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The Constraining of Coal-Fired Power Plant Emission Contribution based on Metal Element Analysis

Poerna Sri Oetari[1, 2], Haryono Setyo Huboyo [4], Soedarto Hadi[2], Karunia Dwi Hari[3], Slamet Isworo[1, *]

[1] Department of Environmental Health, Dian Nuswantoro University, Semarang, Indonesia

[2] Department of Environmental Science, School of Postgraduate Studies, Diponegoro University, Semarang, Indonesia

[3] Environmental Department of Mitra Adi Pranata EIA Consultant, Semarang, Indonesia

[4] Department of Environmental Engineering, Faculty of Engineering, Diponegoro University, Semarang, Indonesia

Abstract: Coal-fired power plants (CFPPs) emit fly ash, and its small particle size affects the health of nearby community settlements. This research was conducted to characterize the dispersion of fine and coarse particles from CFPP to determine air quality around CFPP. The method uses the results of emission characterization to model its dispersion in ambient air with an AERMOD View and 24-hour sampling for ambient air particles, and is characterized by analysis of Inductively Coupled Plasma Mass Spectrometry (ICP-MS). A contribution analysis was performed using the Positive Matrix Factor (PMF) receptor model. The dispersion results lead towards the settlements in six community housing areas near the two power plants and the source analysis showed that the emission sources are CFPPs, biomass and soil combustion, vehicle exhaust, and some unknown sources. A source profile analysis based on the elements in the fine and coarse particles in the air of the studied dispersion area revealed that particle yields vary depending on the location. Results for strong positive correlations in the air around CFPP with the ESP controllers for fine particles showed Na-Mg ($r = +0.996$, $P < 0.01$) and coarse particles V-Fe ($r = +0.975$, $p < 0.01$). From the ESP-WFGD, results for the fine particles showed Ca-V ($r = +0.981$, $p < 0.01$). The complete results from emission contributions to the air at R1 - R6 were 22%, 39%, 2%, 11%, 32%, and 41% for fine particles, and 8%, 14%, 20%, 14%, 14%, and 10% for coarse particles, respectively.

Keywords: fine particles, coarse particles, dispersion, pollution, contribution

基于金属元素分析的燃煤电厂排放贡献约束

摘要： 燃煤电厂（碳纤维聚丙烯）排放粉煤灰，其较小的粒径影响附近社区居民点的健康。进行这项研究以表征碳纤维聚丙烯中细颗粒和粗颗粒的分散情况，以确定碳纤维聚丙烯周围的空气质量。该方法使用排放表征的结果，通过艾尔莫德视图进行建模，并通过 24 小时采样采集环境空气颗粒，以模拟其在环境空气中的扩散，并通过电感耦合等离子体质谱（ICP-多发性硬化症）分析对其进行表征。使用正矩阵因子（PMF）受体模型进行贡献分析。分散结果导致在两个发电厂附近的六个社区住宅区定居，排放源分析表明排放源为碳纤维聚丙烯，生物质和土壤燃烧，车辆尾气以及一些未知源。根据研究分散区空气中细颗粒和粗颗粒中的元素进行的源剖面分析表明，颗粒产量随位置而异。使用静电除尘器控制器对碳纤维聚丙烯周围空气中的强颗粒进行强正相关的结果显示，钠镁（$r = +0.996$，$P <0.01$）和粗颗粒钒铁（$r = +0.975$，$p <0.01$）。从静电

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About the authors: Poerna Sri Oetari, Department of Environmental Health, Dian Nuswantoro University, Semarang, Indonesia; Department of Environmental Science, School of Postgraduate Studies, Diponegoro University, Semarang, Indonesia; Haryono Setyo Huboyo, Department of Environmental Engineering, Faculty of Engineering, Diponegoro University, Semarang, Indonesia; Soedarto Hadi, Department of Environmental Science, School of Postgraduate Studies, Diponegoro University, Semarang, Indonesia; Karunia Dwi Hari, Environmental Department of Mitra Adi Pranata EIA Consultant, Semarang, Indonesia; Slamet Isworo, Department of Environmental Health, Dian Nuswantoro University, Semarang, Indonesia

Corresponding author Slamet Isworo, slamet.isworo@dsn.dinus.ac.id

除尘器，细颗粒的结果显示为钙钒（r = + 0.981，p <0.01）。R1-R6 处的空气排放贡献的完整结果对于细颗粒分别为 22%，39%，2%，11%，32%和 41%，以及 8%，14%，20%，14%，14 %和 10%的粗颗粒分别.

关键词：细颗粒，粗颗粒，分散，污染，贡献。

1. Introduction

Indonesia reached its highest energy consumption rate, 4.7% per year, in 2002. In 2015, 70 million tons of coal were used as a primary energy source for power-plant activities. This value represented 80.72% of the coal utilization [1] in Indonesia. To meet the demands of the projected electricity demand of 6.42% PT PLN (Persero), due to the electricity supply business planned for 2019–2028, will build a power plant that will operate with a mixture of 54% coal, 23% renewable energy, 22% gas, and 0.4% oil [2]. The AERMOD modeling system is specifically designed to support the EPAs regulatory modeling program, this is a regulatory modeling option will be the default operating mode model. These options include the use of stack end downwashes, and routine processing of averaging, when missing meteorological data occurs [3].

The analysis of the distribution pattern of exhaust gas emissions in the plant can show the resulting concentration as well as the distribution pattern and direction. Modeling using AERMOD software requires supporting meteorological data and shows that the distribution of pollutants for SO2, NO2, CO, and particulates is in accordance with the dominant wind direction found in wind rose [4]. Combustion processes at power plants produce particles emitted in the exhaust gas. Such particles are classified based on their aerodynamic diameter, which affects their ability to be transported to the atmosphere [5].

Research on particle emissions from coal-fired power plants (CFPPs) has yielded a variety of results. In India, for power plants producing 2,780–29,900 MW of power, the average emitted particles range from 0.8–9.1 $\mu g/m^3$ [5]. In China, for 600MW and 300MW CFPPs, it was found that the concentration of particles was between 11.7–55 mg/m^3 and 9.2–336.7 mg/m^3, respectively [6]. The combustion processes of CFPPs release trace elements into the environment, including mercury, cadmium, arsenic, molybdenum, vanadium, and various acidic gases [7]. Other studies reported additional trace metal elements in coal combustion emissions, including Be, Cr, Pb, Mg, Se, B, F, Co and Zn [8], as well as Sb, Co, Mn, Ni [9], and Fe [10]. Research on trace elements in fly ash revealed a value range of 76–94% for As, Pb and Cr [11]. In other studies, the characterization of trace metal elements in fly ash from coal combustion identified the presence of Cd, Pb and Mn [12], as well as As, Cd, Sb, Zn, Pb and Cr [8].

Studies on the characterization of the elements in fine particles in Indonesia were carried out on the ambient air near the Cilacap Power Plant, which found that the As and Sb proportions were lower than the other detected elements [13]. The characterization of fly ash emissions (where no particle size information was collected) from seven CFPPs in Java contained Mg, Al, Ca, Ti, Mn, Fe, Sr, and Na with concentrations of 5.572–20.636 mg/kg, 36,353–140,972 mg/kg, 27,729–144,296 mg/kg, 3,680–7,325 mg/kg, 624–9,515 mg/kg, 62,454–114,325 mg/kg, 628–1,775 mg/kg, and 995–12,640 mg/kg, respectively. Minor elements included Se, Cs, Zn, V, Cr, Hg, Th, Sc, Li, Sr, U, Co, Nd, Hf, Rb, Sb, and La with concentrations in the range 2.94–76.5 mg/kg. While each element has its degree of toxicity to humans, that of As and Cr were found to be above the safe threshold [14]. Complete power-plant emission research on fine and coarse particles, which was carried out at plants with different particle control devices, namely ESP and a combination of ESP and WFGD in Central Java, Indonesia, showed that the concentration of fine particles was significantly different ($p<0.05$) for all units. In contrast, the coarse particles did not show significant differences ($p>0.05$). The ratio of fine particle emissions to PM_{10} ranged between 37.3–44.1% and the ratio of coarse particle emissions to PM_{10}ranged between 55.9–63.6%. Some specific elements can be used as a marker, namely Mo and Co for ESP only, and As, Be, Pb, V, and Sn for ESP-WFGD [6].

