Health risk analysis of air pollutant exposure on children's lung function in industrial area of Bandung Regency

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Abstract. Industrial areas are considered to have a higher risk of air pollution impact, especially for children living close to the industry, as children breathe in more air per body weight unit than adults. This study aims to analyse the risk of exposure to ambient pollutants ($PM_{2.5}$, PM_{10}, NO_2, CO, SO_2, and O_3) in children and factors that affect lung function disorders. This study was based in the Dayeuhkolot sub-district of Bandung Regency. A cross-sectional study was conducted on school-aged children (9-12 years old) living in an industrial close to Bandung Regency. Parents or guardians were asked to complete a questionnaire on respiratory symptoms to estimate the exposure to ambient air pollutants risk. Air pollutants ($PM_{2.5}$, PM_{10}, NO_2, CO, SO_2, and O_3) were measured using a portable Air Quality Monitoring System (AQMS), the lung function was measured by Spirometer MSA99, and non-cancer risk (HQ) was determined using the human health risk assessment model. The average results of ambient air pollutants measurement concentration are $PM_{2.5}$ (45,59 ± 15,48 µg/m3), PM_{10} (75,56 ±25,93 µg/m3), SO_2 (9,39 ± 6,27 µg/m3), CO (17,38±6,35 µg/m3), O_3 (12,58 ± 3,12 µg/m3) and NO_2 (15,86 ± 3,39 µg/m3). All pollutants concentrations are still below ambient air quality standards of PP NO.22/2021. With an average non-carcinogen Health Index (HI) of 0,48 ± 0,29. A lung function of total of 35 children were collected, with an average FVC: 1,59 L and FEV1.0: 1,42 L; there were 17 children with restrictive, 5 children with obstructive, and 1 combined lung disorder. The most significant factors of respiratory disorders were gender, height, respiratory complaint, and passive smoking symptoms ($p < 0.05$).

1. Introduction

Ambient air pollution has become one of the most severe public health threats in the world. The World Health Organization estimates that 22% of deaths result from exposure to air pollution [1]. The Global Burden of Disease (GDB) 2020 estimated that 544.9 million people in the world were diagnosed with respiratory diseases in 2017, which is a third major cause of death in the world. . Pollution affects human health in all ages. Normal humans inhale 10-15 thousand liters of air per day, and this is how exposure to pollutants from the air occurs in humans. Among the various air pollutants are $PM_{2.5}$, PM_{10}, NO_2, CO, SO_2, dan O_3, which are of significant concern [2].

Many studies have shown that there is a relationship between exposure to ambient air pollutants and adverse effects on pulmonary health. Residential proximity to industrial areas was linked with adverse health outcomes, including lung and respiratory symptoms [3], Children are a vulnerable sub-population due to the adverse effects of air pollution exposure [4]. According to these studies [5] [4][5],children who live close to industries like steel mills, fertilizer companies, and asphalt plants typically have lower lung functions, higher rates of chronic coughs, and an increased risk of asthma attacks. In contrast to respiratory symptoms, lung function is an objective indicator of respiratory health. Compared to control areas, children living in the industrial neighborhoods have poorer lung function, or a greater prevalence of respiratory symptoms [8]. A cross-sectional study conducted in Canada on children between the ages of 6 and 18 discovered that an increase of 190 in industrial air $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5µm) emissions within 25 km of residence was responsible for a significant 1% reduction in predicted $FEV_{1.0}$ (1-s forced expiratory volume). This correlation was not seen in females, only in boys [9]

Dayeuhkolot is one of the sub-districts in Bandung Regency; there are 16 large-scale factories, the majority of which are textile and garment [10]. Research by Novianti and Sumeru [11] states that the 24-hour average PM_{10} concentration in industrial areas in Bandung Regency is higher than in non-industrial areas. This is in line with Taradita's [12]; PM2.5 and PM10 concentrations in industrial areas

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of Bandung Regency are higher than in agricultural and residential areas. Based on data from the Bandung Regency Health Profile 2018-2021, the diseases with the most cases based on outpatient data at health centers are acute respiratory infections (ARI) and acute nasopharynx; air quality can cause these diseases.

Based on this, this study was conducted to determine the health risk of exposure to air pollutants $PM_{2.5}$, PM_{10}, NO_2, CO, SO_2 and O_3 in residential proximity to an industrial area in Bandung Regency and to measure the impact on vulnerable populations, children, by pulmonary function testing. Deficient lung function in children can be detected using a spirometer; the parameters measured are FVC and FEV1.0 values. The study's results are expected to be a consideration for assessing the status of pollution and its effects on health so that it can help prepare environmental policies in Bandung Regency.

2. Methodology

Cross-sectional study was conducted among school children (aged 9-12 years) in Dayeuhkolot sub-district, Bandung Regency.

