

DRY DEPOSITION STUDY USING FILTER PACKS AT A RURAL AND AN URBAN MONITORING SITES

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Abstract

Air samples were collected from 2004 to 2005 using four-staged filter packs at an urban site Petaling Jaya (PJ) and a rural-agricultural site Tanah Rata (TR). The samples were analysed for reactive gases consisting of NH_3 , HNO_3 , HCl and SO_2 while the aerosol components were analysed for SO_4^{2-} , NO_3^- , Cl^- , Na^+ , K^+ , Ca^{2+} , Mg^{2+} and NH_4^+ . For both PJ and TR, analysis indicates the dry deposition was dominated by the gaseous components. They range from about 78% to 87% of total compositions for urban PJ and 59% to 63% for rural TR. Among the four reactive gases, NH_3 is the most dominating component at both sites. Elevated NH_3 concentration in TR was mainly attributed to the use of nitrogenous fertilizer. For PJ high NH_3 could be due to local air pollution created by industries as well as agricultural activities. The acidic species associated with SO_x and NO_x are typically more abundant at PJ than TR. Their presence, and for most other chemical species, show similar increasing trend, and this reflect the growing use of fossil fuels associated with urbanization and industrialization, especially for PJ.

Keywords: Four-staged filter packs, reactive gases, aerosols, nitrogenous fertilizer

Introduction

The effects of acid deposition such as acidification of lakes and streams, nutrient enrichment of coastal waters and river basins, soil nutrient depletion and decline of sensitive forests, agricultural crop damage, and impacts on ecosystem biodiversity are well documented by several literatures [1][2]. Acid deposition is caused by airborne pollutants in the form of aerosols and gases originating from both local and long-range emission sources. These pollutants may contain acid components which are mainly attributed to oxides of sulfur (SO_x) and nitrogen oxides (NO_x) emitted into the atmosphere where they react to form compounds that are transported over long distances. NO_x especially nitrogen dioxide (NO_2) may be converted to nitric acid (HNO_3) and nitrate (NO_3^-) aerosols in the gas phase through a complex reactions involving free radicals (OH) in daylight and ozone (O_3) in the dark [13]. Ammonium salts are derived from reactions of HNO_3 with ammonia (NH_3) or ammonium sulphate ($(\text{NH}_4)_2\text{SO}_4$) particles and are subsequently deposited to the earth's surface mainly via wet and dry mechanisms. Together with alkaline salts found in aerosols these basic components exert a neutralizing effect on the acidic components found in wet or dry deposition. Wet deposition is a process whereby pollutants are absorbed in the rainwater whereas dry deposition involves the transfer of airborne pollutants directly onto land and water surfaces. Unlike wet deposition, dry deposition process involves air-surface interaction and is assumed to take place continuously irrespective of precipitation events [5]. Air pollution abatement inevitably involves measurement and monitoring the concentrations of these air pollutants, whose methods of sampling and analysis are determined by the two types of deposition mechanisms. In this study, the filter pack method for dry deposition was employed for air sampling. The objective of this study is to characterize dry deposition at two monitoring locations comprising of an urban and a rural site. The quantification of both gaseous and particle components of dry deposition is of great importance for the understanding the impacts of this inputs into the ecosystems [6,10].

Area of Study

Two monitoring sites, Petaling Jaya (PJ), and Tanah Rata (TR), in the West coast of Peninsular Malaysia were selected for the study. They are part of a permanent nationwide meteorological monitoring network which consists of several air pollution stations at strategic sites in Peninsular and East Malaysia (Figure 1). Petaling Jaya which serves as the main office is an urban and residential-type area, located in the most developed region in the country, the Klang Valley. This urbanized-residential site is characterized by high population density, traffic volume, business and commercial centres and industries such as electronic, chemical and automotive.

Although urban in nature, scattered small scale agricultural activities are also practiced by the PJ residents in several areas and in the outskirts.

Like PJ and another station, Lembah Danum in Sabah, TR monitoring station also serves as a Global Atmosphere Watch (GAW) station. It is located in Cameron Highland, about 150 km away from Petaling Jaya. TR is well known for its highland farming and enjoys a distinctively cooler climate than the lowland urban sites. Considered a rural-agricultural type site, this area, however, has seen a lot of recent developments for housing and industrial activities especially in neighboring lowlands. The geographical positions of the sites are summarized in Table 1.



Fig. 1: Environmental (Pollution) monitoring stations in Malaysia. Petaling Jaya and GAW stations at Tanah Rata are located in the mainland peninsula. (Source: The Meteorological Department, Petaling Jaya)

Table 1: Geographical positions of Petaling Jaya and Tanah Rata

	Petaling Jaya	Tanah Rata
Longitude	101° 39' E	101° 22' E
Latitude	3° 6' N	4° 28' N
Altitude:	45.7 m above MSL	1545 m above MSL

