WET DEPOSITION AT URBAN AND RURAL SITES OF INDONESIA

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Abstract

Distribusi pH dan karakteristik kimia air hujan dipelajari dari 2001 sampai 2005 di Jakarta, Bandung, Kototabang dan Serpong (2001-2003). Jakarta and Bandung adalah daerah urban di pulau Jawa, Serpong adalah daerah rural sebelah selatan Jakarta. Kototabang terletak di Sumatera adalah daerah remote dan merupakan Global Air Pollution Watch. pH bervariasi 4,4 - 5,2 dengan rata-rata 4,8 di Jakarta; 4,5 - 5,0 dengan rata-rata 4,9 di Bandung; 4,8 - 5,3 dengan rata-rata 5,1 di Kototabang dan 4,62 - 4,65 dengan rata-rata 4,6 di Serpong. Konsentrasi ion-ion dari tinggi ke rendah adalah $NO_3^- > Ca^{2+} > SO_4^{2-} > Cl^- > Na^+ > NH4^+ > Mg^{2+} > H^+ > K^+$ untuk Jakarta; $NH_4^+ > SO_4^{2-} > NO_3^- > Cl^- > Ca^{2+} > H^+ > Na^+ > K^+ > Mg^{2+}$ untuk Bandung; $Cl^- > NO_3^- > H^+ > Na^+ > K^+ > SO_4^{2-} > NH_4^+ > Ca^{2+} > Mg^{2+}$ untuk Kototabang dan $NH_4^+ > NO_3^- > SO_4^{2-} > Cl^- > H^+ > Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ untuk Serpong. Konsentrasi rata-rata bulanan SO_2 dan NO_2 di Kototabang tinggi di musim kemarau dalam range 2,16 - 3,16 ppb dan 7,86 -10,47ppb. Sedangkan di Jakarta konsentrasi SO_2 terlihat tinggi pada bulan-bulan Maret, Juli, Oktober dan Nopember dalam range 6,42-7,13 ppb. Konsentrasi NO_2 di Jakarta adalah tinggi dari April-Juni dalam range 27,06-33,16 ppb, dan Agustus-Oktober dalam range 28,35-30,56 ppb.

Kata kunci: Deposisi basah, karakteristik kimia, air hujan, kota, pedesaan, Indonesia

Abstract

Distribution of pH and rainwater chemical characteristics are studied since 2001 to 2005 in Jakarta, Bandung, Kototabang and Serpong (2001 – 2003). Jakarta and Bandung are urban areas in Java, Serpong is a rural area in west of Jakarta. Kototabang is a remote area in West Sumatera where Global Atmospheric Watch (GAW) is conducted. Measured pH was varied from 4.4 to 5.2 with an average of 4.8 in Jakarta; 4.5 to 5.0 with an average of 4.9 in Bandung; 4.8 to 5.3 with an average 5.1 in Kototabang and 4.62 to 4.65 with an average 4.6 di Serpong. Ion concentrations starting from high to low were $NO_3^- > Ca^{2+} > SO_4^{2-} > Cl^- > Na^+ > NH4^+ > Mg^{2+} > H^+ > K^+$ for Jakarta; $NH_4^+ > SO_4^{2-} > NO_3^- > Cl^- > Ca^{2+} > H^+ > Na^+ > K^+ > Mg^{2+}$ for Bandung; $Cl^- > NO_3^- > H^+ > Na^+ > K^+ > SO_4^{2-} > NH_4^+ > Ca^{2+} > Mg^{2+}$ for Kototabang and $NH_4^+ > NO_3^- > SO_4^{2-} > Cl^- > H^+ > Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ for Serpong. Monthly averages of SO_2 and NO_2 concentrations in Kototabang were high in dry season in range 2.16-3.16 ppb and 7.86-10.47 ppb. In the other hand Jakarta had high SO_2 concentration in March, July, October and November in range of 6.42-7.13 ppb. NO_2 concentration in Jakarta was high in April-June in range of 27.06-33.16 ppb and August-October in range of 28.35-30.56 ppb.