In the ambient air, the presence of dust particles can contribute to many anthropogenic factors, so it is necessary to determine their source(s), such as through an analysis of a receptor model. One such model is the positive matrix factorization (PMF) receptor model, which provides a flexible modeling approach and allows for the effective use of the available data. PMFs have been successfully applied to modeling receptors throughout the world, and have been used to identify the contribution of various emission sources [15]. PMFs can also be used in PM_{10} studies to determine the source of pollutants (e.g., crust, sea, nitrate, sulfate, traffic, suspended dust, biomass combustion, port industry, or CFPPs). For example, the results of a study that used a receptor model for power-plant activities indicated the $PM_{2.5}$fine particle concentration was15.5 ug/Nm^3 [16]. Research from Ohio, USA, showed that the contribution of a 18-MW bituminous coal power plant accounted for 62.6% of the total emission, which contained an average concentration of fine particles of 14.1 ug/Nm^{3}at a distance of3 km from the plant [17]. Research for three sites in central Italy was conducted using the PMF3.0 and 5.0 models, which were specifically developed to determine the contribution from CFPPs to that of the crust from daily PM_{10} samples collected from urban sites, urban background sites, and rural sites located between 2.8 and 5.8 km from the power plants. The average contributions from the power plants were2% (±1%) at the study sites, with limited differences between the different locations [18].

CFPPs are an important source of air pollution, causing health issues for nearby populations [19]. Some research has indicated that the emissions from power plants may cause around 30 deaths each year, which are caused by secondary particles that contribute to more than 80% of the deaths, most of which arise from sulfate formation (73% of the total impact) and high SO_2 emissions [20]. In this current study, we assess the dispersion of fine and coarse particles from Jepara and Rembang CFPPs, characterized metal elements in fine and coarse particles in the receptors, and analyzed the contribution of sources of contamination mainly from CFPP with the PMF receptor model. There is no dispersion model that has been used to anticipate the distribution of fine dust ($PM_{2.5}$) and coarse dust ($PM_{2.5-10}$) that can reach residential areas in Indonesia.

2. Research Methodology

2.1. Site Identification and Sampling Period

The sampling of fine and coarse particles was carried out in residential areas near two power plants in Jepara Regency: Tanjungjati B Jepara (P1) and Rembang Regency (was Jawa Tengah I Rembang) (P2) in Central Java Province, Indonesia (Fig. 1). Based on the land-use status in the research site's spatial layout, P1 is a strategic area for the use of natural and strategic resources, and P2 is a designated industrial area. Based on the dominant wind direction and wind speed from 2016 and 2017, we chose three sampling locations near each power plant: Jambu Timur Village (R1), Jeruk Wangi Village (R2) and Jinggotan Village (R3) in the Jepara Regency; and Dadapan Village (R4), Sanetan Village (R5) and Trahan Village (R6) in the Rembang Regency. The weather conditions during sampling in both regencies tend to be hot during the dry season, with temperatures ranging from 27–31°C, and humidity between 58.4–76.0%. Six samples were obtained at each site (Table 1).

a. b.

Fig. 1 Sampling location map: (a) Jepara and (b) Rembang

Table 1 Description of the site locations and sampling periods

Regency	Code	Sampling Location	Sampling Period			Distance from Source (m)	
			I	II	III	CFPP	Nearest Highway
Jepara (P1)	R1	Jambu Timur Village	21–22 May, 2018	2–4 June, 2018	26–27 July, 2018	7300	970
	R2	Jeruk Wangi Village	23–24 May, 2018	4–6 June, 2018	28–29 July, 2018	7700	880
	R3	Jinggotan Village	25–26 May, 2018	6–8 June, 2018	30–31 July, 2018	9500	250
Rembang (P2)	R4	Dadapan Village	4–5 Sept, 2018	24–25 Sept, 2018	30 Sept–1 Oct 2018	10,000	3500
	R5	Sanetan Village	6–7 Sept, 2018	26–27 Sept, 2018	2–3 Oct, 2018	4000	2000
	R6	Trahan Village	8–9 Sept, 2018	28–29 Sept, 2018	4–5 Oct, 2018	1100	500

2.2. Field Measurement Method

2.2.1. Emission Measurement

The results of the fine and coarse particle concentrations from CFPP emissions are in accordance with the previous research conducted in [6]. The field records consist of the gas exit temperature, inside stack diameter, gas exit velocity, cross-sectional area, and the emission rate. The emission rate calculation is:

$$\text{Emission rate (g/s)} = \frac{C \times V \times a}{1000}$$

where:

C : Concentration

V : Exit gas velocity

a : Cross-sectional area

2.2.2. Ambient Measurement

The PM_{10} and $PM_{2.5}$ sampling was performed based on Indonesian National Standards, SNI 7119.15:2016 and SNI 7119.14:2016 respectively, of gravimetric methods using a high-volume air sampler. Actual measurements were obtained every 23 hours (plus 1 hour for the preparation of the tool filter paper which was placed in a hold filter, locked with a holder, and then covered with the filter selection; e.g., PM_{10} or $PM_{2.5}$). An EPM 2000 (Whatman Inc.) with a quartz filter area of 20.3 cm × 25.4 cm with a minimum filtering efficiency of 98.5% was used. Coarse particles were obtained from the PM_{10} concentration subtracted by $PM_{2.5}$ concentration [21], so the analyzed data are coarse particles ($PM_{2.5\text{-}10}$) and fine particles ($PM_{2.5}$). The samples were weighed using Mettler Toledo MS 205P4 analytical scales. In total 72 samples of coarse and fine particles were used in this study.

2.3. Sample Processing and Analysis

2.3.1. Dispersion Analysis

Particle dispersion simulations were conducted using AERMOD View, which used the data from the hourly surface and air meteorological observations for the period of July, August, and September 2018 obtained from Ahmad Yani Airport, the nearest weather station from the research location. AERMOD requires meteorological surface data (temperature, wind speed, wind direction with hourly values) that define situations near ground level and in the higher atmosphere respectively. The source pathway consists of the values of gas exit temperature, inside stack diameter, gas exit velocity, and the emission rate. Finally, terrain data was required.

2.3.2. Fine and Coarse Particle Characterization

Characterization of the ambient air samples containing fine and coarse particles was performed by analyzing the metallic elements in the samples. The method of elemental analysis was based on the previous research of [6].

2.3.3. Correlation and Contribution Analysis

A correlation analysis was conducted to determine if several elements were produced by the same source. Elemental correlation analysis was conducted between elements present in emissions and in ambient air. A correlation coefficient value of (r) > 0.9 indicated that the correlation was very strong; 0.7–0.9 indicated a strong correlation, 0.5–0.7 a moderate correlation, and <0.5 a weak correlation. For the contribution analysis, we used the PMF receptor model version 5.0 to measure the distribution of the sources of the fine and coarse pollutants and particles. The PMF model contains a multivariate factor analysis tool that can decompose the sample data matrix into two matrices, namely the contribution of factors and factor profiles. This PMF model requires two inputs: concentration data for each element and uncertainty concentration data for each element [22].

3. Results and Discussion

3.1. Pollution Dispersion

At the study site, the ratio of the fine particle emissions to PM_{10} was in the range of 37.4–44.1%, and the ratio of coarse particle emissions to PM_{10} ranged from 55.9%–63.6% [6]. To analyze the fine and coarse particle dispersion models, data processing was performed based on the stack height, gas exit temperatures, inside stack diameters, gas exit speeds, cross-sectional areas, emission rate calculations and stack location (Table 2).