MSL: Mean Sea Level

Material and Methods

Measuring dry deposition is not as easy and straight forward as wet deposition [9]. Methods for estimating dry deposition measurements are hindered by uncertainties related to variability in physical, chemical and biological properties of the surrogate surfaces and also the complexity and interactions of substances [15]. Methods of measurement include diffusion scrubber [7], bulk deposition [8,16], denuder [4] and filter packs [11,12]. In this study the filter pack method was employed. The four-stage filter pack is composed of four filters arranged in line with the air stream (Figure 2). Aerosols were collected on the first filter (F0), while the gaseous species comprising of sulfur dioxide (SO₂), nitric acid (HNO₃), hydrochloric acid (HCl) and ammonia (NH₃) will pass through the filter. The second filter (F1) collects all HNO₃ and partial SO₂, HCl and NH₃ from the sampling air. The remaining SO₂ and HCl react with alkaline substance on the third filter (F2). NH₃ reacts with acidic substance on the fourth filter (F3) after passing through the first, second and third filters. The type of filters used is designed to trap the intended pollutants. Thus, F0 and F1, are made of teflon and polyamide respectively. F2

is made of cellulose impregnated with a solution containing of potassium carbonate (K_2CO_3) and glycerin. Likewise F3 is impregnated with a solution containing phosphoric acid and glycerin in order to trap the basic NH_3 . In a typical experimental setup shown in Figure 3, air was drawn in through the filter unit using a pump. The pump flow rate was set at 1.5 litres per minute for PJ, but for TR, being a less polluted site and thus with low pollutant concentration, a flow rate of 5.0 litres per minute was used. Air samples were collected weekly after seven days exposure, after which the filter pack samples were sent to the Government Chemistry Laboratory (Jabatan Kimia Malaysia) for analysis. Reactive gases analysed were NH_3 , HNO_3 , HCl and SO_2 . The aerosol components were analyzed using ion chromatography for SO_4^{2-} , NO_3^- , Cl^- , Na^+ , K^+ , Ca^{2+} , Mg^{2+} and NH_4^+ . The air sampling was carried out over a 24-month period from January 2004 to December 2005 except for Petaling Jaya where the monitoring started only in February 2004. In this study a total of 47 and 52 samples were collected in 2004 and 2005 respectively for Tanah Rata. For PJ, the total number of samples were 52 in 2004 and 53 in 2005. Rainfall measurement during this study period was obtained using a rain gauge.

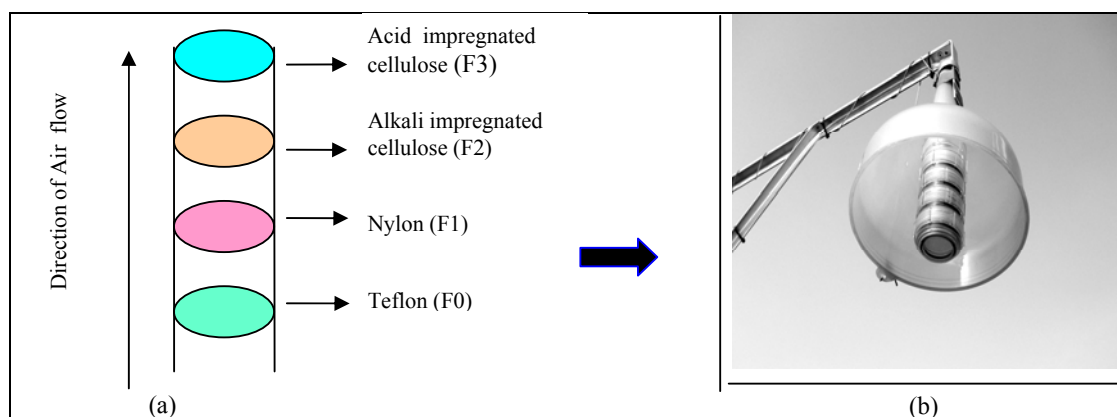


Fig. 2: Four-stage filter pack arrangement

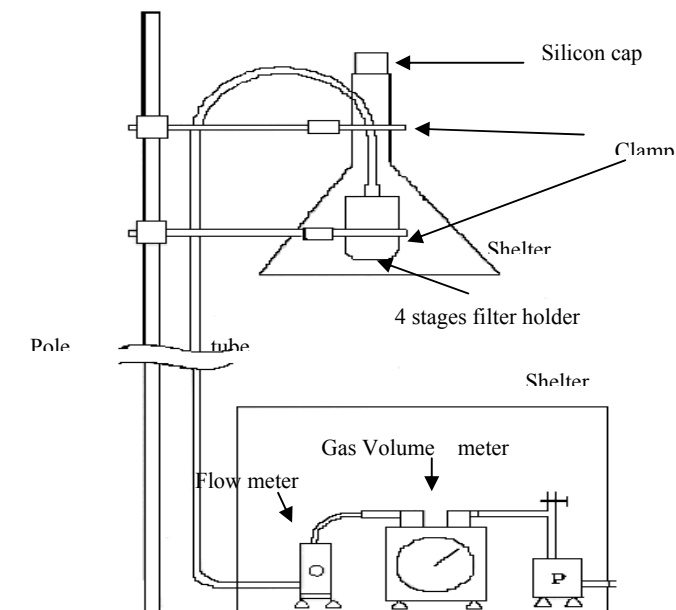


Fig. 3: Experimental setup for dry deposition study

Results and Discussions

The concentration of aerosols components and reactive gases expressed in nmol/m^3 took into consideration the air temperatures and the air volume during sampling. These values are represented as monthly and annual means, together with the standard deviations as shown in Tables 2, 3, 4 and 5. Figure 4 indicates the relative abundance of each pollutant based on annual means. The relative abundance of filter pack components, expressed as percentages are illustrated in Figure 5. Figure 6 is the monthly variation of rainfall amount in mm for the year 2004 and 2005 for both stations. The monthly variations of filter pack components for the two years are shown in Figure 7.