Key word: Wet deposition, chemical characteristics, rainwater, urban, rural, Indonesia

1. INTRODUCTION

Indonesia is an archipelago as shown in Fig. 1. And 2/3 of its' territory consists of sea and its' land lies under equator in tropical areas. Indonesia is located in 6 °LU-11 °LS and 95 °BT -142.5 °BT. There are five biggest islands i.e. Kalimantan, Sumatera, Java, Sulawesi and Papua. Population is 211 millions with population growth rate of 1% in 2002. Economic situation in GDP (gross Domestic Product) is Rp.426,740.50 billions with growth rate of 4.50% in 2006. Energy demand in 2002 was 751 million BOE (Barrel Oil equivalent) with growth rate of 4.94% and energy intensity is 3.56 million BOE/million population (PEUI, 2004). Java is an island that has the highest population number and also the busiest transportation and industries activities compare to other islands. Furthermore Sumatera, Kalimantan and Papua have biggest area of tropical forest that contributes 10% of world total tropical forest. Tropical forest has a very important role because it acts as a world lung.

Indonesia is located between Asia and Australia continents within tropical areas. It is influenced by tropical climate with two seasons i.e. dry and wet seasons. Dry season starts from June-September while wet season starts from December-March. Air temperature all years is in range of 20 – 35 ^{0}C. Air humidity is 45-95% and annual average total rainfall was 2000-3000 mm and above 3000 mm.

Population and economic growth especially in Java has resulted rapid development of cities such as Jakarta, Bandung, Surabaya and Medan. Combination results between population, economic and energy consumptions has lead to increase of gaseous pollutants such as SO_2, NOx, CO_2, CO, NH_3, CH_4 and aerosol released to the air. Most of air pollutions are resulted from industries and transportation from trade centre such as Jakarta and Bandung in Java. Jakarta is a coastal area that acts as a trade, service and industrial city in West Indonesia. Bandung is a city with specific topography because it shapes like a basin and is surrounded with mountains. It is located 743 m above sea level. Nowadays Bandung has experienced rapid development in trading sector. Tropical forests as a world lung that are able to filter air pollutants undergo fire every year. Forest fires often occur during long dry season such as in 2004. Forest fires have lead to visibility reduction and increase in gases released from biomass burning such as CO, NH_3, NO, CH_4 and aerosol.