3. Data Collection

3.1 Ambient Air Pollutant Measurement

Primary data was obtained by measuring the concentration of ambient air pollutants in the Dayeuhkolot sub-district (-6,996164 °;107,619362 °),which is close to the industrial area with a portable Air Quality Monitoring System (AQMS) which has been calibrated with the dilution method, measurements are made in real-time every five minutes, then calculated the average per hour and average per day. The parameters that can be measured are $PM_{2.5}$, PM_{10}, NO_2, CO, SO_2 and O_3 as well as meteorological data which includes air temperature, air pressure, wind speed, wind direction and rainfall. Sampling is carried out for seven days and 24 hours.

3.2 Demographic Data Collection

The collection of the population at risk profile was carried out using the modified ATS-DLD-78-C questionnaire [13]. The questionnaire consisted of parts: sociodemographic characteristics (age, sex, weight, and height), daily outdoor activity, (respiratory) health problems to respiratory disease of the child, and other determinants of indoor air pollution (indoor smoking practices and use of mosquito coil). The questionnaire was administered to the mother/father. If the mother/father was not living with the child, the questionnaire was administered to the guardian, who usually looked after the children. Height and weight were measured according to the standard WHO protocols [14]. Height was measured with an electric stature meter (GEA Brand) and weight with an electronic scale (Xiaomi brand). Ethical clearance was obtained from the Ethics Commission of Padjadjaran University (No. 1166/UN6.KEP/EC/2023). The criteria for inclusion of respondents were school-aged children (9-12 years), a home distance less than 1 Km from the ambient air sampling location. The number of respondents for pulmonary function testing was calculated using the formula:

$$n = \frac{Z^2 \, x \, p \, x \, (1-p)}{d^2} \tag{1}$$

With, n = sample size, Z^2 = confidence degree, p = proportion of people exposed/prevalence of lung disease, d= limit of error. if the value of d is set at 0.05, Z^2 = 1.96 and p is 0.05%, taken from the number of cases of inpatient and outpatient lung disease patterns aged 5-14 years in Bandung Regency in 2021. Then, the minimum sample size is 30 children. To avoid the number of missing samples, the number of samples collected is about 35 children.

3.3 Lung Function Test (LFT)

Lung function proficiency testing followed the 2019 American Thoracic Society guidelines [15]. Using an M&B spirometer type MSA99, it measures the actual respiratory flow with an accuracy of ± 1%, instrument has been calibrated. Prior to lung function testing, height and weight were measured. To obtain optimal values, each spirometry test was repeated three times and according to ATS criteria, the difference between the two FEV1 values should not differ by more than 5%.

Spirometry measurement data were compared with predicted values based on age, gender, height, and ethnicity, expressed as percentages. Pulmonary function impairments detected by spirometry generally have two types: obstructive and restrictive.

- *Obstructive lung function disorder*

If the FVC value is ≥ 80% and FEV1 < 70%, this disorder occurs when the expiratory airflow is slowed down, as seen from the reduction in the volume of air that can be expelled quickly in the first second (FEV1) in general the respiratory volume is not reduced. However, the flow of breath is inhibited; examples of diseases are COPD (chronic obstructive pulmonary disease), emphysema, and bronchitis.

- *Restrictive lung function disorder*

If FVC < 80% and FEV1 ≥ 70%, lung function is restricted; generally, breathing volume is reduced because lung function is impaired. Examples of diseases are pulmonary fibrosis, infant respiratory distress syndrome, weak respiratory muscles, and pneumothorax.

3.4 Health Risk Analysis

Health risk assessment (HRA) estimates the potential impact of a chemical hazard on a human population or ecological system under specific conditions and time frames [16] The Health Risk Assessment process consists of four steps, namely hazard identification, dose-response assessment, exposure assessment, risk characterization [17]. The receptors are children living near industrial areas. The exposure pathway of $PM_{2.5}$, PM_{10}, SO_2, CO, O_3, and NO_2 pollutants is through inhalation exposure. The concentrations of $PM_{2.5}$, PM_{10}, SO_2, CO, O_3, and NO_2 pollutants that enter children's respiratory systems are assumed to be the same as those of ambient air from measurements using the AQMS tool.

3.4.1 Hazard Identification

Hazard identification is used to identify all types of adverse health effects caused by exposure to an agent. Hazard index values are derived from the ambient air pollutant concentrations ($PM_{2.5}$,PM_{10} ,NO_2 ,CO,SO_2 and O_3) obtained from ambient air measurements using an AQMS device, assuming ambient air concentrations are equal to inhaled concentrations.