Table 2 Stack specification

Parameter	Jepara		Rembang		Unit
	Stack Code	Value	Stack Code	Value	
Stack Height	Stack 1, 2, 3, 4	240	Stack 10, 20	215	m
Gas Exit Temperature	Stack 1	64.9	Stack 20	163.53	°C
	Stack 2	66.6	Stack 10	151.23	°C
	Stack 3	55.4			°C
	Stack 4	48.15			°C
Inside Stack diameter	Stack 1, 2, 3, 4	7.5	Stack 10, 20	4.8	m
Gas Exit Velocity	Stack 1	17.27	Stack 20	28.767	m/s
	Stack 2	18.07	Stack 10	29.553	m/s
	Stack 3	24.27			m/s
	Stack 4	16.05			m/s
Cross-sectional Area	Stack 1, 2, 3, 4	44.16	Stack 10, 20	18.09	m^2
Emission Rate					
PM10	Stack 1	5.02	Stack 10	8.87	g/s
	Stack 2	5.52	Stack 20	4.79	g/s
	Stack 3	4.79			g/s
	Stack 4	5.61			g/s
PM2,5	Stack 1	2.71			g/s
	Stack 2	3.12	Stack 10	3.30	g/s
	Stack 3	2.22	Stack 20	2.30	g/s
	Stack 4	2.85			g/s
Coarse	Stack 1	3.58	Stack 10	1.61	g/s
	Stack 2	3.92	Stack 20	2.61	g/s
	Stack 3	3.89			g/s
	Stack 4	4.29			g/s
Stack Location		**Coordinate**			
Stack 1, 2		6°26'41.30"S110°44'32.79"E			
Stack 3, 4		6°26'41.31"S110°44'40.96"E			
Stack 10, 20		6°38'07.07"S111°28'28.60"E			

Next, we considered the available meteorological data to analyze the fine and coarse particle dispersions in the CFPP emissions. From the climatology data, the wind direction was dominant from southeast to northwest; however, the climatology condition that influenced the dispersion of fine and coarse particles the most was the wind from the northwest to southeast, which had a velocity range of 3.6–11.10 m/s (Fig. 2).

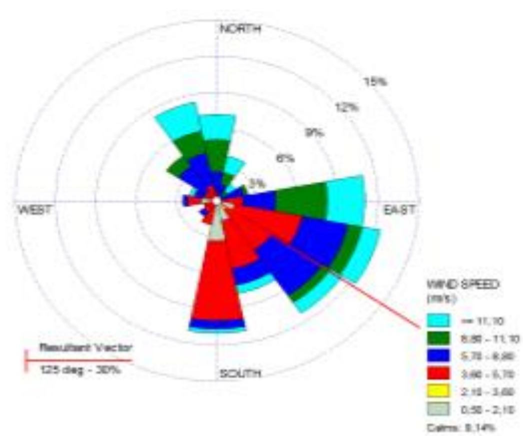
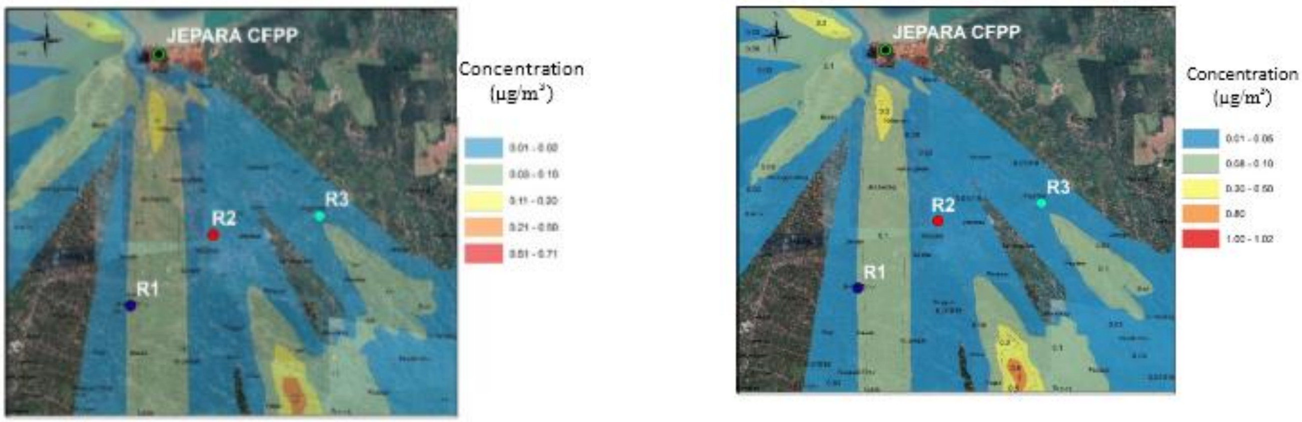


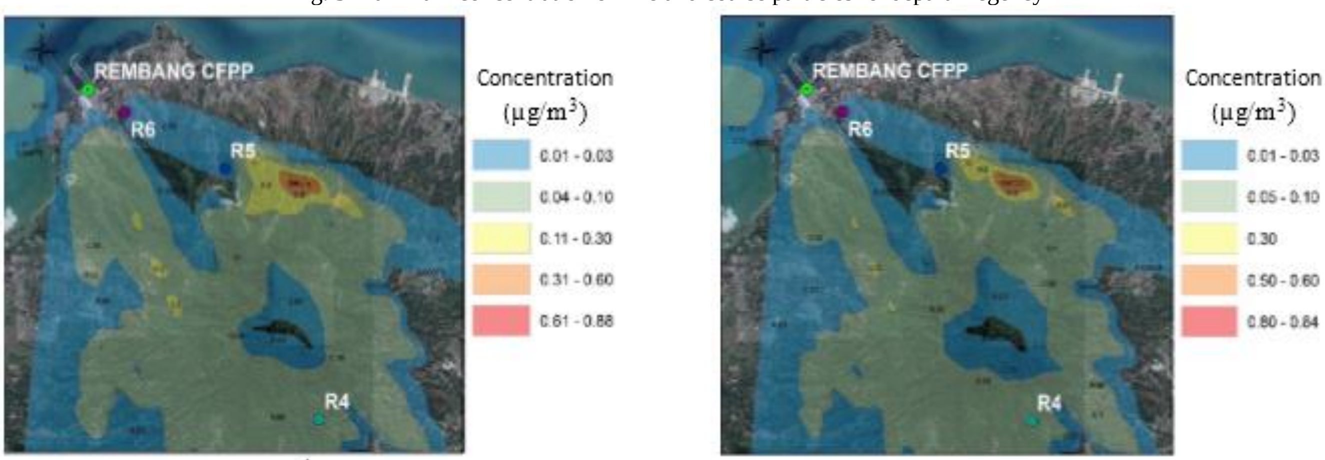
Fig. 2 Wind direction, which influenced the dispersion of particles emitted by the CFPPs during measurement

Based on the dust dispersion modeling in P1 (Fig. 3) and P2 (Fig. 4), it reached six villages. The results of dispersion concentrations from modeling in P1 for fine particles in R1 (Jambu Timur village), R2 (Jeruk Wangi village), and R3 (Jinggotan village) are 0.05 μg/m³, 0.02 μg/m³, and 0.01 μg/m³, respectively, while for coarse particles the concentrations were 0.08 μg/m³, 0.01 μg/m³, and 0.01 μg/m³, respectively. In addition, based on the results of the Aermod model for P2, the concentration of fine particles ($PM_{2.5}$) and coarse particles ($PM_{2.5-10}$) in R4 (Dadapan village) were 0.08 μg/m³ and 0.06 μg/m³, and R5 (Sanetan village) and R6 (Trahan village) were found to have the same values of fine and coarse particles, 0.03 μg/m³. The receptors' locations varied for the power plants, the closest being R6 at a distance of 1.1 km, and the farthest being R3 at a distance of 10.3 km. Based on the receptor distance, the results did not affect the distribution concentration, but in this study, it was influenced by winds to the southeast [23].