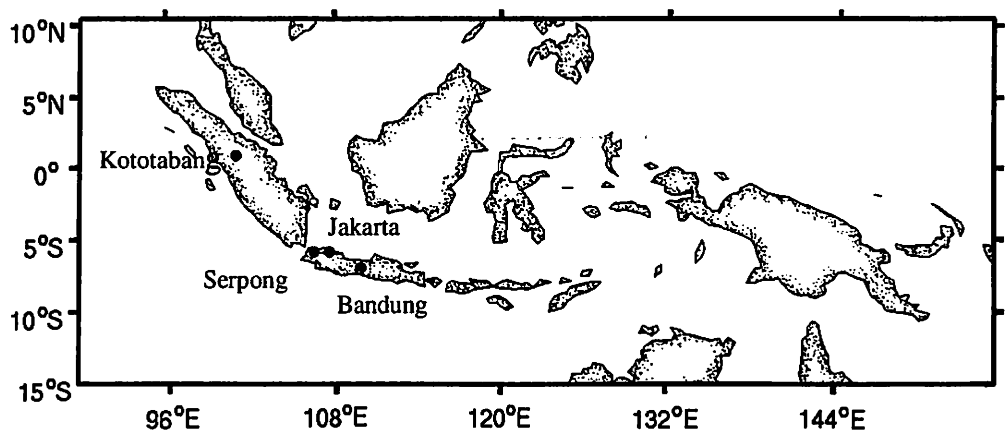

Fig.1.1. Indonesian map

Increase in gaseous released to the air has lead to poor air quality and acid precipitation. Furthermore the impacts can influence badly to ecosystem and also directly or indirectly to human health (Hu et al., 2003). Pollutants will remain in the air during certain time and finally are deposited to the earth through wet and dry deposition. During their stay in the air the pollutants can decrease ambient air quality and furthermore contribute to direct effect to human health. Pollutants such as sulphur oxides (SO_2) and nitrogen oxides (NO_2) undergo oxidation process that converts them to SO_3 and NO_3, and then they experience further change to sulphates and nitrates (Seinfeld and Pandis, 1998). Finally sulphates and nitrates will be removed from the atmosphere to the earth through precipitation and direct deposition, or commonly known as wet and dry deposition. Wet deposition starts with cloud formation that falls as rain, snow or fog with acid content. Rainwater chemistry compositions are used to understand atmospheric pollutant contribution from various sources. Wash and rain dissolved processes are considered here. If the sources are influenced by human activities, then acid rainwater is resulted from anthropogenic sources such as SO_2 and NO_x, while base rainwater is from NH_3 or soil dusts such as $(NH_4)_2SO_4$, NH_4NO_3 or NH_4Cl (Ohta and Okita, 1990). In coastal city, marine aerosols influence rainwater chemistry. In coastal areas most of chloride particles in troposphere comes from marine aerosols. NH_4Cl is formed from HCl released from coal burning and reacts with atmospheric ammonia.

Acid deposition issues have become international attentions, therefore Indonesia conducts wet and dry deposition monitoring in Jakarta and Bandung as urban areas in Java, Serpong as a rural area in west of Jakarta and Kototabang as a remote area (Global Atmospheric Watch) in west Sumatera (Fig. 1). In this context the Japanese Government has taken initiative in establishing monitoring network in the region, the Acid Deposition Monitoring Network of East Asian (EANET). The network and ADORC at Niigata have actively organized workshops and trainings for capacity building for professionals in the region. Indonesia has been actively participating since 1998 both in intergovernmental and scientific advisory committees in setting up the policy and methodology of monitoring acid deposition. In this paper we will identify rainwater chemical composition and pH distribution as indicators of rainwater acidity during 2001 to 2005.

2. SAMPLING AND ANALYSIS

2.1. Monitoring stations

The monitoring of acid deposition in Indonesia is carried out by Pusarpedal (EMC) of the Ministry of Environment, National Geophysics and Meteorology Agency (BMG) and The Indonesian National Institute Aeronautic and Space (LAPAN) for wet and dry deposition. Monitoring stations of acid deposition (wet deposition) in Indonesia are:

a. Serpong Station (Pusarpedal)
- Location : rural
- Interval : daily
- Variables : pH, electrical conductivity (DHL), concentration of SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+}
- Methods : glass electrode cell, ion chromatography, atomic absorption spectrophotometry and spectrophotometry.
- Laboratory : Pusarpedal – KLH.

b. Jakarta (BMG office)
- Location : urban
- Interval : weekly
- Variables : pH, electrical conductivity (DHL), concentration of SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+}.
- Methods : glass electrode cell, ion chromatography, atomic absorption spectrophotometry and spectrophotometry.
- Laboratory : BMG - Jakarta.

c. Kototabang, West Sumatera (BMG office).
- Location : remote area
- Interval : weekly
- Variables : pH, electrical conductivity (DHL), concentration of SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+}.
- Methods : glass electrode cell, ion chromatography, atomic absorption spectrophotometry and spectrophotometry.
- Laboratory : BMG, Jakarta.

d. Bandung (LAPAN office)

- Location : urban
- Interval : daily (every 24 hour)
- Variables : pH, electrical conductivity (DHL), concentration of SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+}.
- Methods : glass electrode cell, ion chromatography.
- Laboratory : LAPAN - Bandung.