3.4.2 Dose Response Analysis

Dose-response analysis by finding literature RfD values of risk agents $PM_{2.5}$, PM_{10}, NO_2, CO, SO_2 and O_3, which are research parameters. The RfD values used for calculation are PM2.5: 0,01 mg/kg. Day [18], PM10: 0,83 mg/kg. Day[19], NO2: 0,053 mg/kg. Day [20], CO: 0,02 mg/kg. Day[21], SO2 : 0,04 mg/kg. Day [20] and O_3: 1,03 mg/kg. Day [22].

3.4.1 Exposure Analysis

The data used to perform the calculation is primary data from measuring the concentration of air pollutant risk agents. ($PM_{2.5}$, PM_{10} , NO_2 , CO, SO_2 and O_3). The intake calculation uses some default values as exposure factor variables. The calculation formula used is as follows.

$$I = \frac{C \ x \ R \ x \ t_E \ x \ F_E \ x D_E}{W_b \ x \ t_{avg}} \quad (1)$$

I = intake mg/Kg. Day, C= concentration mg/m^3), R= inhalation rate (m^3/hours), tE = time exposure (hour/day), f_E = exposure frequencies (day/year), D_t = exposure duration (year), W_b= body weight, t_{avg} = time average (D_tx365 day/year, for non-carcinogenic substance).

3.4.3 Risk Characterization

Determination of risk characterisation by determining the RQ (Risk Quotient) value using the following equation[23] :

$$RQ = \frac{Intake}{RfD} \quad (2)$$

RQ = *Risk Quotient*, I = *Intake*, RfD = *Reference Dose.* To calculate the HI (Health Index) value, which is the cumulative value of the RQ value, use the equation:

$$HI = \sum(RQ) \quad (3)$$

In addition, the characterization and risk assessment were conducted by determining the risk of exposure to air pollutants ($PM_{2.5}$,PM_{10},NO_2,CO,SO_2 and O_3) on respondent's lung impairment observed from FVC and FEV1.0 values. The risk studied was expressed as Odds Ratio (OR).

3.5 Statistical Data Processing

Statistical analysis in this study used SPSS 22 software. Interval used 95% with 5% error. Univariate analysis was used to describe the parameters studied ($PM_{2.5}$, PM_{10}, NO_2, CO, SO_2 dan O_3). Correlation analysis used the rank spearman correlation test to determine the correlation between children's lung function and ambient air pollutant concentrations.

4. Result and Analysis

4.1 Respondents Characteristics

In total, 35 of the school children aged 9-12 years underwent an examination of lung function. Table 1. Shows the characteristics of the children.

Table 1. Characteristics Respondent (n=35).

Variable	Category	n	*P-value*
Body weight	<35	19	0,302
	≥35	16	
Sex	Boys	17	**0,024**
	Girl	18	
age	9	6	0,082
	10	13	
	11	8	
	12	8	
Height (cm)	<135	8	**0,000**
	≥135	27	
Time lived	<5	1	0.478

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(year)	≥5	34	
Time exposure(jam)	<5	10	0.273
	≥5	25	
Respiratory complaints	No	18	**0,000**
	Yes	17	
Distance between house and road (m)	<150	21	0,398
	>=150	14	
Use of mosquito coils	Not use	23	0,119
	Fréquent use	12	
Passive Smoking	No	17	**0,024**
	Yes	18	

4.2 Ambient Air Concentration Measurement

Ambient air quality measurements continuously for seven days 24 hours, with measurement parameters $PM_{2.5}$,PM_{10} ,NO_2 ,CO,SO_2 and O_3 described by the average daily diurnal variation and daily average concentration of air pollutants. The diurnal variation of air quality parameters describes the condition or behavior of each air pollutant parameter for one day, usually shown in the morning to evening period. Each parameter has different behavior from one another. This occurs due to several factors, such as the nature of pollutant particles/gases that quickly react with other materials or due to external factors such as photolysis, wind, and temperature [24].

Figure 1 shows the diurnal variation of $PM_{2.5}$ and PM_{10} over the seven days of measurement. Generally, diurnal concentrations of $PM_{2.5}$ and PM_{10} peak in the morning between 06.00-07.00, then continue to decline until noon and increase again at night. This is because the air temperature reaches a minimum in the morning, and the stable atmosphere causes the $PM_{2.5}$ mass to be concentrated near the surface [25] On the other hand, anthropogenic activities such as the number of vehicles due to work or school departure hours can trigger increased pollutant concentrations in the morning. Meanwhile, the minimum concentration of $PM_{2.5}$ occurs during the day between 11:00-and 14:00. This is because, during the day, the air temperature reaches a maximum value, which causes the $PM_{2.5}$ mass to be lighter and lifted due to the vertical motion of air and high solar radiation reaching the earth's surface. This causes rapid vertical diffusion of aerosols so that the measured $PM_{2.5}$ concentration is lower. At night, the atmospheric conditions are more stable, which causes the formation of an inversion layer, which can prevent pollutants on the surface from moving vertically so that the measured $PM_{2.5}$ concentration is higher [26]. This is in line with the research of Kusumaningtyas et al. (2021) [27], who observed the concentration patterns of $PM_{2.5}$ and PM_{10} for one year in the rainy season and dry season in Jakarta, the results of which were that the concentrations of $PM_{2.5}$ and PM_{10} peaked in the morning at 07.00, and decreased during the day.

