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PM_{10} Composition of the Air Quality at the Bukit Nanas Forest Reserve of Kuala Lumpur, Malaysia

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Abstract: This study was conducted to determine the concentrations of PM_{10} and air composition in the vicinity of the Bukit Nanas Forest Reserve within the city of Kuala Lumpur. Sampling of PM_{10} was conducted using a High Volume Sampler (HVS) with a flow rate of 1.13 m^3 air min^{-1} for a total period of 24 h. The composition of PM_{10} analyzed constituted anions (SO_4^{2-}, NO^{3-}, Cl^-), cations (K^+, Na^+, Mg^{2+}, Ca^{2+}, NH_4^+) and heavy metals (Pb, Zn, Cd, Ni, Mg, Cu, Fe and Mn). The concentrations of SO_4^{2-}, NO^{3-} and NH_4^+ ions were determined using the HACH spectrophotometer, whilst Cl^- ions were measured using the argentometric method. The total mean concentration of PM_{10} for the three sampling stations was 13.44±7.12 μg m^{-3} (station 1), 17.91±4.56 μg m^{-3} (station 2) and 20.23±4.34 μg m^{-3} (station 3), compared to 4.27±1.67 μg m^{-3} recorded at the non-urban Bangi Forest Reserve. The highest mean concentration of anions and cations for the three stations was for SO_4^{2-} ions, followed by Cl^-, NO^{3-}, Na^+, K^+, Mg^{2+}, NH_4^+ and Ca^{2+}. For heavy metals, Fe recorded the highest value, followed by Ni, Zn, Cu, Pb, Mg, Mn and Cd. Air quality within the vicinity of the study area for the sub-index of PM_{10} was found to be good, with the highest API value recorded during the study period being 14 at station 3.

Key words: PM_{10}, air quality, heavy metals

INTRODUCTION

The Bukit Nanas Forest Reserve (BNFR) is unique in being the smallest existing tropical rainforest in the world, situated in the heart of Kuala Lumpur city centre. Gazetted as a forest reserve in 1906, it is also a wildlife reserve and bird sanctuary and is the oldest such reserve in Malaysia. The rich diversity of flora in BNFR includes giant bamboos, climbers, creepers, ferns and tropical tree species such as meranti (*Shorea* sp.), keruing (*Dipterocarpus* sp.) and chengal (*Balanocarpus* sp.). In 1950, a central, pristine section of about five hectares of BNFR was gazetted as Virgin Forest Reserve, with the significance of being the only remaining Virgin Forest Reserve in Malaysia and one of the oldest remnant tropical forest ecosystems that is fast becoming a forest island due to extensive urbanization around it. The air quality has also deteriorated due to increased number of motorized vehicles. It is very crucial that the BNFR is protected as a biodiversity reserve and a vital green lung for the Kuala Lumpur metropolis.

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From the year 2004 to 2005, Kuala Lumpur experienced 54.25% increase in motorcycles, 42.09% in cars and 4.70% in overall motorized vehicles (DOE, 2004, 2006). In fact, Kuala Lumpur Federal Territory has the highest number of registered vehicles (21.55% or 2.9 million) in Malaysia. Vehicular emissions that comprise CO, CO_2, SO_x, NO_x, suspended particulates (PM_{10}), hydrocarbons and Volatile Organic Compounds (VOC) are the main contributors to disease-related premature births in humans (Brimblecombe, 2003; DOE, 2004; Kingham *et al*., 2007). Particles with a diameter of less than 10 μm (PM_{10}) comprised 25% inorganics, 25% carbon and 50% organics that pose serious health hazards at high levels in ambient air (Heinsohn and Kabel, 1999). Ayers *et al.* (1997) found a threefold increase in PM_{10} loading in Petaling Jaya and Kuala Lumpur cities during a peak haze event that they studied.

The aim of the present study is to investigate any adverse changes in the air quality of the BNFR as a result of long term exposure to vehicular emissions. The concentration and chemical composition of PM_{10} at three selected sites in the BNFR were compared with those of a control site at the Bangi Forest Reserve, in Selangor. Increased air pollution is related to elevated levels of SO_x, NO_x and acid rain, which could affect the integrity of the rain forest ecosystem in the long term (Radojevic and Hasnah, 1999).