Reactive Gases

Overall, the concentration of chemical species are significantly greater for urban PJ than rural farmland TR (Tables 2, 3, 4, 5, Figures 4 and 5). For both sites, the dry deposition is dominated by the gaseous components, comprising of NH_3 , SO_2 , HCl and HNO_3 . They range from about 78% to 87% of total compositions for urban PJ and 59% to 63% for rural TR. Among the four reactive gases, NH_3 has the highest concentration at both TR and PJ (Tables 2, 3, 4 and 5, Figures 4 and 5). The dominating species, NH_3 in the dry deposition component demonstrates the importance of its role in the acidification process brought about by acidic species, which mainly consist of nitrogen oxides (NO_x) and sulfur oxides (SO_x). This NH_3 would eventually be converted to NH_4^+ through a series of chemical transformation and incorporated in aerosols or rainwater and eventually settle through dry deposition and wet precipitation. NH_4^+ is a basic specie which exerts a neutralizing effect on acidification and influences the pH and acidity of wet precipitation. The presence of high NH_3 concentration in TR is conveniently explained by the fact that TR is dominated by agricultural activities. TR experienced an increase of NH_3 by more than 30% in 2005 compared with the previous year. The increase is seen to be an indicator of increased use of nitrogenous fertilizers and manures to meet the growing demand for farm produce by the population to which this farming region supplies. NH_3 volatilization from fertilizers such as urea and ammonium bicarbonate is an important pathway for N loss from agricultural soils [8]. In this case NH_3 would normally be deposited close to its source of production and its concentration is proportional to the distance from the source [14].

As seen from Figure 6, compared to TR (36%, 47%), NH_3 concentration in PJ was much higher, (47%, 57%) for both 2004 and 2005. The high NH_3 concentration particularly from March to August and peaked in August (Table 4) had contributed to the high annual mean for PJ in 2005 (52 nmol/m^3). PJ may not be a dedicated farmland like TR; however it is known that scattered farming activities and animal husbandry are still practiced as cottage industries particularly in the suburbs. Hence the use of nitrogenous fertilizer may not be ruled out. In addition, domestic animal production (e.g. poultry) and related industries has greatly increased due to expanding domestic and commercial demand. Such activities produce animal waste which produce more NH_3 than from fertilizer use [8]. Another plausible explanation for the elevated NH_3 concentration in PJ could have been due to emissions from local pollution originating from anthropogenic activities including industries which exist in the vicinity of the sampling site, where N-containing or NH_3 -emitting chemicals were used. It is known that industries such as laundries, fertilizer manufacture, coke production and refrigeration are sources of NH_3 . The close proximity of the sampling site to Government Chemistry Laboratory which uses many chemicals may also have contributed to the overall concentration. Besides, it is expected that PJ which is undergoing urbanization and industrial development at faster rate than rural TR would inevitably create more anthropogenically produced fixed nitrogen (N) to be redistributed back to the atmosphere as reduced N (NH_3 , NH_4^+) and oxidized N (NO_x) [8].

Next in abundance after NH_3 is SO_2 followed by HNO_3 and HCl (Figure 6). This feature is true for both sites. SO_x emission is associated with power consumption using fossil fuels in combustion process by vehicles and also industries. Like NH_3 , similar pattern is observed for SO_2 , whose annual mean for TR is 3.1 nmol/m^3 in 2004 increasing to 5.4 nmol/m^3 in 2005. The figures for PJ are much higher; 52 nmol/m^3 in 2004 and 177 nmol/m^3 in 2005. Such a significant difference between the two sites could be explained by the fact that TR is a region dedicated to farmland, has much less land area than PJ, and as such, the expansion for industries, housing and roads is more limited than for urban site PJ. Hence activities which generate SO_x emission such as the use of coal containing sulphur for energy would be much less for TR than for PJ. Increased in the volume of vehicles may also lead to increasing HNO_3 concentration. HNO_3 is a gas phase oxidation product of nitrogen dioxide (NO_2), itself a component of NO_x . NO_x is a pollutant generated during high temperature combustion

and the main sources in urban areas are from vehicles and fossil fuel power-generating plants. For urban PJ the fact that the number of vehicles have never been on the decline as evident from constantly congested highways and lack of parking space and with consequent increased NO_x is a testimony of increased dependence on personal vehicles for transportation as well as increasing consumption of fossil fuels. For TR increased NO_x emission could be attributed in part to increased traffic volume as an indirect result of the Malaysian Government promotion drive for local tourism for the past years. More and more tour buses are flocking local destinations including Cameron Highland and TR.

Similar explanation applies for other reactive gases, whose concentrations are expectedly higher for urban site compared with rural site. The increasing concentration of reactive gases is reflective of increasing emissions due to increased anthropogenic activities at both sites, with urban site experiencing greater growth and industrial expansion than the rural site. The accelerated N cycle was the result of anthropogenic activity which included the increasing use of fertilizer, animal husbandry and fossil fuel consumption by vehicles as well as industries.