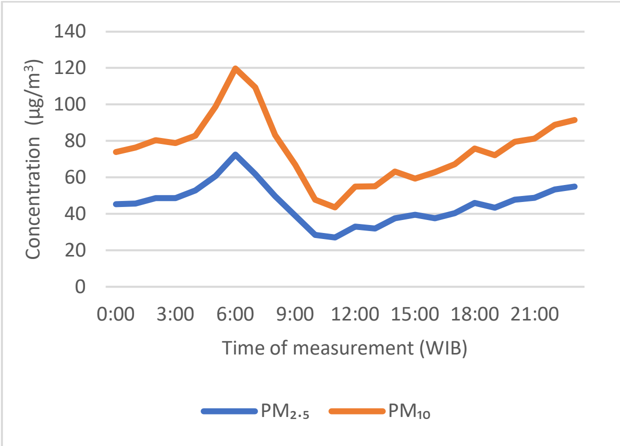

Fig 1. Diurnal pattern of $PM_{2.5}$ and PM_{10}

Figure 2 shows the diurnal pattern variations of O_3, NO_2, CO and SO_2. During the day, ozone (O_3) concentration will increase and maximize at midday because of the photolysis process; this occurs due to the reaction process of ozone precursor in the presence of sunlight and reacts with oxygen molecules to form secondary pollutant O_3, this process is usually referred to as photochemical reaction. The increase in O_3 concentration throughout the day coincides with the decrease in NO_2 concentration due to photolysis. In contrast, the reduction in O_3 concentration in the afternoon is probably the result of dry deposition, the lowering of the boundary layer, and titration with NO. There are no photochemical processes at night, and atmospheric conditions are relatively stable. Surface ozone (O_3) is a secondary pollutant because surface ozone is formed from changes in other gas particles. About 70% of atmospheric chemical oxidants react with CO gas [28].

The average concentration of CO increased at 07:00 until it reached a maximum concentration of 29.73 rg/m^3, which occurred at 13:00 and then continued to decrease to a minimum concentration of 13.25 rg/m^3 at 20:00. This can be attributed to the hours of heavy vehicle traffic in Dayeuhkolot, causing an increase in pollutant concentrations. Similarly, as reported in a study in Malaysia conducted by Azmi et al. (2010) [29], the average daily CO concentration increases from morning until noon, especially during rush hour, which leads to higher amounts of CO in the air.

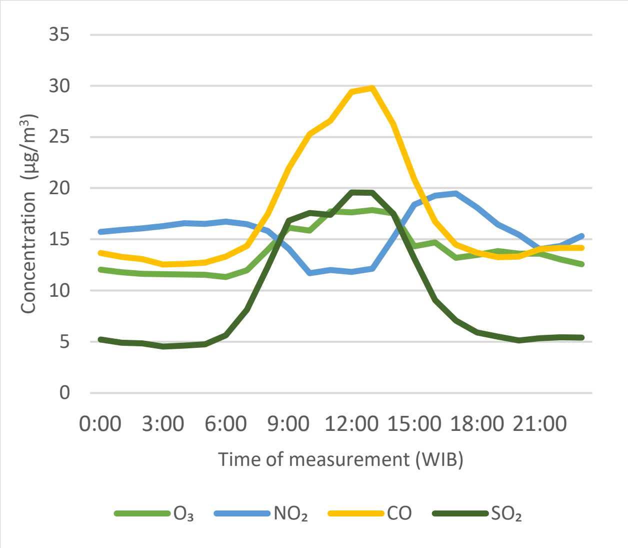

Fig 2. Diurnal pattern of O_3, NO_2, CO and SO_2

The average concentration of pollutants ($PM_{2.5}$, PM_{10}, NO_2, CO, SO_2 and O_3) for seven days of measurement at the research location can be seen in Table 2.

Table 2. Average pollutant concentration

Polutans	Concentration (rg/m^3)	Air quality standards of PP No.22/2021
$PM_{2.5}$	45,59 ±15,48	55 rg/m^3
PM_{10}	75,56 ± 25,93	75 rg/m^3
SO_2	9,39 ± 6,27	75 rg/m^3
CO	17,38 ± 6,35	40000 rg/m^3 (8 hours)
O_3	12,58 ± 3,12	65 rg/m^3
NO_2	15,86 ± 3,39	100 rg/m^3 (8 hours)

The concentration of pollutants during the seven days of measurement can be seen in Figure 1. which were $PM_{2.5}$ 45,59 ±15,48 rg/m^3, PM_{10} 75,56±25,93 rg/m^3, SO_2 9,39 ±6,27 rg/m^3, CO 17,38±6,35 rg/m^3, O_3 12,58±3,12 rg/m^3, NO_2 15,86 ±3,39 rg/m^3. All pollutants concentrations are still below ambient air quality standards of PP No.22/2021.