MATERIALS AND METHODS

Study Area

Three sampling stations were selected in Bukit Nanas Forest Reserve (BNFR), in the heart of Kuala Lumpur city, namely at the Forestry Information Centre (S1), at the secondary school Convent Bukit Nanas Secondary School (S2) and at the Puncak Niaga Holdings water treatment plant (S3) (Fig. 1a). The control unpolluted site was the Bangi Forest Reserve (S4) in Selangor, about 40 km from the BNFR site (Fig. 1b).

Wind speed, temperature and humidity were also measured at each station during the sampling visits, i.e., between 11-14 November 2005, 25-28 November 2005 and 2-5 December 2005. During this period, particles were not effectively dispersed in the air because of the rainy season, whereby the relative humidity would be higher compared to clear and cloudy days. This is because air humidity is capable of reducing the suspended particles in dry air by combining them with water vapor and eliminating rapidly in the form of rainfall washout.

According to Jawad-Al-Obaidy and Joshi (2006), rainfall is one of the effective ways of removing atmospheric pollutants including gases, particles and trace elements. Báez *et al.* (2007) noted that over 80% of wet deposited trace elements were dissolved in rainwater, reaching the vegetation canopy in the most favorable form for uptake.

Sampling

The daily readings were averaged. Particulates (PM_{10}) were sampled in a high volume air sampler (HVS) model Staplex, provided with a glass-fibre filter paper (20.3×25.4 cm), at the rate of 1.13 m^3 min^{-1} for a total period of 24 h. The experiment was replicated thrice to minimize random errors.

Methods

For analysis, the filter paper was then divided into two halves, one of which was analyzed for heavy metals (Pb, Zn, Cd, Ni, Mg, Cu, Fe and Mn) while the other half was used to determine the anions (SO_4^{2-}, NO_3^-, Cl^-) and cations (K^+, Na^+, Mg^{2+}, Ca^{2+}, NH_4^+), using the atomic absorption method recommended by Fuzzi *et al.* (1982).