Fine Coarse

Fig. 3 Maximum concentration of fine and coarse particles for Jepara Regency



Fine Coarse

Fig. 4 Maximum concentration of fine and coarse particles for Rembang Regency

3.2. Characterization of the Metallic Elements in the Fine and Coarse Particles in the Ambient Air

3.2.1. Results of the Fine and Coarse Particle Concentrations in the Ambient Air

For validation, fine and coarse particles directly from the air in the dust dispersion area of generators P1 and P2 were measured. The results of the average fine particle concentration at locations P1 (R1, R2, and R3) were 79.53 μg/Nm^3, 88.3 μg/Nm^3, and 60.82 μg/Nm^3, respectively, while for the coarse particles ($PM_{2.5-10}$) they were 79 μg/Nm^3, 87.87 μg/Nm^3, and 106.58 μg/Nm^3, respectively. For P2, the average concentration of fine particles ($PM_{2.5}$) at R4, R5, and R6 were 58.85 μg/Nm^3, 70.75 μg/Nm^3, and 65.03 μg/Nm^3, respectively, while for the coarse particles ($PM_{2.5-10}$) they were 86.48 μg/Nm^3, 47.28 μg/Nm^3, and 62.25 μg /Nm^3, respectively. In each sampling, the concentration results vary due to the influence of wind direction and wind speed, which affect particle transport. The results of fine and coarse concentrations are presented in Fig. 5. The complete set of concentration measurements are shown in the appendix. The measured particle concentrations were compared with those from the AERMOD model. The results seen from the concentration of particles measured in the air are higher than those obtained with the

AERMOD model, namely the concentration of dispersions in the simulation with a range of values from 0.01% to 0.13%. In ambient air, particles originate from anthropogenic and natural activities [24, 25], and consist of a mixture of heterogeneous solids and suspended liquid particles [26]. Therefore, predicting the spatial variations of pollutant concentrations is a complex problem due to the influence of these various sources and inputs [27]. The fine and coarse particle ratios can be seen in Table3 for each location, where the smallest $PM_{2.5}/PM_{10}$ ratio, 0.363%, was found in R3. Compared to other studies, this ratio can be considered as a threshold because the ratios from other measurements range from 0.3% to 0.7%. Moreover, the smallest ratio of fine to coarse particles was also found in R3, which is 0.57%. In other studies, the smallest ratio was found with a value of 0.61% [28]. The range of fine to coarse particles ratio was 0.6% to 2.9% (Table 3). Thus, our sampling results are still within the range of other studies [28–32].

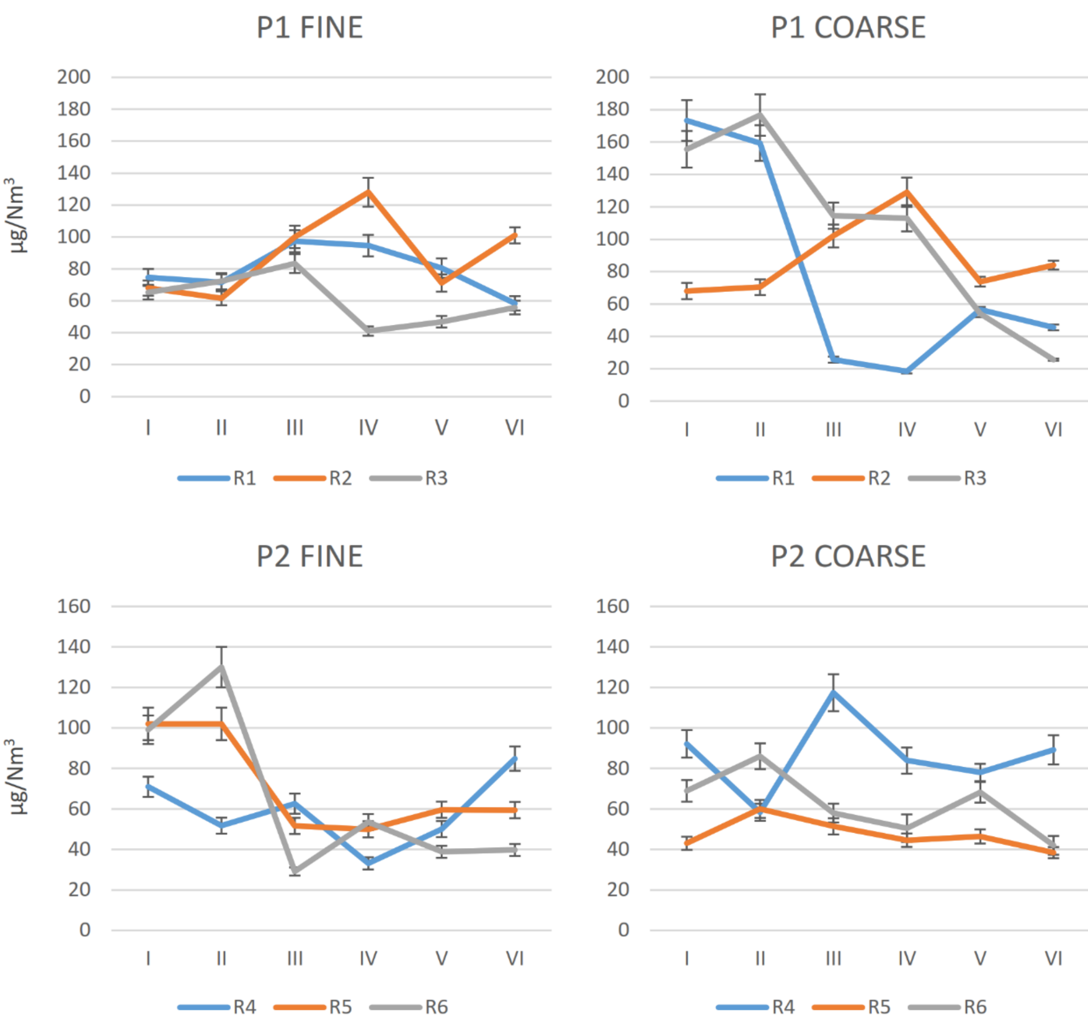


Fig. 5 Fine and coarse particle concentrations for Jepara (P1) and Rembang (P2)

Table 3 Particle masses (μg/Nm^3) of PM_{10}, $PM_{2.5}$, and $PM_{2.5}/PM_{10}$ ratios, fine/coarse ratios (%)

Reference	**Results**						**Study of**				
Location	**Jepara (P1)**			**Rembang (P2)**							
	Jambu Timur	**Jeruk Wangi (R2)**	**Jinggotan (R3)**	**Dadapan (R4)**	**Sanetan (R5)**	**Trahan (R6)**	**(1) [29]**	**(2) [32]**	**(3) [28]**	**(4) [30]**	**(5) [31]**

	(R1)										
Fine/PM $_{2,5}$	79.3	88.3	60.8	58.9	70.8	65.0	7.7	41	89.12	73.2	36.2
Coarse	79.8	87.9	106.6	86.5	47.3	62.3	2.6	18	145.28	67.8	29.6
PM10	159.3	176.2	167.4	145.3	118.0	127.3	10.3	59	234.4	141	65.8
Ratio $PM_{2.5}/PM_{10}$	0.49	0.50	0.36	0.40	0.59	0.51	0.75	0.71	0.38	0.52	0.55
Ratio Fine/Coarse	0.99	1.01	0.57	0.68	1.49	1.05	2.96	2.28	0.61	1.08	1.22

The different composition values of the fine and coarse particles may differ depending on the environmental management practices or emission sources in the area [33]. Moreover, they are influenced by natural causes, such as wind, and also from local anthropogenic activities [34], such as burning biomass, vehicle emissions, and soil suspension [15]. Communities in the study area manage organic waste by burning it, and indeed high biomass combustion conditions affect the proportion of high coarse particles in the surrounding air. The fine particles measured at R2 and R5 are influenced by the activity of nearby highways that affect the surrounding air.