2.2. Analysis and Quality

Measured parameters in wet deposition monitoring cover are pH, electrical conductivity (DHL) and ion concentrations (SO_4^{2-}, NO_3^-, Cl^-, NH_4^+, Na^+, K^+, Ca^{2+} and Mg^{2+}). All equipments and chemical substances have to be free from contamination in order to ensure accuracy of measurement and analysis of sample, and blank sample low value for parameter pollutant. Data quality of rainwater samples is checked by ion balance according to ADORC guidance. Deviation of the ion balance is about 15% i.e. interval between total cation and anion divided by total cation and anion.

3. RESULTS AND DISCUSSION

3.1. Chemical Composition of Rain Water

Annual average volume weights of main chemical component concentrations are summarized in the table 3.1 together with precipitation amount, EC (electrical conductivity) and pH. The main chemical components of rainwater are anion such as SO_4^{2-}, $nssSO_4^{2-}$, NO_3^-, Cl^-, and cation such as H^+, NH_4^+, Na^+, Mg^{2+}, Ca^{2+}, $nssCa^{2+}$ and K^+. Kototabang had highest annual total amount of precipitation in range of 1209-3127 mm and average of 2160 mm, Serpong in range of 1607-2505 mm and average of 2085 mm, Bandung in range of 894-2605 mm and average of 1879 mm and Jakarta in range of 1237-2086 mm and average of 1588mm.

Table 3.1. Annual average volume weight of main chemical component concentrations (μmol/l), total amount of precipitation (mm), EC (electrical conductivity in mS/m) and pH

Location	Time	Number of sample	amount of precipitation	SO_4^{2-}	nss-SO_4^{2-}	NO_3^-	Cl^-	NH_4^+	Na^+	K^+	Ca^{2+}	nss-Ca^{2+}	Mg^{2+}	H^+	pH	EC
		n	(mm)	umol/l	umol/l	umol/l	umol/l	umol/l	umol/l	umol/l	umol/l	umol/l	umol/l	umol/l		mS/m
Jakarta	2001	28	1237	108.4	104.1	96.5	72.7	124.1	74.7	12.7	116.2	114.6	133.1	7.6	5.1	47.2
	2002	21	1572	38.5	36.4	28.2	28.1	27.5	35.3	11.3	42.9	42.2	13.1	16.9	4.8	3.0
	2003	23	1617	66.7	65.1	58.4	52.2	4.6	27.1	5.2	101.3	100.7	12.7	7.0	5.2	4.8
	2004	34	1430	72.8	69.6	120.1	54.2	33.5	54.4	15.5	78.3	77.3	10.1	31.9	4.8	4.9
	2005	35	2086	44.7	43.5	58.7	42.6	18.5	20.4	8.5	19.3	18.9	3.7	53.3	4.4	3.7
Bandung	2001	109	2605	33.7	32.5	26.9	25.0	37.9	20.2	12.6	24.2	23.7	4.1	10.1	5.0	2.1
	2002	69	2541	27.7	27.2	26.3	20.3	29.9	8.6	2.0	17.1	16.9	1.6	34.9	4.5	1.7
	2003	80	1606	20.4	20.0	20.4	13.0	32.7	7.1	4.1	10.9	10.7	1.7	10.0	5.0	1.5
	2004	98	894	27.7	27.0	28.2	17.4	36.8	10.8	3.3	18.3	18.0	3.3	9.3	5.0	1.8
	2005	90	1749	35.0	34.3	19.0	14.5	35.6	11.9	4.6	15.8	15.3	2.4	9.3	5.0	1.7
Kototabang	2001	58	1209	4.7	4.4	2.7	6.6	2.4	4.5	1.0	1.4	1.4	0.8	8.5	5.1	0.4
	2002	30	1798	7.5	7.1	5.6	16.8	2.1	6.3	5.1	4.9	4.8	2.6	4.9	5.3	4.9
	2003	34	3127	8.6	8.0	46.2	26.1	0.3	9.0	18.7	5.2	5.0	6.3	4.7	5.3	1.8
	2004	49	2472	5.1	4.6	3.1	13.1	11.9	9.3	6.6	9.9	9.7	1.9	18.3	4.9	1.1
	2005	49	2194	5.3	4.9	1.5	7.6	9.9	6.7	4.6	3.8	3.6	1.1	21.4	4.8	0.8
Serpong	2001	68	1607	38.2	36.8	50.7	32.3	67.6	23.8	7.0	13.6	13.1	3.5	23.7	4.6	2.9
	2002	73	2505	25.7	24.2	32.6	23.0	46.0	25.2	3.9	9.9	9.4	4.5	22.6	4.6	1.9
	2003	57	2143	23.0	22.3	30.7	27.1	44.8	11.2	7.9	6.6	6.4	2.7	24.0	4.6	2.3
	2004															
	2005															