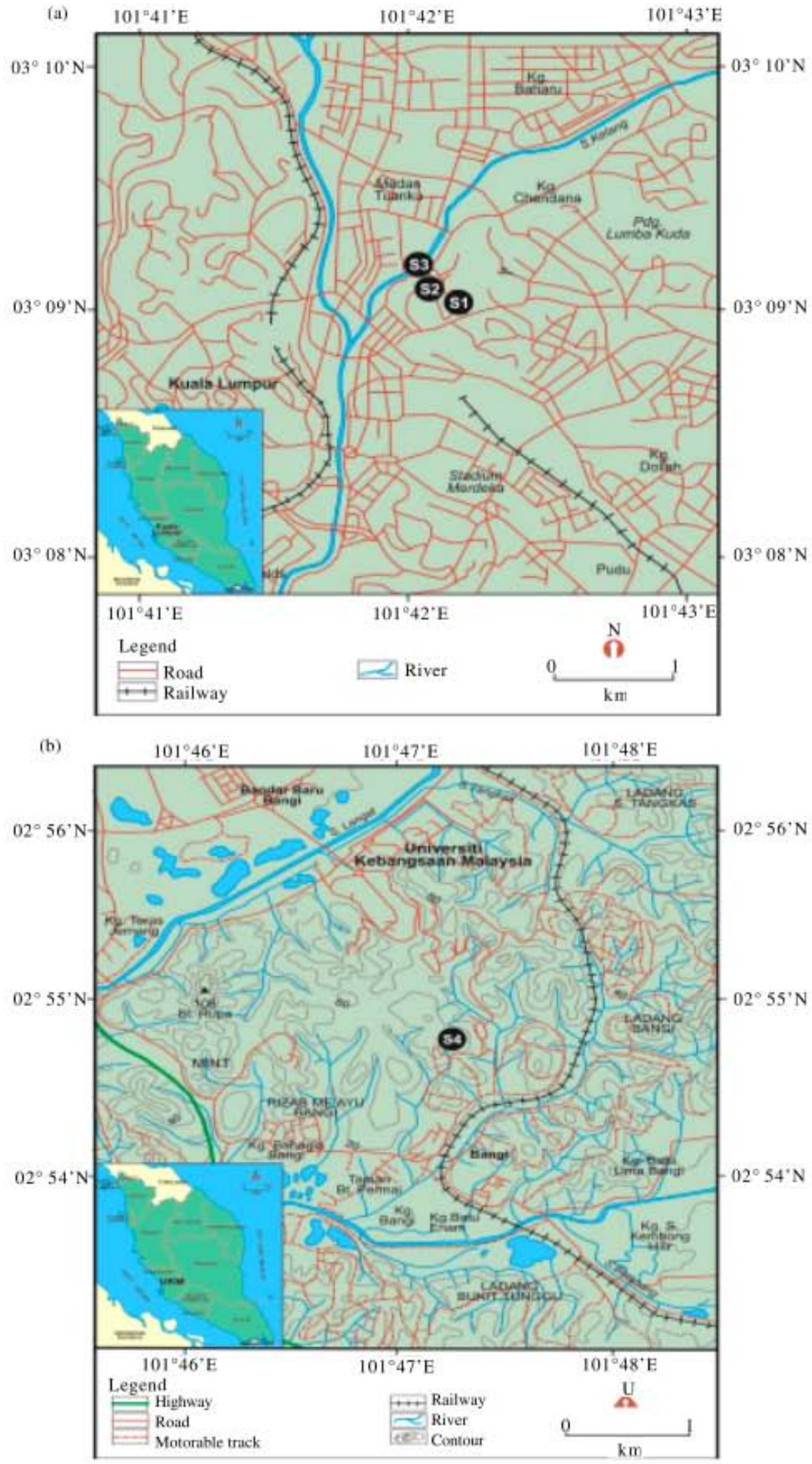

Fig. 1: Location of the study areas (a) (S1-S3) and (b) (S4)

For metals extraction by acid digestion, one half of the filter paper was shredded and digested in 40 mL conc. HNO_3 acid and 10 mL conc. $HClO_4$ acid (4:1), then cooled and filtered, the filtrate then diluted to 250 mL with distilled water. The metals content was determined by Inductively-Coupled Plasma Emission Spectrometry (ICPES) (Anna *et al*., 1984). The second portion of the filter paper was shredded into 100 mL deionized distilled water, heated for 2 h, agitated for 15 min in a shaker water bath and then filtered into a 250 mL flask. A blank test was conducted on an unused glass-fibre filter paper by repeating the above procedure.

The SO_4, Cl^-, NO_3^- and NH_4^+ ion contents were determined using the turbidity method, argentometric method, the cadmium reduction method and the Nessler method (APHA, 1989), respectively. The levels of SO_4^{2-}, NO_3^- and NH_4^+ ions were determined using a HACH spectrometer model DR 2010, while K^+, Na^+, Mg^{2+} and Ca^{2+} were measured by Atomic Absorption Spectrophotometer (AAS) Model 4100 ZL.

Air Pollution Index

The PM_{10} sub-index concentration value was calculated based on recommendations by the Department of the Environment, Malaysia (DOE, 1997). The API report takes into account the highest mean value, stating the equivalent health level.

X = PM_{10} (average: 24 h, unit μg m^{-3} (DOE, 1997)
API = X and since, the X value is less than 50 μg m^{-3}, then API = X

Statistical Analysis

The regression test was used to determine any significant correlations between PM_{10} and meteorological factors, whilst the correlation test was used to determine the correlation between the concentration of PM_{10} and its chemical composition in different sampling stations.

RESULTS

PM_{10} Composition

The concentration of PM_{10}, temperature, relative humidity and wind speed at the four study sites are summarized in Table 1. The overall value of PM_{10} for the stations (S1, S2 and S3) located at Bukit Nanas fell within the range of 13.44-20.23 μg m^{-3}. Station 3 had the highest recording for the mean PM_{10} concentration (20.23 μg m^{-3}). The lowest PM_{10} value was recorded at station 4 (4.27 μg m^{-3}). Station 4 was the control station located on the slope of a rural forested area surrounded by the natural environment of the Bangi Forest Reserve.