Aerosol compositions

Based on annual mean, aerosol components of filter packs constitute much less than the reactive gas components. The range is not more than about 27% - 13% for PJ but presents a bigger proportion for TR (Figures 4 and 5). Among the aerosol components, NH_4^+ , SO_4^{2-} and NO_3^- form major constituents for both sites, especially for PJ. It is apparent that the acidic indicator species, NO_3^- and SO_4^{2-} which are the main precursors of acid rain in wet precipitation are more dominant in PJ than in TR. (Tables 2, 3, 4, and 5, Figures 4 and 5). NO_3^- and SO_4^{2-} could be traced to NO_x and SO_x emissions characteristic of air pollutants resulting from fossil fuel combustion. Expectedly acidic emissions would be more for urban and industrialized PJ than rural and agricultural TR. NH_4^+ , another major aerosol component is alkaline and thus would have neutralizing effect in acidification process explained previously. The contribution from K^+ and Na^+ , both also alkaline species further enhance the neutralizing capacity with the overall buffering effect on potential acidification. NH_4^+ is associated with NH_3 and would have the same origin. Together with K^+ and Na^+ , they are attributed mainly to soil dust and biomass burning. The overall trend for aerosol constituents does not show marked changes compared with gaseous components for the two-year study period for both sites. It is apparent that gaseous components play a more dominant role than the aerosols in the dry deposition in PJ and TR.

Table 2: Mean concentration of aerosols and reactive gas components of filter packs for Tanah Rata (2004)

2004/ Month	Particles (nmol/m ³)								Gas (nmol/m ³)				No of sampling
	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	SO ₂	HNO ₃	HCl	NH ₃	
Jan	1.396	4.560	3.506	3.742	5.612	0.544	0.246	0.882	1.288	0.850	5.290	18.880	5
Feb	1.430	0.805	11.858	17.243	2.735	2.473	0.803	0.205	3.220	1.508	7.708	17.135	4
Mac	2.640	13.385	15.858	23.510	7.200	4.095	1.580	1.900	1.063	0.400	2.905	19.490	4
April	0.230	1.230	16.593	18.358	1.055	2.293	0.288	0.000	1.650	0.343	13.855	28.875	4
May	0.314	0.158	1.964	3.172	0.342	0.270	<0.1	<0.1	0.950	0.770	3.988	38.796	5
June	0.000	4.105	10.345	16.625	1.310	2.818	1.058	29.328	5.535	4.688	19.903	32.738	4
July	0.052	2.198	8.088	9.510	2.194	1.876	0.472	10.812	4.890	3.510	28.922	32.462	5
August	1.105	2.320	12.448	18.230	2.970	4.073	0.473	3.073	6.378	4.075	26.315	40.778	4
Sept	0.000	0.865	0.188	10.885	2.525	2.040	0.150	<0.1	2.843	0.150	12.453	14.088	4
Oct	1.002	0.804	6.228	5.466	4.460	2.352	0.420	1.020	2.900	5.742	7.834	22.050	5
Nov	0.838	0.888	5.678	4.970	3.475	0.630	0.375	3.500	5.010	8.313	5.068	31.210	4
Dec	1.836	1.878	6.344	6.130	4.460	1.800	0.540	2.060	1.758	3.164	3.710	36.100	5
Annual mean	0.905	2.686	7.972	10.932	3.215	2.036	0.515	4.262	3.051	2.794	11.350	27.900	Total = 47
Std. dev	1.921	4.962	8.373	13.262	4.139	2.262	0.678	14.532	3.783	5.809	10.904	19.482	

Table 3: Mean concentration of aerosols and reactive gas components in nmol/m³ of filter packs for Tanah Rata (2005)

2005 Month	Particles (nmol/m ³)								Gas (nmol/m ³)				No of sampling
	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	SO ₂	HNO ₃	HCl	NH ₃	
Jan	0.610	3.718	11.995	13.058	5.025	4.018	0.575	1.975	2.840	3.885	6.250	44.663	4
Feb	1.013	4.273	21.350	26.720	11.025	5.623	1.325	1.050	4.018	8.440	5.558	47.108	4
Mac	1.303	4.880	23.610	17.878	11.150	28.140	1.375	1.675	2.605	9.203	9.963	60.615	4
April	0.186	0.826	6.822	13.570	3.540	2.082	0.380	0.420	3.486	4.706	4.608	59.766	5
May	0.360	1.458	7.850	5.900	0.575	0.695	0.200	0.350	2.930	4.840	3.338	74.243	4
June	0.873	5.380	14.945	16.973	3.675	2.933	0.850	3.025	4.130	8.335	5.958	26.348	4
July	1.158	1.452	14.308	20.492	3.940	3.028	0.620	2.720	6.268	11.198	9.888	28.266	5
August	1.553	7.048	18.135	12.945	3.800	2.590	0.625	2.700	15.513	16.165	8.718	140.678	4
Sept	0.480	2.278	10.995	18.978	5.450	13.058	0.750	2.925	7.465	8.440	4.298	52.598	4
Oct	0.210	0.068	1.524	1.976	0.600	0.366	0.040	0.420	6.758	2.788	4.514	41.434	5
Nov	3.343	3.883	2.840	5.070	1.375	0.688	0.300	0.450	6.490	0.463	5.995	26.550	4
Dec	0.196	0.344	2.032	2.764	0.700	0.446	0.060	0.300	2.622	0.674	1.730	33.808	5
Annual mean	0.902	2.791	10.968	12.771	4.081	5.011	0.567	1.460	5.378	6.460	5.846	52.069	Total = 52
Std. dev	1.509	4.220	13.408	14.988	5.658	15.743	0.762	2.484	6.625	7.396	4.317	47.483	