3.2.2. Metallic Elements in Fine and Coarse Particles

The results of the analysis of the metallic elements present in fine and coarse particles indicate that their concentrations around the housing areas are low, around 1% [35]. In the air around the second power plant (P2), more metallic elements were detected. For all power plants, the highest fraction was found for Cu, except for the coarse particles in P1, namely Al, with all the highest fraction values being in the range 0.02–0.33%. The Cu element is estimated from vehicle sources, and the Al element is estimated from soil dust. The variations in the amounts of metallic elements in the fine and coarse dust particles in the atmosphere are influenced by many factors, the causes of which are beyond the scope of this research. Indeed, it is worth noting that particles in the atmosphere are present in complex mixtures [29]. The range of fraction values for R1 to R6 can be seen in the supplementary materials (Fig. 1S).

3.3. Metal Contribution to the Fine and Coarse Particles Emitted by CFPPs

3.3.1. Strong Element Correlation as a Marker Element

A correlation analysis was performed to determine the marker element(s) of CFPP activities. For CFPP emissions, the correlation results have been reported in a previous article, where the ESP controller was found to have a strong positive correlation with fine particles, namely Be-Pb, Cs-As, V-Sc, Co-Mo, Sn-As and Sn-Sc. The highest correlations were found for Co-Mo ($r = +0.985$) at a significance of $p<0.01$. For coarse particles, strong positive correlations were found for Fe-K, Zn-Na, Zn-Pb, Be-K, V-Na, V-Pb, Mo-Fe, Mo-Be, Co-K, Co-Mo, Cu-Fe, Cu-Be, Cu-Co, Ag-Fe, Ag-Be and Ag-Co, with the highest correlations being found for V-Na ($r = +0.986$) and V-Pb ($r = +0.986$). For Coal-Fired Power Plants (CFPPs), Electrostatic Precipitators Wet Flue Gas Desulfurization (ESP-WFGD) was found for fine particles correlations between K-As, Pb-As, Be-As, Be-K, Be-Pb, Sc-K, V-As, V-Pb, V-Be, Cu-Co, Sn-As, Sn-Pb, Sn-Be and Sn-V, with the highest correlations being found for the Be-As, V-Pb, Sn-Pb and Sn-V elements, all of which had $r = 1.000$ at the $p<0.01$ significance level. For coarse particles, only the element pair Pb-Fe ($r=+0.888$) was found [6].

The measurements of fine and coarse particles in the surrounding air were used to search for strong positive correlations between the different elements. The overall results for strong positive correlations in the air around CFPP with the ESP controllers for fine particles are Hg-Ag, Na-K, Na-Mg, K-Mg, Ba-Al, V-Mn, V-Fe, Cr-Ag, and Mn-Fe with the highest positive correlation found for Na-Mg ($r = +0.996$, $P < 0.01$). The coarse particles' results are Sb-Pb, Pb-Zn, Pb-K, Pb-Ba, Na-Mg, K-Mg, K-Ba, K-Ni, K-Al, Ba-Al, V-Mn, V-Fe, Mn-Fe and Ni-Al, with the highest positive correlation found for V-Fe ($r = +0.975$, $p<0.01$). From the ESP-WFGD results for the fine particles, the strongest correlations are Na-Ca, Na-Mn, K-Mn, Mg-Mn, Ca-V, Ca-Mn, Ca-Fe, V-Mn, V-Fe, Mn-Fe, with the highest correlation found for Ca-V ($r = +0.981$, $p<0.01$). For the coarse particles, all the positive correlations were low. In supplementary materials Figs. 2 and 3, it can be seen that there is a strong correlation for the same metallic elements in the ambient air. According to the results, Rembang power plant (P2) has a higher correlation value than that of Jepara plant (P1). Differences results indicate that the atmosphere's effect is very complex, and during the process of transporting particles in the air, many factors affect the physical and chemical changes in elements [29].

3.3.2. CFPP Source Contribution with PMF Model

In the PMF receptor model, four factors were found to be a source of pollutants in a dust-dispersion residential area (Supplementary materials, Figs. 4S-7S). Origin and variability in volatile organic compounds observed at an

Eastern Mediterranean background site (Cyprus). PMFsare widely used in research to determine the proportion of particles in the air. Receptor analyses are performed to isolate sources and the mixtures that contribute to the measured samples. The PMF model includes the variable uncertainties that are often associated with environmental samples. It forces all values in the solution profile and the contributions to be non-negative, which is more realistic than the solution obtained via other methods. Positive Matrix Factorization (PMF) An introduction to the chemometric evaluation of environmental monitoring data using PMF.

The PMF model results are presented in Fig. 6. The first result is that for CFPPs, the amount of fine particles is higher than that of the coarse particles. The highest fine particle proportion was found for R6 (41%) and the lowest for R3 (39%). Particle transportation in the atmosphere is influenced by climatic conditions [23]. Based on the locations of the CFPPs, it is suggested that the wind direction has the most considerable influence, particularly the northwest to southeast wind speeds of 3.6–11 m/s at R3 and R6.

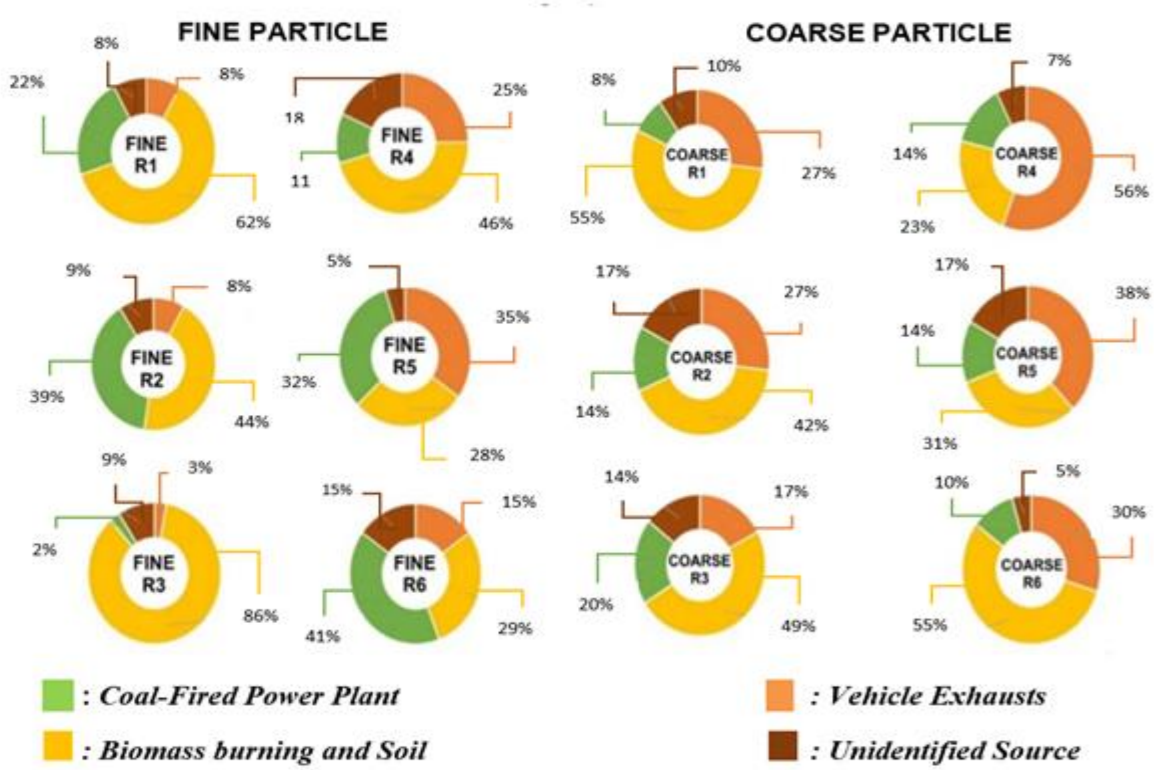


Fig. 6 Fine and coarse particles based on the source factor

A key result of this study is that the contribution of fine particles is higher than that of coarse particles, where the highest values were found at R5 (32%) and R6 (41%). This demonstrates that aerodynamic diameter size influences particle transport in the environment, which then affects human inhalation. Particle transportation in the atmosphere is also influenced by climatology conditions.