The concentrations of anions and cations found at stations 1, 2 and 3 in descending order is listed as follows: $SO_4^{2-} > Cl^- > NO_3^- > K^+ > Na^+ > Mg^{2+} > NH_4^+ > Ca^{2+}$ (Table 2). The highest mean concentration of SO_4^{2-} ions was recorded at station 3 (9.87 μg m^{-3}) whilst the lowest value (3.84 μg m^{-3}) was recorded at station 1. Values for SO_4^{2-}, Cl^- and K^+ were found to be lower at S4 (control site) than at the other three stations located in Bukit Nanas (urban site).

Table 1: Mean concentration of PM_{10} (μg m^{-3}) and meteorological factors at each sampling station

Station	Concentration of PM_{10} (μg m^{-3})	Temperature (°C)	Relative humidity (%)	Wind speed (mph)
1	13.44±7.12	29.55±0.66	66.58±6.40	1.13±1.13
2	17.91±4.55	27.73±0.47	82.20±8.27	3.30±2.64
3	20.23±4.34	27.88±1.19	70.25±4.89	1.20±1.28
Means	17.12±5.34	28.38±0.77	73.10±6.52	1.87±1.68
4	4.27±1.67	29.00±3.16	75.90±5.84	1.33±0.47

Maximum PM_{10} Malaysia permissible value suggested by the DOE: 150 μg m^{-3}

Table 2: Mean concentrations of anions and cations (μg m^{-3}) during the study period

	Concentrations (μg m^{-3}) of anions and cations							
Station	SO_4^{2-}	Cl^-	NO_3^-	K^+	Na^+	NH_4^+	Mg^{2+}	Ca^{2+}
S1	3.84±1.14	14.55±6.79	0.83±0.06	0.71±0.05	0.08±0.02	0.15±0.04	0.07±0.02	0.01±0.00
S2	8.34±1.83	0.80±0.29	0.06±0.04	0.65±0.03	0.14±0.05	0.01±0.01	0.06±0.02	0.01±0.01
S3	9.87±2.65	0.89±0.14	0.06±0.04	0.59±0.05	0.12±0.06	0.01±0.01	0.06±0.02	0.01±0.00
Overall mean	7.35±3.13	5.41±7.91	0.32±0.44	0.65±0.06	0.11±0.03	0.06±0.08	0.06±0.01	0.01±0.00
S4	3.92±1.83	4.57±1.62	2.31±1.52	0.39±0.15	0.13±0.06	0.08±0.07	0.07±0.01	0.00±0.00

Table 3: Mean concentrations of heavy metals (μg m^{-3}) during the study period

	Mean concentrations of heavy metals (μg m^{-3})							
Stations	Fe	Ni	Zn	Cu	Pb	Mg	Mn	Cd
S1	0.48±0.04	0.17±0.01	0.10±0.01	0.02±0.01	0.02±0.01	0.01±0.01	0.01±0.002	0.007±0.002
S2	0.56±0.07	0.16±0.01	0.09±0.01	0.02±0.00	0.02±0.01	0.02±0.01	0.009±0.003	0.003±0.001
S3	0.61±0.09	0.16±0.01	0.08±0.01	0.03±0.01	0.03±0.02	0.02±0.01	0.01±0.003	0.004±0.003
Mean	0.52±0.08	0.17±0.01	0.09±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.01±0.002	0.05±0.002
S4	0.44±0.04	0.02±0.01	0.08±0.01	0.03±0.01	0.02±0.08	0.02±0.01	0.01±0.001	0.004±0.002

The highest mean concentration of NO_3^- ions was recorded at station 4 (2.31 μg m^{-3}), whilst the lowest value (0.06 μg m^{-3}) was recorded at both stations 2 and 3. Open burning of garbage and plant biomass was observed at station 4 during the study period and this could be the reason for the high nitrate concentration. The highest mean concentrations of Cl^- (14.55 m^{-3}) and NH_4^+ ions (0.15 μg m^{-3}) were recorded at station 1 (Table 2), while the lowest value was recorded at station 4 (0.002 μg m^{-3}). Similarly, the highest mean concentration of K^+ ions (0.07 μg m^{-3}), was recorded at station 1 whilst the lowest value of Mg^{2+} ions was recorded at station 3 (0.06 μg m^{-3}). The highest concentrations of K^+ and Na^+ were recorded at station 1 and 2, respectively (Table 2).