Table 4: Mean concentration of aerosols and reactive gas components of filter packs for Petaling Jaya (2004)

2004/ Month	Particle (nmol/m ³)								Gas (nmol/m ³)				No of sampling
	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	SO ₂	HNO ₃	HCl	NH ₃	
Feb	1.280	28.927	22.797	16.297	20.290	3.650	1.590	7.300	25.073	15.457	14.567	7.797	3
Mac	6.403	3.083	6.745	17.283	14.510	5.860	1.620	5.915	6.143	22.980	61.880	4.105	4
April	0.736	0.878	6.632	9.954	2.492	1.620	0.216	1.580	135.258	25.124	10.430	14.080	5
May	0.478	0.728	9.610	7.600	4.055	2.398	0.475	4.018	4.903	24.200	22.578	224.658	4
June	1.690	9.653	15.835	14.118	7.740	4.905	1.880	45.423	8.080	23.415	21.973	11.783	4
July	2.952	8.736	18.144	14.060	8.536	4.804	1.576	32.120	9.878	29.146	21.056	167.370	5
August	1.750	13.563	30.248	30.383	16.480	23.715	2.738	44.258	75.528	14.430	30.280	294.973	4
Sept	0.568	2.533	4.958	5.543	1.890	2.063	0.175	1.750	19.675	16.788	22.993	241.168	4
Oct	4.352	5.294	4.136	11.934	4.260	2.964	0.580	8.560	24.718	11.590	3.518	98.890	5
Nov	1.123	2.068	4.293	3.320	6.350	1.383	0.300	5.150	93.958	17.498	5.170	137.335	4
Dec	3.218	13.198	13.044	12.296	6.980	3.732	0.840	8.000	137.716	17.130	12.836	271.106	5
Annual mean	2.301	7.528	12.020	12.832	8.007	5.060	1.055	14.878	52.047	19.969	20.051	136.951	Total = 52
Std. dev	3.205	15.928	11.853	13.775	6.843	4.314	1.000	7.741	24.846	12.412	6.129	59.196	

Table 5: Mean concentration of aerosols and reactive gas components of filter packs for Petaling Jaya (2005)

2005/ Month	Particle (nmol/m ³)								Gas (nmol/m ³)				No of sampling
	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	NH ₄ ⁺	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	SO ₂	HNO ₃	HCl	NH ₃	
Jan	0.580	80.650	2.048	3.433	1.925	1.750	0.300	2.275	142.245	26.088	18.533	241.005	4
Feb	0.000	5.533	1.565	3.688	0.650	2.415	0.000	0.000	174.165	24.338	72.723	271.228	4
Mac	0.298	1.365	2.998	7.643	3.000	2.875	0.475	0.850	167.163	8.078	25.955	476.295	4
April	5.626	1.450	3.344	0.848	3.060	2.600	0.700	1.320	341.698	36.750	42.236	609.864	5
May	1.743	5.338	2.650	5.083	5.800	2.275	0.425	1.075	352.968	36.093	29.080	884.630	4
June	10.695	52.270	125.678	161.660	36.575	29.648	8.600	30.975	176.500	83.183	56.648	577.723	4
July	27.320	11.970	83.394	123.962	19.140	14.918	1.720	5.000	130.120	53.644	109.528	501.822	5
August	0.453	7.935	16.253	24.338	5.350	3.800	0.825	5.650	59.185	22.935	14.830	514.088	4
Sept	1.430	9.998	17.775	26.433	9.400	4.278	0.925	4.625	117.738	19.058	16.105	298.373	4
Oct	3.612	7.500	7.070	12.022	3.500	1.062	0.160	1.040	59.624	19.296	19.228	306.198	5
Nov	7.145	9.853	4.255	2.485	1.050	0.488	0.175	0.750	35.905	5.973	11.245	199.103	4
Dec	1.528	9.308	13.964	18.904	5.260	3.334	0.860	7.080	155.520	25.884	21.924	313.984	5
Annual mean	5.953	17.934	26.207	36.547	8.719	6.376	1.364	5.468	177.410	33.635	41.384	478.917	Total = 53
Std. dev	15.923	49.997	74.001	111.947	19.506	15.385	4.932	16.811	133.996	33.334	40.635	288.868	