General variation of annual mean EC (electrical conductivity) was 0.4-47.2 mS/m from 2001 to 2005 in Jakarta, Bandung, Serpong and Kototabang. Jakarta had EC in range of 3.0-47.2 mS/m with highest sulphate, nitrate and chloride contents especially in 2001. Bandung had EC in range of 1.5-2.1 mS/m, not much different from Serpong i.e. in range of 1.9-2.9 mS/m. Electrical conductivity (EC) variation in Kototabang was in range of 0.4-4.9 mS/m. High EC value was shown in 2002 because SO_4^{2-}, NO_3^-, and Cl^- concentrations were also high.

Table 3.1 and fig. 3.1 showed high annual average of primary ions concentration i.e. anion and cation in Jakarta, followed by Bandung, Serpong and Kototabang. Jakarta as a coastal city had high nitrate and sulphate concentrations as a reflection of urban city with busy transportation in Indonesia. As a coastal city it was influenced by marine elements such as Ca^{2+}, Cl^-, Na^+ and Mg^{2+} that their concentrations were found very high. Rainwater ion concentrations contents in Jakarta starting from high to low were $NO_3^- > Ca^{2+} > SO_4^{2-} > Cl^- > Na^+ > NH_4^+ > Mg^{2+} > H^+ > K^+$. Probably high concentrations of NH_4^+ and Ca^{2+} were influenced by $(NH_4)_2SO_4$ or $(NH_4)NO_3$ from aerosol and from soil dusts or marine minerals.

Bandung a city with high density of transportation activities, eventhough it is not as high as Jakarta, had dominant oil burning emission shown by its' high SO_4^{2-} and NO_3^- concentrations. Probably relatively high ammonium concentration in Bandung was caused by influences of $(NH_4)_2SO_4$ of $(NH_4)NO_3$ from aerosol or soil dusts. Bandung had typical high monthly average of SPM (dust) in dry season (JJA) (Budiwati et al., 2001). Ions concentration contents of rainwater in Bandung starting from high to low were $NH_4^+ > SO_4^{2-} > NO_3^- > Cl^- > Ca^{2+} > H^+ > Na^+ > K^+ > Mg^{2+}$.

Chemical component contents of rainwater in Kototabang were relatively low compared to other places in Indonesia since it was a remote area in West Sumatera which had low transportation density and was located far from sea. Ions concentration contents of rainwater in Kototabang from high to low were $Cl^- > NO_3^- > H^+ > Na^+ > K^+ > SO_4^{2-} > NH_4^+ > Ca^{2+} > Mg^{2+}$. High Cl^- and NO_3^- concentration were probably caused by biomass burning, especially in 2003. The combustion of biomass (fuel wood, brush, vegetation, grass, and other organic materials) is a rich source of atmospheric emissions such as CO_2, CO, NO, CH_4, CH_3Cl and particulate matter.

Serpong is a rural area near Jakarta and Tangerang (industries area). Table 1 and fig. 3.1 explained ions concentrations starting from high to low in Serpong i.e. $NH_4^+ > NO_3^- > SO_4^{2-} > Cl^- > H^+ > Na^+ > Ca^{2+} > K^+ > Mg^{2+}$. High NH_4^+ concentration was probably due to extent farming and soil dust. On the contrary NO_3^- and SO_4^{2-} were mostly produced by oil burning. Low marine elements concentrations such as Cl^-, Na^+, Ca^{2+}, K^+, and Mg^{2+} were significant due to location far from sea.