Table 3 shows the concentration of heavy metals in the air samples from the four stations studied. The hierarchical list of heavy metal concentrations found at stations 1, 2 and 3 was as follows: Fe > Ni > Zn > Cu > Pb > Mg > Mn > Cd (Table 3). The highest Fe content in PM_{10} was recorded at station 3 (0.61 μg m^{-3}), whilst the lowest was at station 4 (0.44 μg m^{-3}). The heavy metal with the second highest value for mean concentration was nickel, recorded at station 1 (0.17 μg m^{-3}) and the difference in nickel content among the three urban sites, was presumably due to differences in the level of air pollution as all sites were subject to some air pollution due to constant traffic flow. Station 1 had the highest recording for mean concentration of zinc (0.10 μg m^{-3}), whilst stations 3 and 4 recorded the lowest value (0.08 μg m^{-3}). The average concentrations of Cu, Mg and Pb from the three urban sampling sites in Bukit Nanas ranged from 0.02 to 0.03 μg m^{-3} and were not very different from the concentration at station 4. Cadmium had the lowest recorded mean concentration among all the heavy metals. Station 1 had the highest recorded mean concentration for Cd (0.007 μg m^{-3}), whilst station 2 recorded the lowest value (0.003 μg m^{-3}).

Air Pollution Index

According to the DOE (1997) standards, if the value of the API is less than 50, the air quality is considered good, if it ranged from 51-100: moderate, from 101-200: unhealthy, from 201-300: very unhealthy, from 301-500: hazardous and >500: emergency. The API sub-index for pollutants at all the sampling stations was found to be within the good status (0-50) as the values recorded for the stations S1, S2, S3 and S4 were 9, 12, 14 and 3, respectively.

DISCUSSION

The readings of PM_{10} obtained from S1, S2 and S3 were considerably lower than the permissible value as stipulated by the Clean Air Act Amendment 1978 of the Environmental Quality Act 1974 which is 150 μg m^{-3} for 24 h. The PM_{10} value was lower than that obtained in a case study at the Perlis National Park (58.8 μg m^{-3}) but higher than the readings obtained from the Pahang National Park (16.51 μg m^{-3}) (Norela *et al*., 2001) and Fraser's Hill (13.30 μg m^{-3}) (Norela, 2001). Table 1 shows that the temperature range in the study area was fairly uniform, whilst the relative humidity and wind speed were slightly higher at S2 than at the other stations. According to Sham (1983), temperature inversion occurs in Kuala Lumpur when hotter air covers and traps the much cooler air. A temperature inversion will cause the trapping of gases and particulates and will indirectly elevate the concentration of pollutants in the atmospheric air. The effects of temperature were the same across the four locations, but the level of pollutants measured differed. Low temperature was strongly correlated with higher concentration of suspended particulates in the atmosphere.

From Table 1 it can be seen that the highest mean values for PM_{10} were obtained at station 3. This could be due to its position of being located in a hilly area surrounded by tall buildings and skyscrapers and the associated heavy traffic flow. This situation could be responsible for the accumulation of air pollutants, as it had a fairly still atmosphere and low wind speed. It has been reported that the concentration of PM_{10} increases proportionally to increase in anthropogenic activities (Norela *et al*., 2001). Pollutants originating from human activities were dust from the roads and fumes from motorized vehicles (Chelani *et al*., 2005). With regard to the remaining urban sampling sites, station 1 was located at the intersection of some main roads in Kuala Lumpur and was adjacent to an unpaved parking area, whilst station 2 was located in a commercial area that had school buildings, hotels, a church and some shops.