Another key result is related to the marker elements Na, Fe, K, Al, and Ca, which are produced by soil dust and biomass burning. At locations R1 through R6, soil dust and biomass burning sources had significant contributions compared to the three other factors.

This could be due to wind direction and velocity, as well as human activity, in the study area. In resident interviews, 62.2–93% of the respondents claimed that they process their domestic waste by burning it. In addition, the marker elements V, Cd, Sb, and Ag originated from vehicles (S2). Vehicles were a significant contribution to the sampling site monitoring in S2, as the site was located only 1.35 km from a busy highway. Finally, the marker elements Sn, Pb, and Ba originated from other, unidentified sources. The contributions from these unknown sources were minimal, with an average of 11% for fine particles and 12% for coarse particles.

4. Conclusions

The characteristics of fine and coarse dust particles are dominated by trace elements. The positive correlation of elements in particles was used to determine emission markers with electrostatic potential (ESP). These elements are molybdenum and carbon monoxide. Emission markers determined with ESP and wet flue gas distribution are As, Pb, Be, V and Sn.

The contribution value for fine dust is higher than for coarse dust. Contribution values at R1 through R6 locations for fine dust ($PM_{2.5}$) are 22%, 39%, 2%, 11%, 32%, and 41%. Contribution values at R1 through R6 locations for coarse dust ($PM_{2.5-10}$) are 8%, 14%, 20%, 14%, 14%, and 10%.

In the Jepara and Rembang CFPP areas, wind direction and speed influenced the dispersion and mass concentration of fine and course particles. In both areas, the southeast wind measured at speeds of 3.6–11 m/s. Based on the model, the concentration of ambient particles originating from the Coal-Fired Power Plants (CFPPs) reached six villages around the power plant, and the dispersion concentration results have values ranging between 0.01–1.02 $\mu g/Nm^3$. To validate these results, measurements of ambient air were taken, and the concentration values were higher than in the model by a difference in value of 0.01–0.13%. Influencing source factors are power generation activities, vehicle exhaust, biomass, soil dust burning activities, and activities from unknown sources. PMF gave mixed results at the six sampling locations R1 through R6. The emission contribution from electricity generation is lower than the contribution of biomass combustion and vehicle exhaust. The CFPP contributions of fine particles were higher, except in the villages of Jinggotan (R3) and Dadapan (R4), where the contribution of coarse particles was higher.

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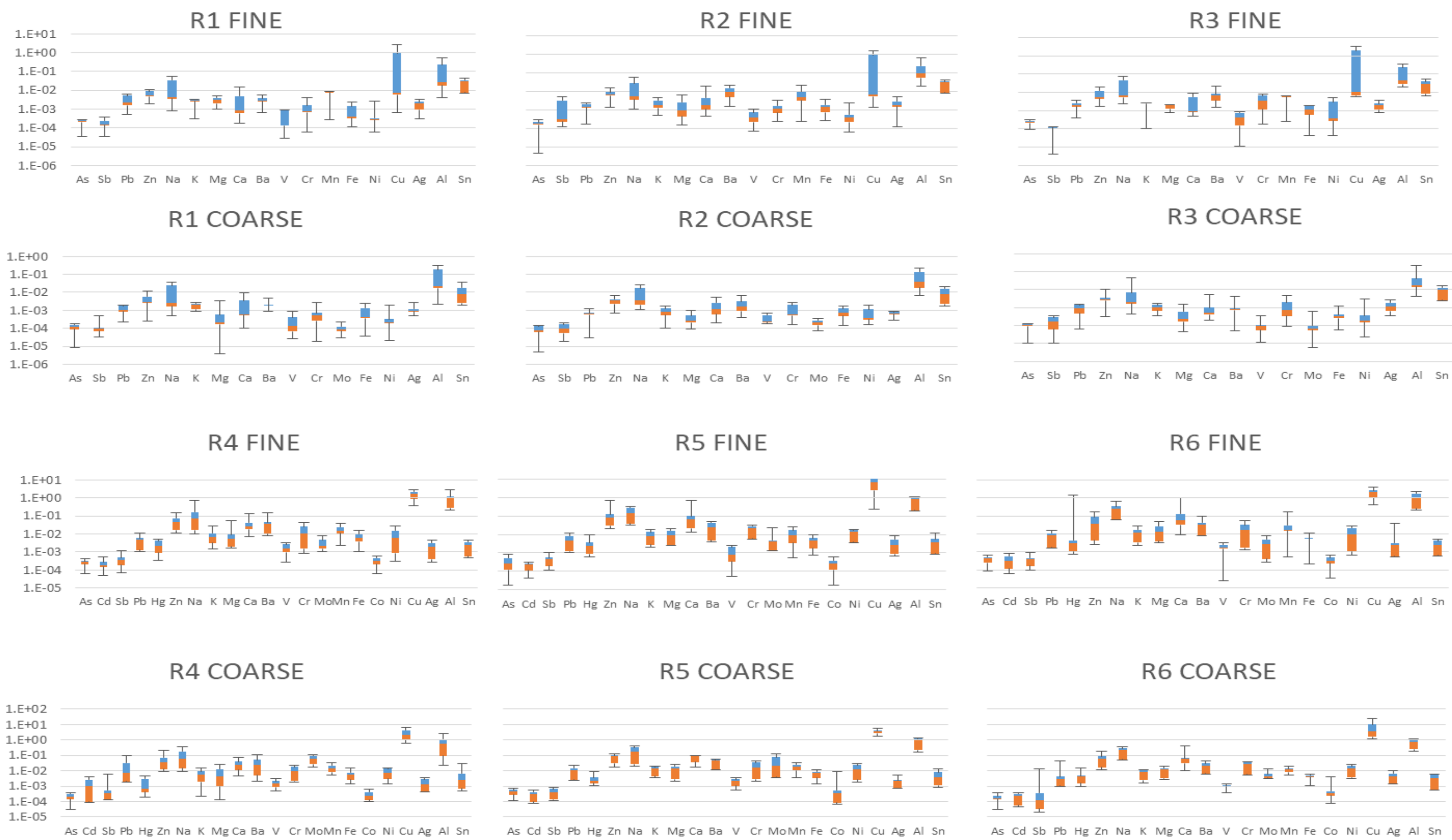
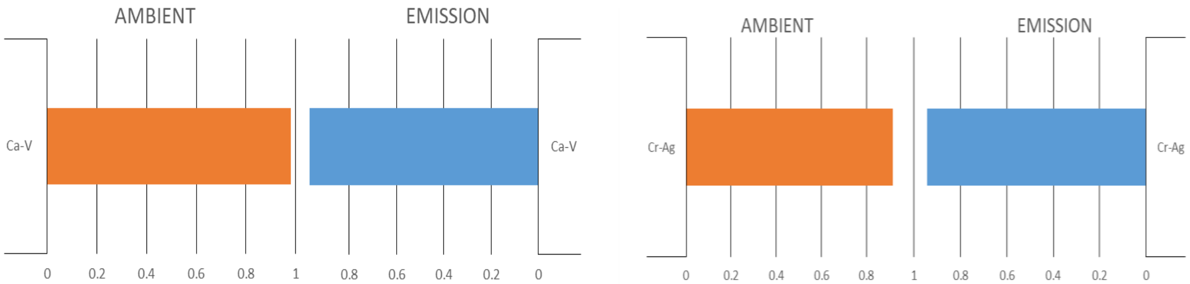
SUPPLEMENTARY MATERIAL



*R1, R2, R3: Jepara CFPP

*R4, R5, R6: Rembang CFPP

Fig. 1S Abundances in the fine and coarse particles



(a) (b)

Fig. 2S Strong positive element correlation on the fine particle at (a) Jepara, (b) Rembang