Generally, Jakarta was influenced by transportation and sea while Bandung was dominated by transportation and soil dust. Local conditions held important role in determining pollutants in cities in Indonesia such as Jakarta, Bandung, Kototabang and Serpong.

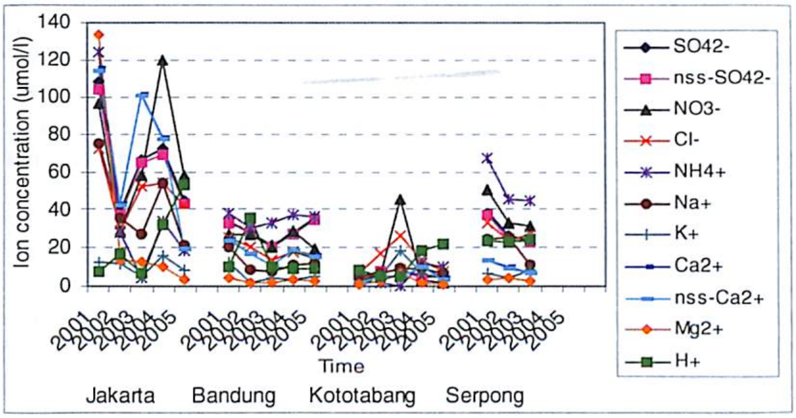

Fig. 3.1. Chemical composition of rainwater in Jakarta, Bandung, Kototabang (2001-2005) and Serpong (2001-2003).

3.2. pH distribution

Fig. 3.2 showed pH distribution data during period 2001 to 2005 in Jakarta, Bandung and Kototabang. Rain with pH less than 5.6 was indicated as acid. According to Lacaux et al. (1987) rainwaters were categorized basic or acid as followed:

- Basic rainwater had pH above 5.6.
- Acid rainwater had pH between 4.5 and 5.6.
- Acid rainwater with pH less than 4.5 indicated a very high air pollution contaminated area.

pH distribution was grouped in range of 4.0-4.5; 4.5-5.0; 5.0-5.5; 5.5-6.0; and 6.0->. Percent frequency values in group range of 4.0–4.5 in Jakarta, Bandung and Kototabang were 77%, 4% and 6% respectively in 2005. For group range of 4.5–5.0 they were 19%, 28% and 33% in Jakarta, Bandung and Kototabang respectively. For group range of 5.0-5.5 they were quite high i.e. 16%, 28% and 34% in Kototabang, Bandung and Jakarta respectively. Group of pH bigger than 5.6 or basic rain according to Lacaux was 37%, 37% and 26% in Jakarta, Bandung and Kototabang respectively. Generally, rainwater with pH less than 5.6 was often found in Indonesia. Group of pH less than 5.6 was 63%, 63% and 73% in Jakarta, Bandung and Kototabang respectively.