Data from BPS Kab. Bandung (2019) [10], there are 16 large-scale industries in Dayeuhkolot Sub-district. Most industries are engaged in textile manufacturing, such as dyeing, knitting, weaving, and garments. Based on Tekmira's 2008 research (Eskayudha, 2015) [30], 52.65% of the textile industry in Bandung Regency uses coal fuel. Waste gases and particulates generated by the textile industry can come from several emission sources, one of which is coal-fired boilers. In coal boilers, fuel combustion produces pollutants in the form of air emissions released through the chimney. The air emissions released generally contain contaminants in the form of particulates (dust) or gases such as NO_2, CO, and SO_2. Coupled with the population density, Dayeuhkolot is the largest of the two other sub-districts, which is 9745.2 people/km^2 [31] a high population will increase mobility/travel per day, which will increase the number of motorized vehicles used.

4.3 Effect of Meteorological Factors on Pollutant Concentrations

A Pearson correlation test statistical analysis was conducted between temperature, humidity, pressure, and wind speed on pollutant concentrations to determine the correlation between meteorological factors and pollutant concentrations.

The results of the Spearman correlation of temperature with $PM_{2.5}$: 0.285 (p-value: 0.211), PM_{10}:0.285 (p-value: 0.211) and NO_2: 0.073 (p-value: 0.753) of the three pollutants resulted in a low positive correlation with temperature, which is a unidirectional relationship means that the concentration of pollutants increases with increasing temperature. However, the correlation value shows a low relationship. This may be due to the small number of measurement days, so statistically, it cannot show a strong relationship. It aligns with research by Zhang et al (2015) [32], who measured ambient air for one year in winter in Guangzhou, China, showing a low Spearman correlation for temperature with $PM_{2.5}$, PM_{10}, and NO_2. While the Spearman correlation of temperature with SO_2: -0.132 (p-value: 0.570), CO: -0.175 (p-value: 0.449), and O_3: -0.289 (p-value: 0.204) with temperature produces a low negative correlation, meaning that the higher the temperature, the concentration of pollutants decreases.

Spearman correlation results of pressure with $PM_{2.5}$: 0.656 (p-value: 0.211), PM_{10}: 0.656 (p-value: 0.211), SO_2: 0.712 (p-value: 0.753), CO: 0.381 (p-value: 0.753), O_3: 0.243 (p-value: 0.753) and NO_2: 0.605 (p-value: 0.753). Of the six pollutants, $PM_{2.5}$, PM_{10}, SO_2, and NO_2 had strong positive correlations with pressure, while CO and O_3 had weak positive correlations with pressure. According to research conducted [33], when on Earth at low pressure, high air mass pressure rotates counterclockwise around the center of the flow so that the formation of air moving upwards, and the wind will increase, which will help pollutants move upwards so that the concentration of contaminants at the earth's surface will decrease. On the contrary, when the earth's surface is controlled by high pressure, the air in the central part will descend to the surroundings, show clockwise rotation, and form anticyclones. So, the weather will be calm, and the wind speed will decrease. Under this circumstance, it will be straightforward to develop a thermal inversion layer, resulting in the atmospheric condition becoming stable so that pollutants will be more difficult to diffuse and accumulate around the surface, increasing the concentration of contaminants.

The results of Spearman correlation between humidity and $PM_{2.5}$: 0.516 (p-value: 0.017), PM_{10}: 0.516 (p-value: 0.017), SO_2: 0.121 (p-value: 0.602), CO: 0.04 (p-value: 0.952) and NO_2: 0.201 (p-value: 0.360). Five out of six pollutants, positively correlated with humidity. The relationship is unidirectional, which means that pollutant concentrations increase as humidity increases. In contrast, the Spearman correlation between humidity and O3 pollutant was -0.049 (p-value: 0.823), resulting in a negative correlation. This is in line with Hu et al.'s (2008)[34] study that $PM_{2.5}$, PM_{10}, SO_2, CO and NO_2 pollutants are positively correlated with humidity because high humidity can phase semi-volatile compounds into aerosol phase. O_3 pollutants are negatively correlated with humidity because high wind speeds can remove particulates and increase solar radiation, thereby increasing O_3 formation Ran et al., (2009)[35]. A lower surface layer usually comes with a more humid atmosphere [36].