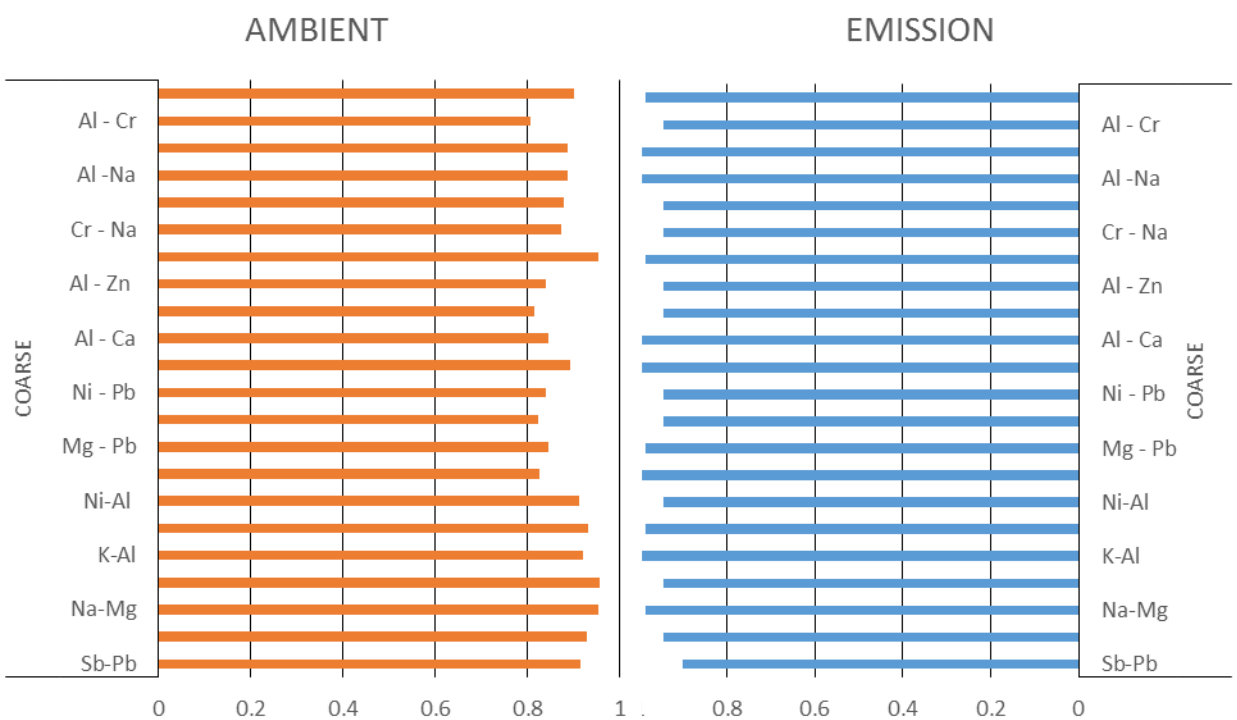


Fig. 3S Strong positive element correlations for the coarse particles at Rembang

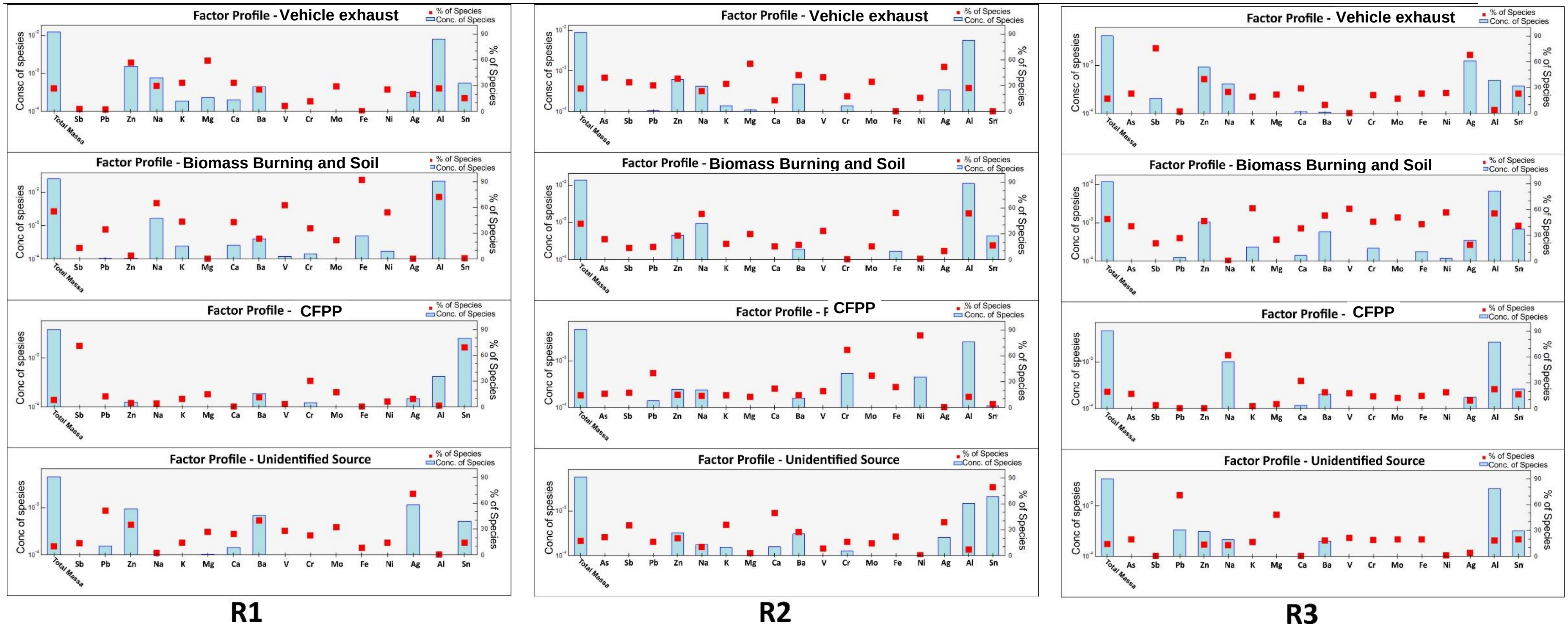
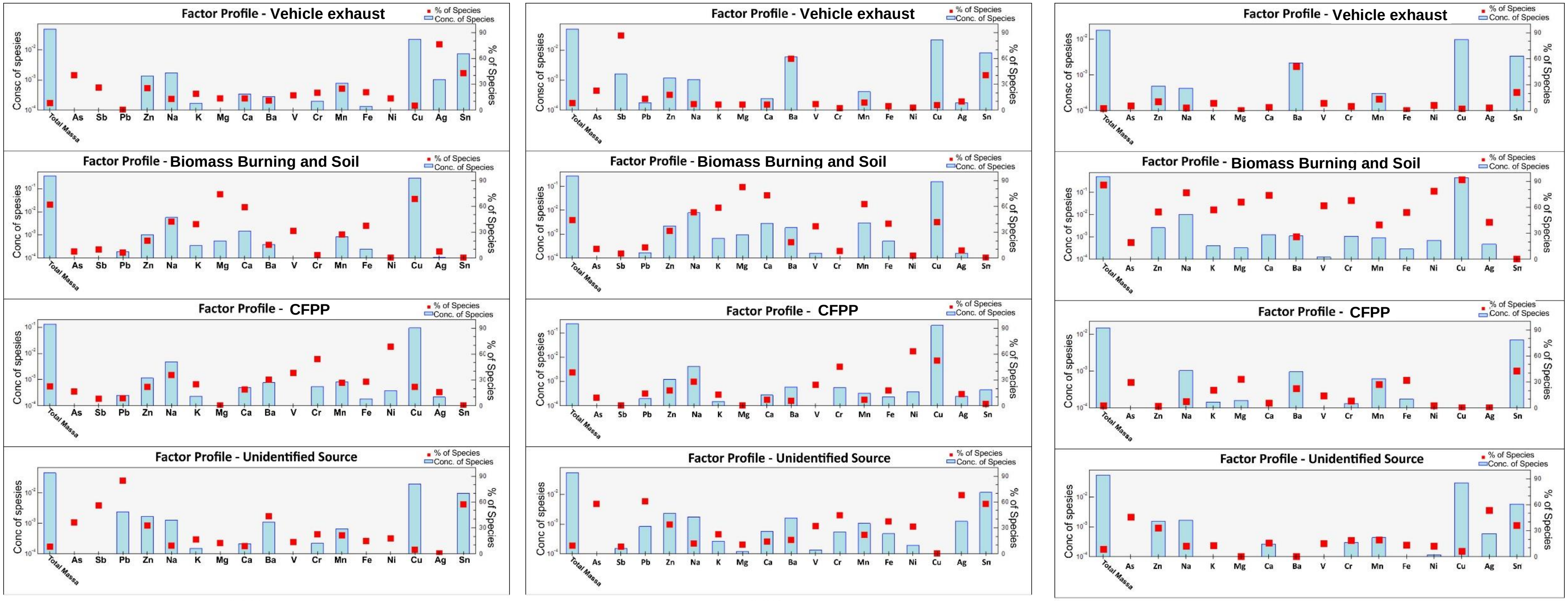