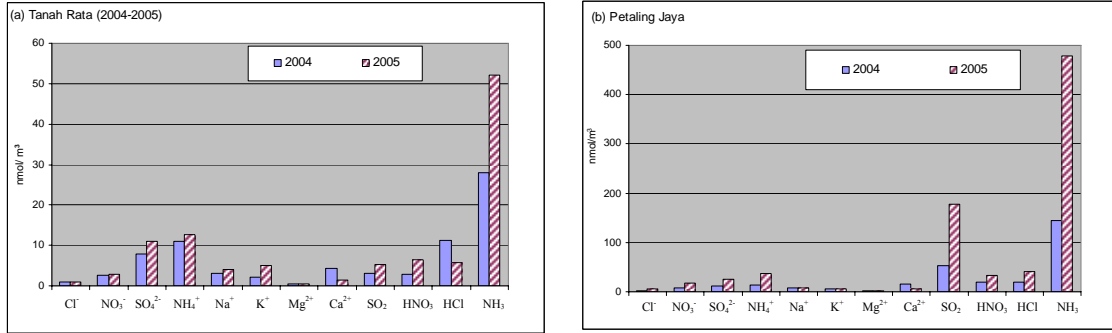


Fig. 4: Annual concentration of dry deposition components for (a) Tanah Rata and (b) Petaling Jaya

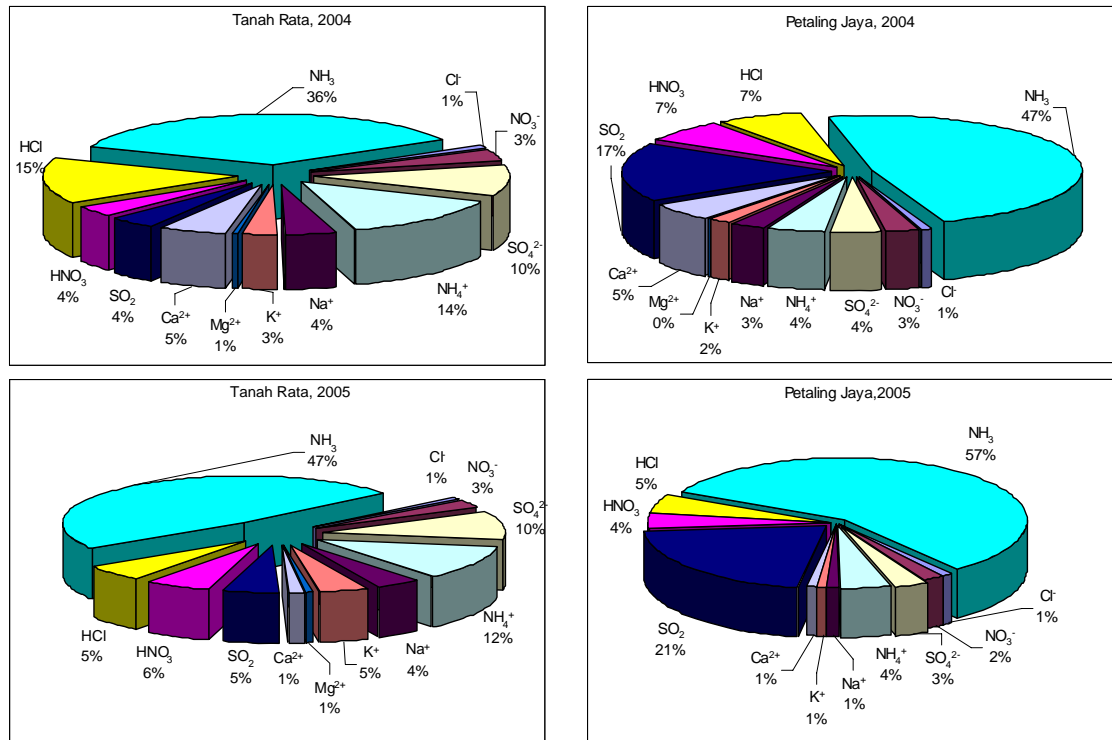


Fig. 5: Compositions of filter pack expressed as percentage for Tanah Rata and Petaling Jaya

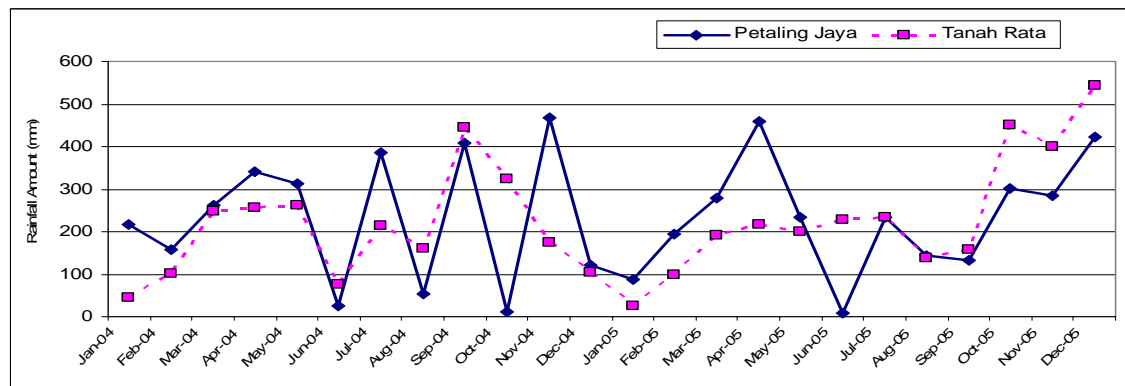


Fig. 6: Rainfall amount 2004-2005 for Tanah Rata and Petaling Jaya.