Spearman correlation results of wind speed with $PM_{2.5}$: -0.138 (p-value: 0.552), PM_{10}: -0.108 (p-value: 0.552), SO_2: -0.308 (p-value: 0.175), CO: -0.247 (p-value: 0.281) and NO_2: -0.125 (p-value: 0.590), and five pollutants are negatively correlated with wind speed. The relationship is in the opposite direction, meaning that the concentration of pollutants increases as wind speed decreases. Meanwhile, the Spearman humidity correlation with the O3 pollutant was 0.125 (p-value: 0.590), resulting in a positive correlation. The same thing happened in Beijing in Zhang et al.'s (2015)[37] study in spring, autumn and winter, where concentrations of $PM_{2.5}$, PM_{10}, SO_2, CO and NO_2 pollutants increased when wind speed was low, indicating that horizontal dispersion plays a vital role in changing pollutant concentrations. For the secondary pollutant O_3, the correlation with wind speed is negative in summer and autumn but positive in winter. High wind speeds remove PM and increase solar radiation, which can increase O_3 production [35].

4.4 Lung Function

The lung function values of the respondents were measured using a spirometer. Lung function measured by a spirometer is expressed in the form of FEV1.0 and FVC values. In Figure 3, a comparison of the FVC and FEV1.0 values of boys and girls shows values are greater in boys than girls. Girls had significantly lower lung function levels than boys. Sex-related variations in the development of the lungs and airways may contribute to gender disparities in lung function in response to air pollution or other environmental stimuli [38]. One explanation for this is that boys typically have bigger lungs than girls do, with more alveoli and more surface area at birth. According to certain studies, females are less likely than boys to develop lung disease during adolescence if they synthesize more estrogen [39]

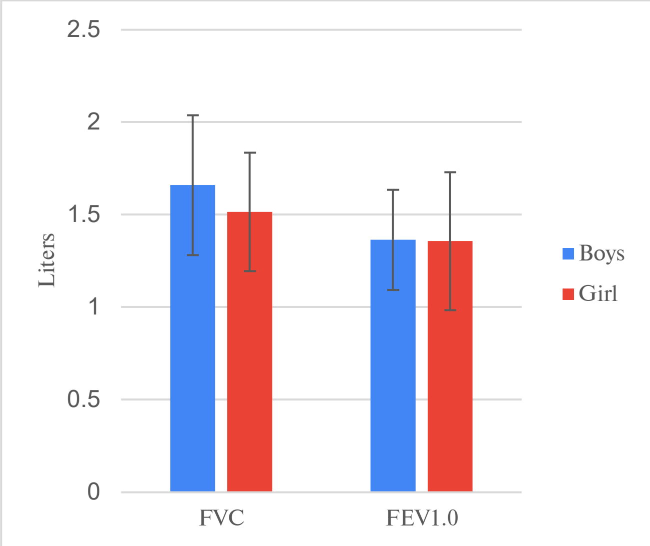

Fig 3. Comparison of $FEV_{1,0}$ and FVC for boys and girls

The results of the pulmonary capacity test of school-age children in this study will be compared with standards and analyzed to determine the influence of other factors obtained during the interview. The distribution of respondents' lung function is attached in Figure 4. There were 12 respondents with normal lung capacity, five with obstructive lungs, 17 with restrictive lungs and one with combined lungs; the dominant lung condition in this study was restrictive, with the highest proportion in 49% or 17 people.

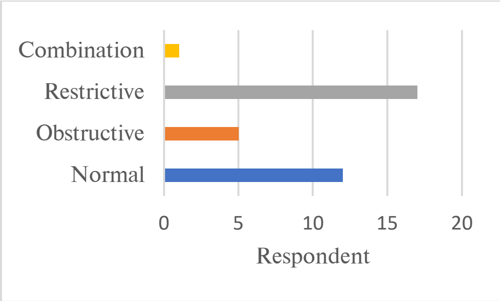

Fig. 4. Lung Function Distribution

4.4 Doses Response Analysis Relationship Between Intake and Lung Function

Table 3. shows the result from linear regression analysis, which was performed to observe if any pollutant was significantly associated with lung function levels. Lung function of childrens significantly declined as $PM_{2.5}$, PM_{10}, SO_2, CO, O_3 and NO_2 levels increased (*p*-value <0,05). study results indicated that inhalation exposure to environmental air pollution was significantly associated with lung function problems. Several similar studies have been previously reported by Hong et al (2018); the sample population is 1963 respondents, consisting of an exposed group (n = 1487) living within a radius of 5 km of industrial complexes and a control group (n = 476) living over a radius of 10 km from the industrial complexes in Gwangyang and Yeosu cities. In multiple linear regression analysis, forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) levels significantly declined as SO_2, CO, and O_3 levels increased. In 2002, Kwon et al. reported that Asian dust events (CO, NO_2, SO_2, PM_{10}, and O_3) were significantly related to elevated risk of death from cardiovascular and respiratory diseases among the general population in Seoul from 1995 to 1998. Son et al (2010) [42], conducted a study that showed an association between environmental air pollutants—which included CO, NO_2, SO_2, PM, and O_3—with adverse effects on lungs using a large-scale population (n = 3827) recruited from Ulsan industrial complexes in Korea from 2003 to 2007. The authors found that FVC levels were associated with all types of air pollutants. In particular, pulmonary functions declined by 6.1% for FVC and 0.5% for FEV1 as O_3 level increased by 11 ppb.