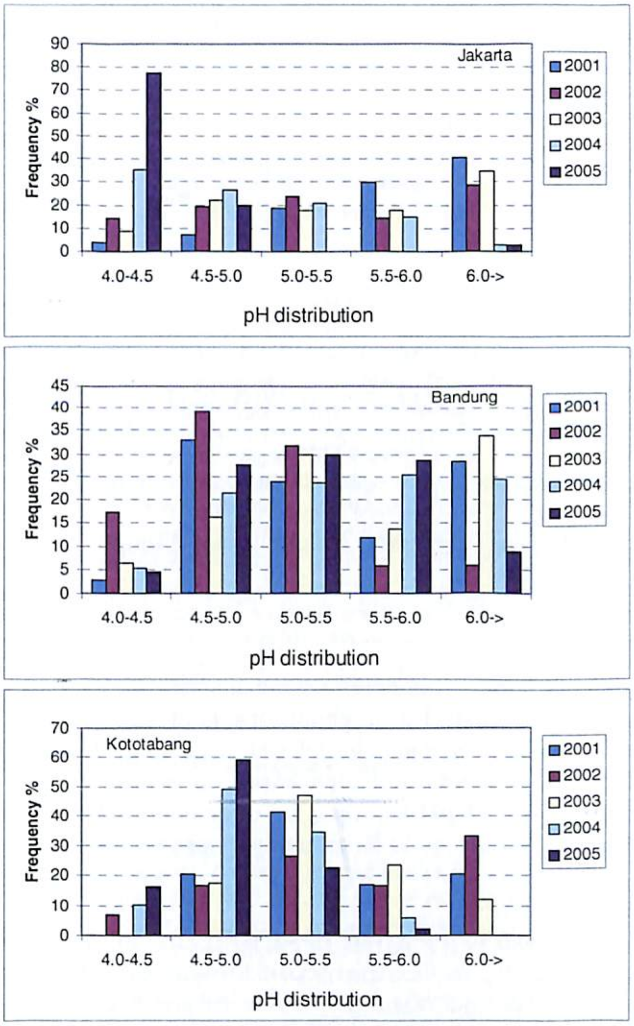

Fig 3.2. pH distribution in Jakarta, Bandung and Kototabang in 2001-2005.

Annual pH averages in Jakarta, Bandung and Kototabang in 2001 to 2005 and Serpong in 2001 to 2003 were shown in fig. 3.3. pH varied from 4.4 to 5.2 with average of 4.8 in Jakarta, from 4.5 to 5.0 with an average of 4.9 in Bandung; from 4.8 to 5.3 with an average of 5.1 in Kototabang and from 4.62 to 4.65 with an average of 4.6 in Serpong. Based on annual pH averages it can be concluded that acid rain had occurred in Indonesia according to pH limit of 5.6 as a neutral limit according to Seinfeld and Pandis (1998), and the best was Kototabang.

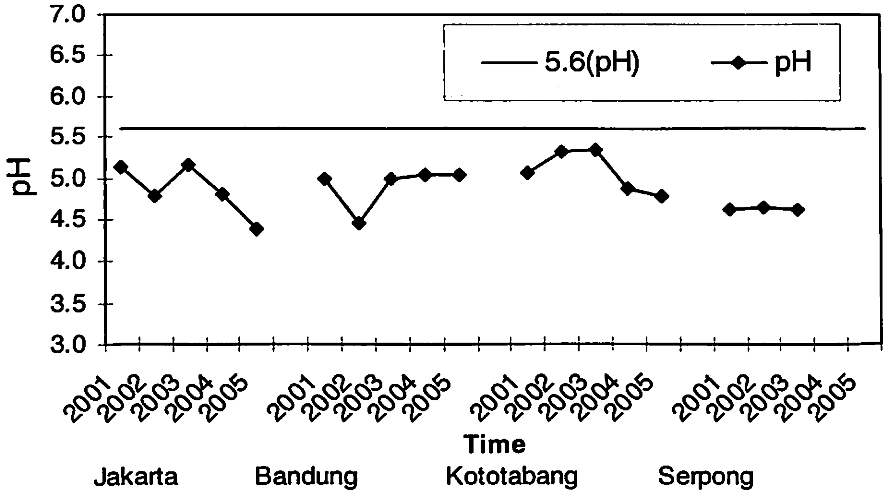

Fig. 3.3. Annual pH average in Jakarta, Bandung and Kototabang in 2001 to 2005 and Serpong in 2001 to 2003.

4. CONCLUSION

Generally, Jakarta was dominated by transportation and sea, while Bandung was by transportation and soil dust. Local conditions held important role in determining pollutant in cities in Indonesia such as Jakarta, Bandung, Kototabang and Serpong. Indonesia was indicated as having acid rain based on annual average pH values which were mostly less 5.6. Rains with pH less than 5.6 often occurred having frequency of 63%, 63% and 73% in Jakarta, Bandung and Kototabang respectively.

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