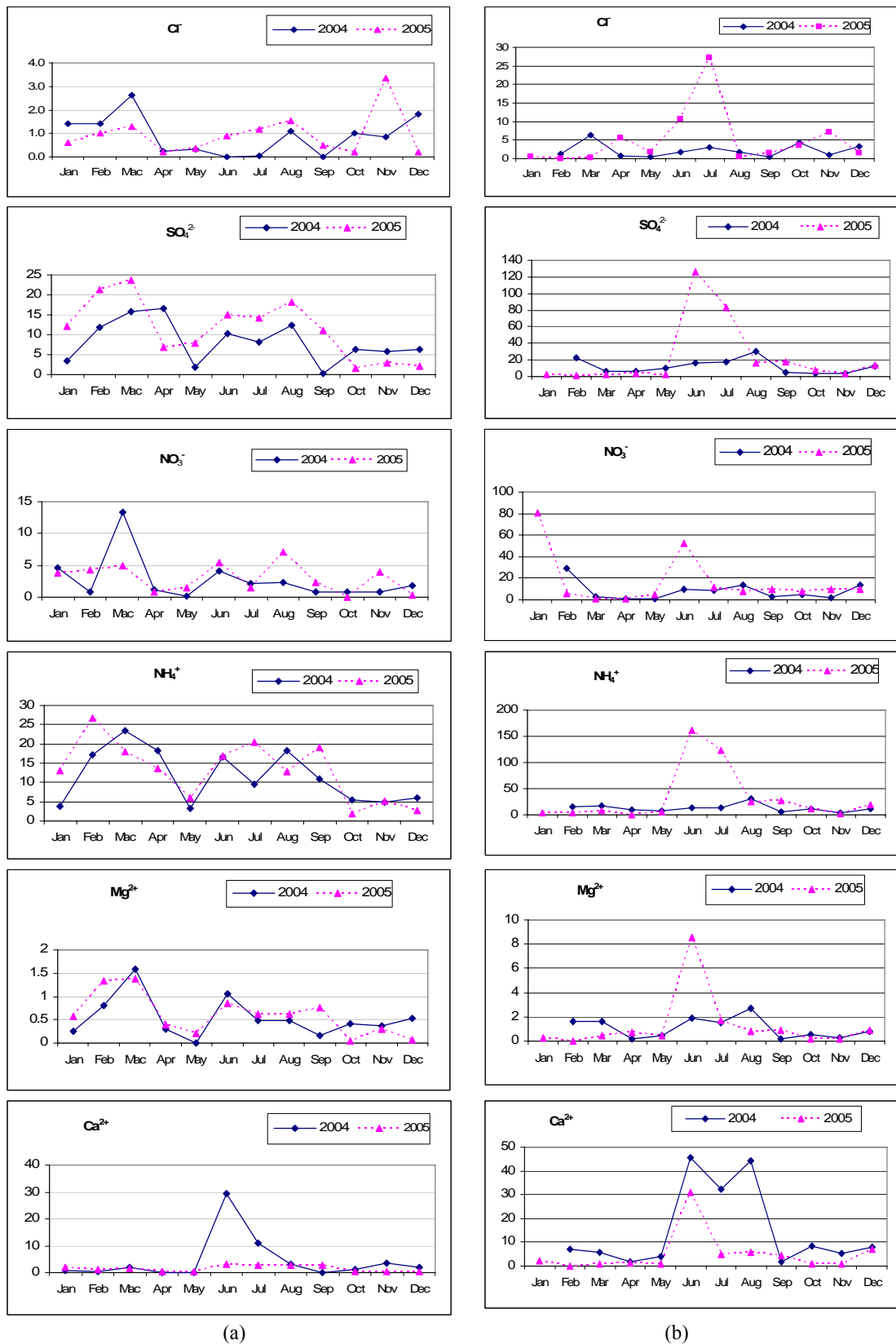
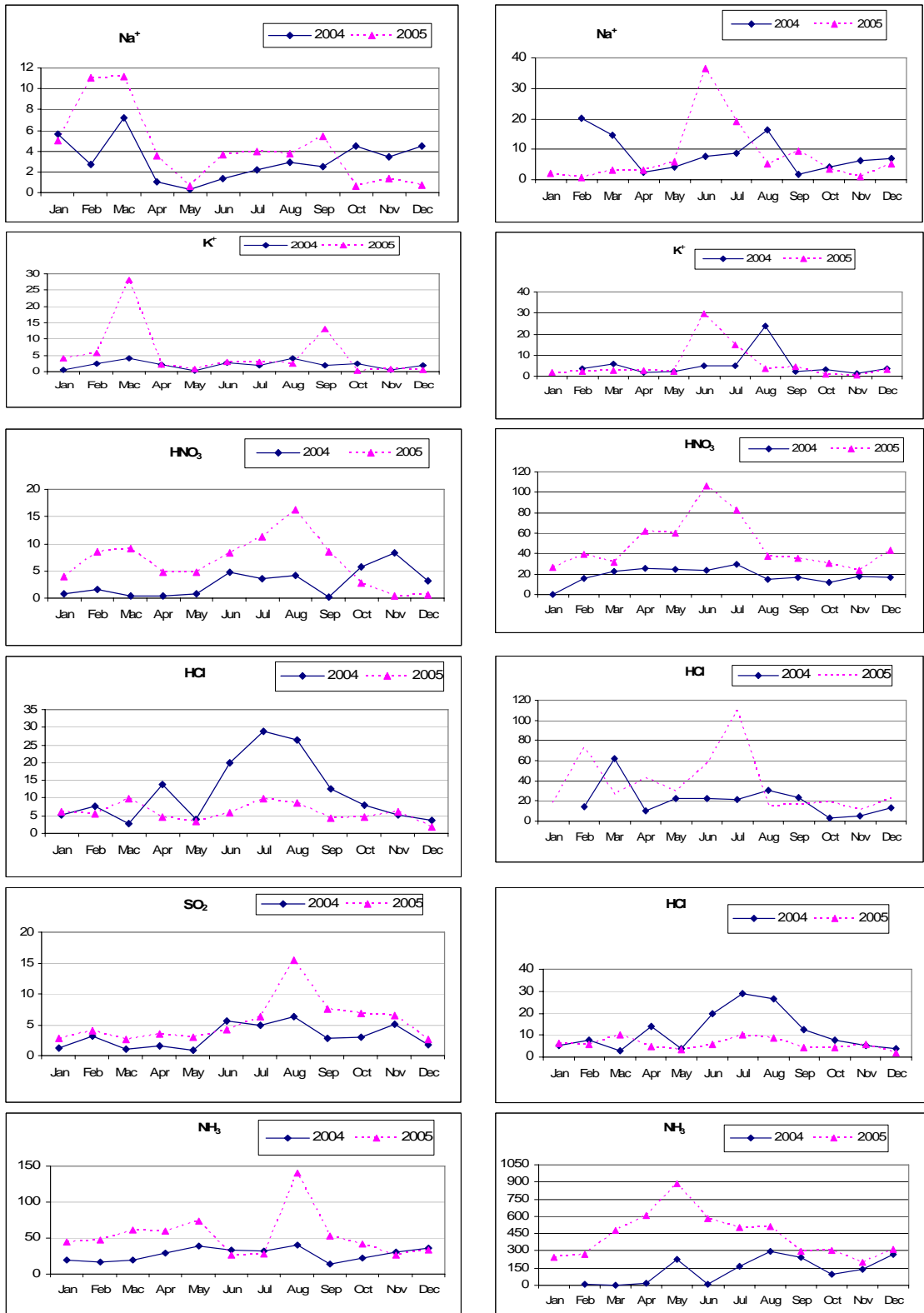