Based on the Spearman correlation statistical test (rho) In Table 3. $PM_{2.5}$, PM_{10} dan O_3 are moderately correlated with a decrease in FVC values while other variables are weakly correlated. in line with research Hwang et al (2015), The study provides evidence that long-term exposure to $PM_{2.5}$ and O_3 may have a detrimental effect on the development of lung function in children. The estimated deficits were more significant in boys, compared to girls. Exposure of the bronchial epithelium to particles may generate reactive oxygen species and increase the expression of a marker of oxidative stress: heme oxygenase 1 [44]. Oxidative stress could be induced by particles, thus promoting inflammation via activating the transcription factors NF-κB and activator protein-1, and other processes implicated in inflammation, including histone acetylation and the MAPK pathway [45]. An animal study showed that chronic exposure to particulate matter during the pre- and post-natal periods leads to decreased surface-to-volume ratios in 15-day-old and 90-day-old mice [46]. These changes were accompanied by decreased lung volumes at different inspiratory and expiratory pressures in young , which support the role of particle exposure ($PM_{2.5}$) on lung function growth in children.

O_3 is a strong oxidant and reacts with the epithelial lining fluid to generate free radicals [47]. In vitro exposure of bronchial epithelial cells to O_3 increases the production of inflammatory mediators [48]. O_3 leads to an increased risk of airway inflammation, such as that occurring in bronchiolitis, resulting in subsequent deficits in lung function growth [43].

Table 3. Linear regression and spearman corelation

Polutan	FEV 1.0			FVC		
	β	*p* - value	Rho	β	*p* - value	Rho
PM 2.5	-47	0,006	-0,356	-69	0,000	-0,4
PM 10	-29	0,006	-0,358	-41	0,000	-0,4
SO_2	-181	0,019	-0,319	-240	0,004	-0,335
CO	-75	0,058	-0,263	-99	0,021	-0,268
O_3	-180	0,003	-0,371	-262	0,000	-0,423
NO_2	-132	0,007	-0,352	-185	0,000	-0,391

4.5 Relationship Between Lung Capacity and Respondent Characteristic

To assess the relationship between lung capacity and respondent characteristics, Chi-square bivariate statistical analysis and Spearman correlation were conducted. Based on the results of the chi-square analysis Table 1, the variables that have the most different proportions include gender (p: 0.024), height (p: 0.000), respiratory complaints (p: 0.000) and passive smoking (0,024). Based on the correlation, height had a moderately strong positive correlation (0.418) with lung capacity. Respiratory symptoms have a moderately strong positive correlation (0.442) with lung capacity. While the other variables have a weak correlation.

Another factor that affects a person's lung capacity is gender, which is a statistical analysis obtained with a p-value = 0.016 (<0.05) so that it is proven that gender significantly affects the results of lung capacity measurements. By this study, it can be seen in Figure 3 that the FEV1.0 dan FVC lung capacity of boys is more significant, which is FVC 1.659 ± 0,37 litters (boys), 1.51±0,31 (girls) and FEV1.0 1.36±0,27 litters (boys), 1.357 ±0,37 litters (girls).Girl have a smaller lung capacity of about 20-25% compared to boy. However, this does not mean that all girls have a smaller lung capacity than boys because pollutant intake/exposure factors also affect a person's lung capacity. Boys generally have more outdoor activities and are exposed to more pollutants from ambient air than girls. This difference in intake/exposure will considerably impact the difference in lung capacity of boys and girls. It is in line with the research of Hwang et al. (2015)[49] on 2941 children in Taiwan by comparing the decline in lung function of boys and girls against exposure to air pollutants, the results of which decreased lung function in boys was greater than that of girls. Sex differences in lung function in response to air pollutants or other environmental stimuli may occur due to inborn differences in lung and airway development. When a male baby is born, he has more alveoli than a female. However, at the same time, airway development is stunted, resulting in a relatively narrow airway compared to female infants. This occurs until adolescence, known as dysanaptic growth [38]. Therefore, males during infancy, childhood and early adolescence have a lung phenotype that is more susceptible to the effects of air pollutant exposure than females [50]. However, during puberty, the risk of respiratory distress in males is less than that of females because some studies have shown the influence of estrogen (female sex hormones) on increasing the incidence and severity of asthma [39].

