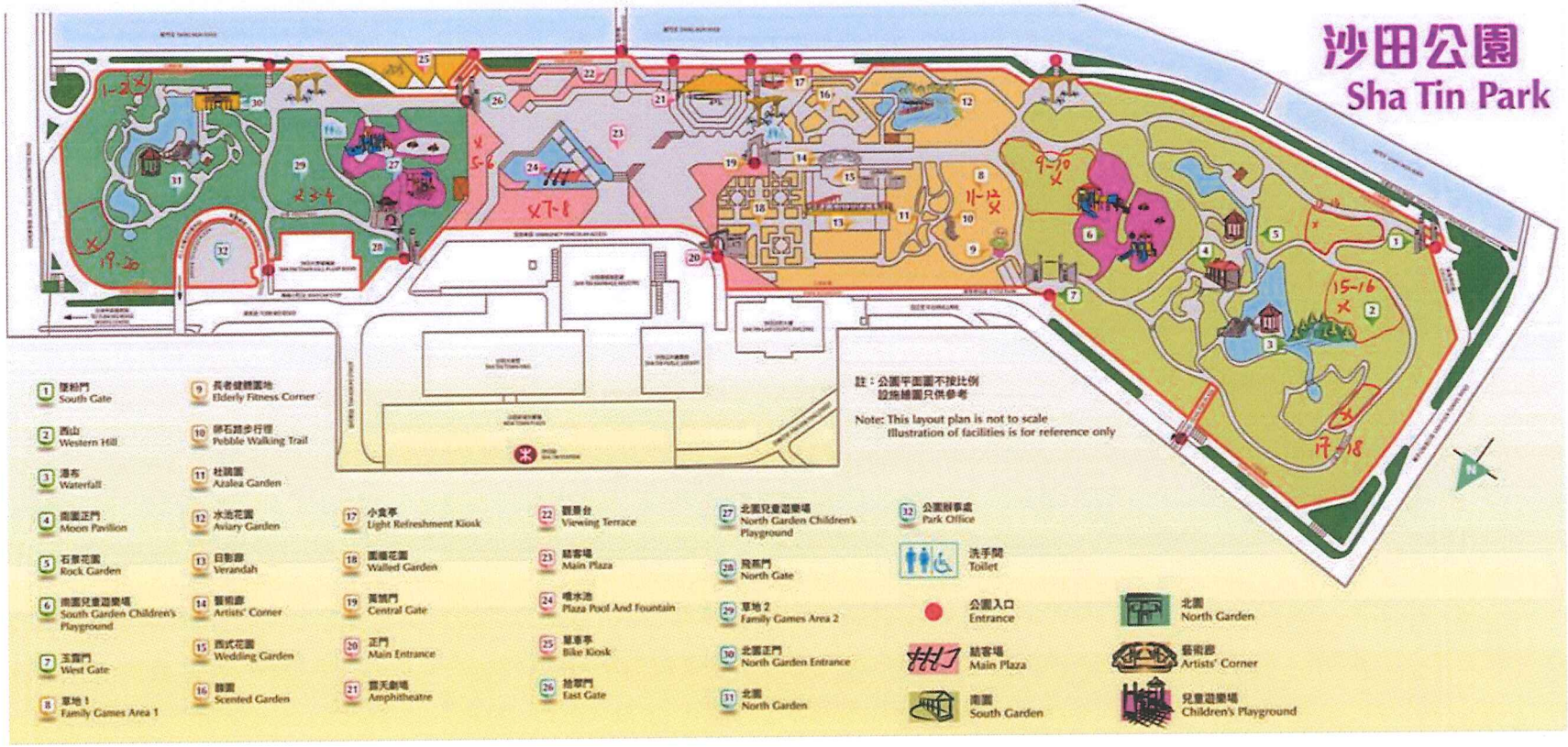
Appendix 2-12: Site map of the Po Hong Park (PHP) with sampling points denoted



Appendix 2-13: Site map of the Hong Kong Science and Technology Park (SP) with sampling points denoted



Appendix 2-14: Site map of the Sha Tin Park (STP) with sampling points denoted



Appendix 2-15: Site map of the Tai Po Waterfront Park (TPWP) with sampling points denoted

Tai Po Waterfront Park.

Appendix 2-16: Site map of the Tin Shui Wai Park Park (TSWP) with sampling points denoted

Appendix 2-17: Site map of the Tuen Mun Park (TMP) with sampling points denoted

Appendix 2-18: Site map of the Yuen Long Park (YLP) with sampling points denoted