Fig. 7: Monthly variation of pollutant species in dry deposition for (a) Tanah Rata (b) Petaling Jaya for 2004-2005



(a) (b)
 Fig. 7 (cont.): Monthly variation of pollutant species in dry deposition for (a) Tanah Rata (b) Petaling Jaya 2004-2005

Temporal Variation of chemical species

As shown in Figure 7, the monthly average variations of the chemical species from 2004 to 2005 reflect the inhomogeneous pattern of anthropogenic activities at this two sites. Such spatial variability is expected for dry deposition, which is influenced by heterogeneous landscape structures [13]. However, it is noted that the monthly pattern trend for most species are similar, reflecting similar sources and chemistry. Overall there is an increasing trend for most chemical species reflecting increased anthropogenic activities normally accompanied by air pollution emission. The increasing trend seems more discernable for the reactive gases compared to aerosol components. Thus for PJ for example, this increase is obvious in 2005 for SO₂, HNO₃, HCl, and NH₃ while for TR, this trend is characteristic for the N-containing species HNO₃ and NH₃ but for other reactive gases, the increase if any is minimal.

In addition rainfall plays a role in scavenging, washout, rainout and deposition of these pollutants. However the pattern is not obvious as other influencing factors such as chemical interactions and winds also influence the dry deposition. However HNO₃ and NH₃ find high concentration in June for PJ during relatively low rainfall with lower concentration in between January to March and September when rainfall is more abundant. It is also observed that high level of NO₃⁻ coincides with high level of HNO₃, indicating the chemical association between the N-species as well as the relationship between wet and dry deposition..

Conclusion

The foregoing study illustrates the importance of nitrogen-containing species in characterizing the dry deposition compositions of ambient air sampled using filter packs. The bulk of filter pack compositions mainly composed of reactive gases which range from about 78% to 87% of the total compositions at urban PJ and 59%-63% at rural TR. Of the reactive gases, NH₃ has the largest concentration. For PJ high NH₃ could be due to local pollution emitted by industries as well as agricultural activities but for TR, NH₃ is more associated with the use of nitrogenous fertilizers and agricultural activities on a large scale. The acidic species SO₂, HNO₃, HCl, NO₃⁻ and SO₄²⁻ are typically more abundant at urban site than rural site. Their presence reflect the growing use of fossil fuels which in turn is associated with urbanization and industrialization. Overall, this study indicates that urbanization is closely linked to the production of air pollution.

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