Spatial assessment on health impact of atmospheric pollution in Makassar, Indonesia

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Abstract. There has been little discussion to date on air pollution and its potential relationship with health in Makassar, Indonesia. This study aims to create a starting point for this discussion by investigating existing data points and the potential correlation between ambient air pollution and health in Makassar, Indonesia. Six months of air quality data (July-December, 2018) on CO, SO2, NO2, O3, PM10, and PM2.5 were provided by the city and were analyzed alongside tuberculosis and pneumonia data provided by the hospital and community health centers in Makassar. Data were analyzed using principal component analysis, dendrogram, and some GIS mapping. Quantitative data from the USAID-funded Building Health Cities project were also used to help explain some of the quantitative findings. Results show that principal component analysis (PCA) gave three statistics factors having eigenvalues exceeding one, which account for 83% of the total variance in the dataset. The three factors accounted for a strong impact by CO, O3, SO2, PM10, and PM2.5 attributed to the incomplete combustion of fuel from automobiles, bush burning, and industrial emission. Air pollution-related illnesses such as tuberculosis and pneumonia are found to prevail in the area. Real-time air quality monitoring is required to benchmark the health impact of extreme conditions. This study also encourages urgent intervention by decision-makers to tackle the level of tuberculosis and pneumonia occurrence that may be favored by the poor air quality in Makassar.

1 Introduction

Air pollution originates from a diverse source and consists of a mixture of substances found in chemical and physical states, many of which are considered harmful to human health. Air pollution was identified as a major environmental challenge associated with respiratory disease and reduced life expectancy [1]. To standardize the monitoring and quantification of air pollutants on a global scale, the World Health Organization (WHO), among others, has established a particular set of indicators, as the measurement of all possible air pollutants is not yet feasible worldwide. Therefore, WHO has defined four air pollutants that have severe impacts on the health of people including; Particulate Matter (PM), which is further divided into PM_{10}, or coarse particles which have an aerodynamic diameter of fewer than 10 µm, and $PM_{2.5}$, or fine particles with an aerodynamic diameter of fewer than 2.5 µm, sulfur dioxide, nitrogen dioxide, and ozone [2]. Focusing solely on these pollutants is not meant to undermine the impacts of other air pollutants on the environment and human health, rather it is meant to optimize the monitoring of the general state of air quality [2].

Ninety percent of the people across the world breathe polluted air that does not meet the WHO air quality guidelines [3-4]. Annually, ambient air pollution contributes to the death of three million people worldwide; however, South East Asia and the Western Pacific are the most affected regions [3]. Obstructive pulmonary infections such as pneumonia and tuberculosis have been reported to be among the chronic causes of death [5] and by 2020, it is estimated to be third among the leading cause of death in adults and children worldwide. Ambient air pollutions have proven to be

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associated with adverse cardiopulmonary health effects [6].

Indonesia, located in South East Asia, is a consortium of over 17000 islands and is the world's largest archipelagic State [7]. It is ranked fourth among the world's most populated countries with about 260 million people [7], and land-use change and deforestation make it a significant emitter of greenhouse gases [8]. Bush burning and fuel combustions are the primary determinants of climate change and air pollutions in Indonesia. Urban areas tend to be the most affected by air pollution. Pollution from industrial and domestic activities, forest fires, and the vast majority (about 80%) coming from the transportation sector may also play a significant role [9]. This is due to a fuel combination, poor infrastructures that result in traffic congestion, and long queues of vehicles emitting air pollutants which gravely impact human health, buildings, forests, the quantity and quality of crops, and surface water quality [9]. According to Haryanto and Franklin [10], 50% of the morbidity across the country is caused by poor air quality.

Especially in the last decade, there has been unusually high growth in the number of motor vehicles in major Indonesian cities, including Makassar [11]. Makassar is the capital of Indonesia's province of South Sulawesi and is a major and largest urban city in Eastern Indonesia. It has largely remained a trade hub of the country, especially Eastern Indonesia, albeit less developed than other major cities of Indonesia such as Jakarta, Bandung, and Serpong.

Makassar is a coastal city with complex local climatic conditions (land and sea breeze) which may result in the recirculation and accumulation of pollutants. However, the air quality indices still exceed the WHO guidelines. Generally, from October to March, Makassar experiences rainfall, and it is classified as the wet period; whereas, from April to September, it experiences dry season which is characterized by less rainfall and biomass burning, leading to high PM concentrations [12]. Previous studies as described in table 1 highlight the concentration of air pollution in Makassar, Indonesia.