This is in accordance with research conducted by Salami et al. (2014) [51], which examined two industrialized regions in Indonesia that were compared, namely Kalimantan and Bogor, West Java. Fifty children (boys and girls aged 6-15 years) were involved in South Kalimantan, while in West Java, 48 children (boys and girls aged 10-12 years) were involved. It was seen that the lung capacity of boys in South Kalimantan was always higher than that of girls.

Another parameter affecting lung capacity is height; from statistical analysis, a p-value of 0.000 significantly affected the results of lung capacity measurements. The same thing was found in 250 children aged 6-12 years in Kano, Nigeria, in a study by Mohammed et al. (2015) [52], finding an association between lung function and children's height; height is an influential parameter in predicting FEV1.0 and FVC values, this is related to the height/length of the child's body which is related to thoracic length and chest circumference. Children with tall bodies usually have a larger chest circumference to inhale more air than children with shorter bodies. The higher the air volume that can be inhaled, the higher the lung capacity.

Respiratory symptoms are a factor that affects lung vitality in this study, based on the results of statistical analysis, resulting in a p-value of 0.000 (<0.05). It is in line with Yogev-Baggio et al (2010) [53] that air pollution exposure has a more significant impact on children with respiratory symptoms such as asthma and bronchitis, as the group with respiratory symptoms may experience an overreaction or sensitivity of their respiratory system as a result of exposure to ambient air pollution, reflected by the reduction in FEV1 values.

Passive smoking is factor that affects lung function in this study (p-value <0,005); this is by research conducted by Fernбndez-Plata et al. (2016) [35] ; passive smoking in children is a significant risk factor for respiratory diseases and reduced lung function growth, which is coupled with air pollution levels, asthma, and the presence of respiratory symptoms in schoolchildren aged 8-17 years and exposed to cigarette smoke at home.

4.5 Risk Characterization

Risk characterization is expressed in the non-carcinogen health index (HI) by summarizing all RQ values for each pollutant. The HI value is unitless and defined as safe when intake ≤ RfD or represented as HI ≤ 1. The risk level is defined as unsafe when intake > RfD or HI > 1. The distribution of HI values of respondents can be seen in Figure 8. to an average non-carcinogen Health Index (HI) of 0,48 ± 0,29, Out of 35 children, only 1 child had a HI value >1.

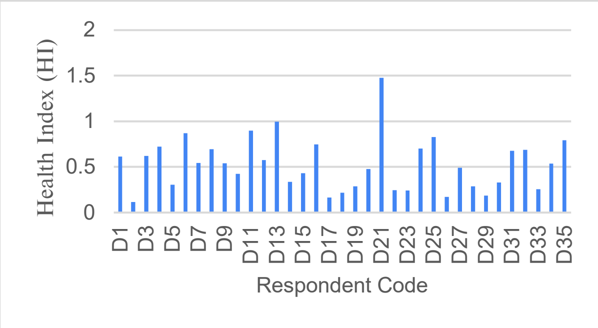

Fig. 5. Health Index (HI) for each Respondent

5. Conclusion

The average results of ambient air pollutants measurement concentration $PM_{2.5}$ (45,59 ± 15,48 rg/m3), PM_{10} (75,56 ±25,93 rg/m3), SO_2 (9,39 ± 6,27 rg/m3), CO (17,38±6,35 rg/m3), O_3 (12,58 ± 3,12 rg/m3) and NO_2 (15,86 ± 3,39 rg/m3) All pollutants concentrations are still below ambient air quality standards of PP No. 22/2021. With an average non-carcinogen Health Index (HI) of 0,48 ± 0,29. A total of 35 children were collected, with an average FVC: 1,59 L and FEV1.0: 1,42 L; there were 17 children with restrictive, 5 children with obstructive and 1 combined lung disorder. The most significant factors of respiratory disorders were gender, height, respiratory complaint, and passive smoking symptoms ($P < 0.05$).

Based on the prevalence rate of children's lung function disorders in the Dayeuhkolot sub-district, the figure is relatively high in the study, so the government and the industry need to do things that can prevent the occurrence of lung function disorders in children living in the Dayeuhkolot industrial area, including:

1. To prevent the release of harmful pollutants into the air, industrial estates should implement an efficient emission control system.
2. Environmental hygiene standards should be carefully enforced in industrial parks. This includes the safe management of safe waste management, proper handling of chemicals, and preventive measures for air and water pollution.
3. Industrial estates should create safe green spaces for children, including parks and open areas, in the vicinity; this can improve air quality around industrial sites and give children access to a better and fresher environment.
4. Industrial estates can run initiatives to inform and raise awareness among their employees and the local community of the impact of air pollution on children's lung health.

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