As shown in Table 1, the PM_{10} in an environment such as that in which station 4 was located would be derived mainly from natural sources such as pollen grains, forest fires and dispersion of dust by the wind (Stern *et al*., 1984). The low concentration of PM_{10} could also be due to the fact that the distance between station 4 and the other stations was almost 40 km, so it was quite far from the polluting effects of the Kuala Lumpur city centre. Despite being in a controlled area, the concentration of PM_{10} in station 4 was still found to contain suspended dust and pollutants resulting from human activities such as combustion of fossil fuels.

The highest concentration of Cl^- and NH^{4+} ions was detected at station 1 (Table 2). This could possibly be due to its proximity to the herbal and flower gardens that could have been sprayed with pesticides for the control of pests and fertilized with supplementary nutrients. Celis *et al*. (2003) concluded from their studies that high levels of NH_4^+ ions in the air were linked to the application of pesticides and fertilizers in agricultural areas.

The highest concentration of Ca^{2+} ions at station 1 may have originated from dust pollutants from the roads, arising from traffic as well as from human activities in the urban area. The release of Ca^{2+} ions into the atmosphere depends on the wind direction (Celis *et al*., 2003), as Ca^{2+} ions occur in the earth's crust as well as in chalk and limest one used as fillers for road surfaces. Increase of Ca^{2+} ions in the atmosphere could also be due to the intensive construction activities in urban areas.

Station 1 had higher levels of K^+ and Mg^+ ions, while Na^+ ions were detected at station 2. The higher levels of these cations at the above stations could have been due to the presence of bare areas that had been cleared for construction activities, located nearby.

According to John *et al.* (1981), when the earth's crust is bared, wind erosion can carry away K^+ and Na^+ ions from the exposed soil. The highest readings of Mg^{2+} ions at station 1 could be due to suspended soil particles which contributed to the release of Mg^{2+} ions into the air. The highest recording of Ni was at station 1 (0.17 μg m^{-3}) and the difference in nickel content among the three urban sites, could presumably be caused by air pollution due to traffic.

The results showed that the Fe content was the highest at station 3 which was situated near a construction area that was involved with earthworks and land clearing activities. When the earth's crust is bared, wind erosion can carry away dust laden with Fe cations from the exposed soil. Besides, the high traffic volume through the area could also contribute to the production of coarse iron particulates from the usage of brakes, in addition to other releases and corrosion of the engines.

The results showed that the highest reading for Zn was at station 1. This could be associated with its proximity to the main road, which had a high volume of urban traffic. Although, zinc is an element which is abundantly found in the earth's crust, it could also have been released into the air as dust from construction activities near the sampling sites. It may be possible that the high level of zinc found at this station could have originated from zinc released in tyre friction (Chelani *et al*., 2005) which is noticeably higher in urban traffic because of frequent braking.

It should be noted that Pb and Cu concentrations at the three urban sampling sites in Bukit Nanas were not much different from those at station 4. The primary source of Pb in the atmosphere could be from vehicle emissions. According to Williamson (1973), approximately 75% of Pb in gasoline is emitted through the exhaust. Cu and Mg are primary pollutants that could arise from combustion of petrol, cement and asbestos (Fung and Wong, 1995). The highest reading of Cd at station 1 could be due to the burning of fossil fuels by motorized vehicles constantly passing by. The cadmium levels at station 4 were similar to those recorded at the urban stations.

In conclusion, the study showed that the highest concentration of PM_{10} recorded was 20.234 μg m^{-3} and this was still well below the maximum allowable limit of 150 μg m^{-3} for a period of 24 h, as stipulated by the DOE. The API for the PM_{10} at the Bukit Nanas Forest Reserve came under the good category. The current API pertaining to PM_{10} obtained from the Continuous Air Monitoring station nearest to the study site shows that the API is good with value ranging between 32 to 45 μg m^{-3}. This indicates that the concentration of PM_{10} in the vicinity of Bukit Nanas is still good (DOE, 2010). Although, the air pollution situation in the Bukit Nanas Forest Reserve is currently good, the situation is unstable and vulnerable to increased construction, traffic and other anthropogenic activities that could seriously affect the air quality and cause it to degenerate to hazardous/problematic levels.

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