Fig. 4S Source profiles of fine particles at Jepara (P1)



R1 R2 R3

Fig. 5S Source profiles of coarse particles at Jepara (P1)

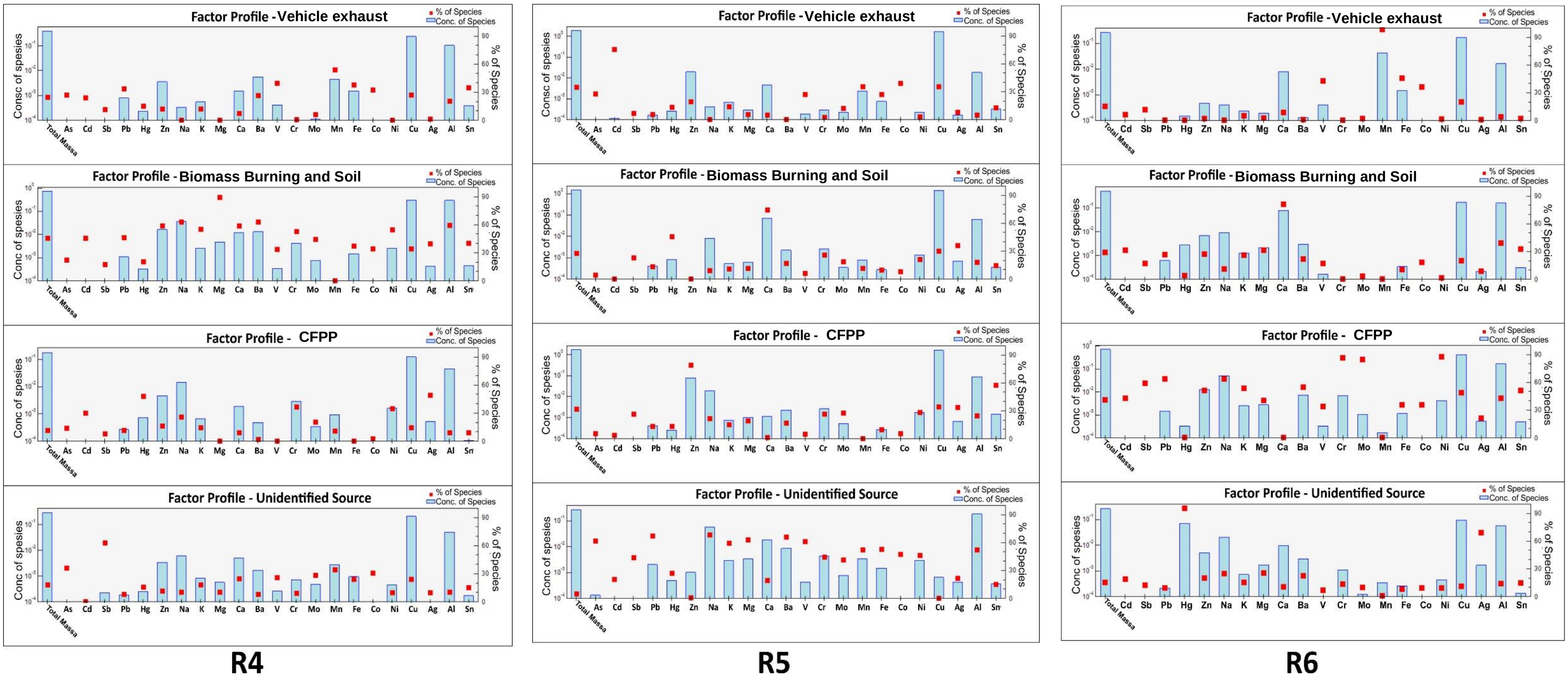
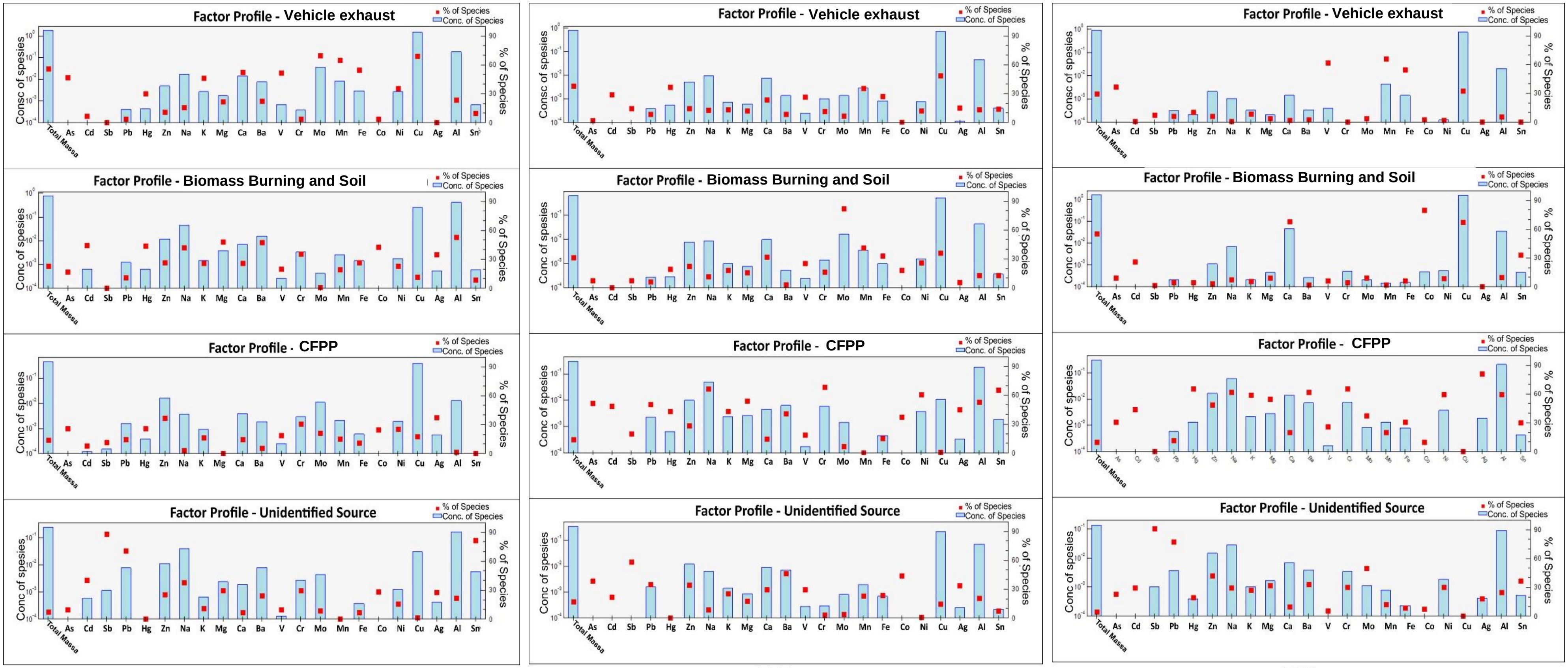


Fig. 6S Source profiles of fine particles at Rembang (P2)



R4 R5 R6

Fig. 7S Source profiles of coarse particles at Rembang (P2)