Table 1. Studies on air pollution in Makassar

Period covered	**Pollutant studied**	**Concentration**	**Ref**
2006 - 2010	SO_2, CO, NO_2, O_3, Pb, TSP, and PM_{10}	76 μg/m^3, 1041 μg/m^3, 43.2 μg/m^3, 54.5 μg/m^3, 0.7 μg/m^3, 188 μg/m^3, 54.6 μg/m^3, respectively	[13]
2010	$PM_{2.5}$	280 ug/m^3	[14]
2006 - 2012	Particulate matter	80 ug/m^3 – 380 ug/m^3	[15]
2012 - 2013	PM_{10}	32.9 ug/m^3	[12]

This study aims to start to fill this data gap in Makassar, by a) identifying what routine data are available in the city for air pollution and related health conditions; b) defining any limitations to those data; c) analyzing these data for any useful correlations or information that can help support a discussion on air pollution and health by Makassar decision-makers.

2 Materials and methods

2.1 Study Area

Makassar (Indonesia) is an urban city with high population density, traffic congestion, and industrial activities. It's the capital of the province of South Sulawesi. It is located between 119° 24' 38" east longitude and 5° 8' 19" south latitude covering an area of about 175,77 sq km with 14 districts [13]. This area is characterized by a tropical climate embedded with two major seasons (rainy and dry season). The rainy season is between September and January. The topographical and geology of the area is made up of hills, plains, and beaches. The average temperature is 27°C.

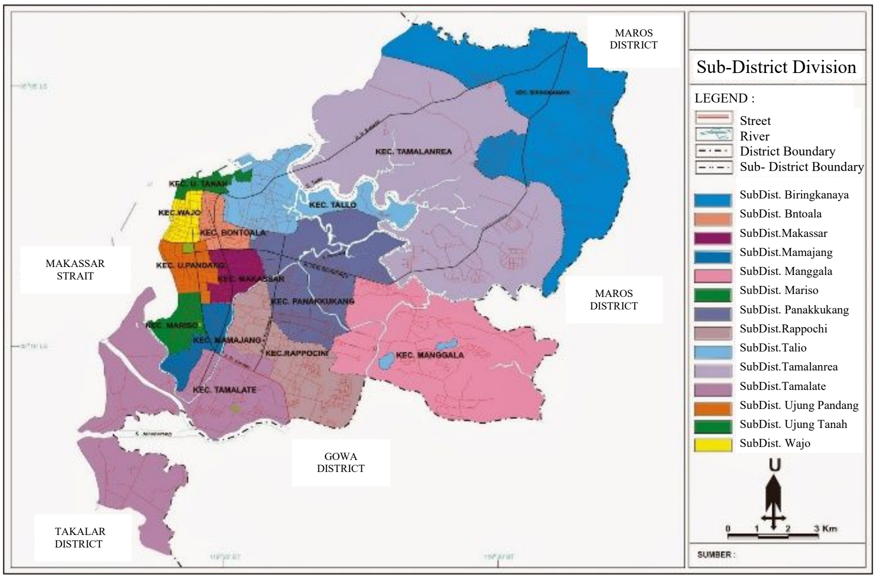


Fig. 1. Administrative Map of Makassar

2.2 Data compilation and analyses procedures

Data compilation and analysis procedure comprise of the data collection, air quality assessment, and health risk assessment using descriptive statistics, multivariate statistical techniques, and geographical information system as described in Fig. 2.

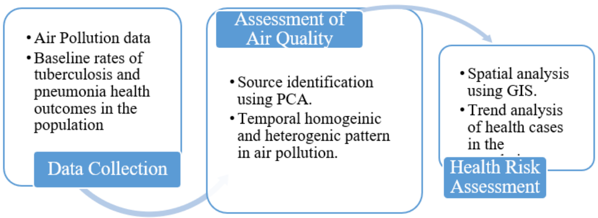


Fig. 2. Data collection and analysis procedures

2.3 Data screening procedure

Air quality monitoring data of Makassar, Indonesia comprising of CO, SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ were provided by the department of the environment while the health data (Tuberculosis and Pneumonia) were made available by the department of health Makassar from July 2018 to December 2018. The data were collected from a single available site and recorded by the department, which represents the period when measurements are monitored, recorded, and reported to assess extreme conditions and possible health impacts. This site represents the only functional station that monitors air quality status in the area with the availability of data. Except for July 2018 (where half of the data were collected at 5-minute intervals), all other air quality data (August-December) were collected at 30 minutes intervals, daily.

The data provided comprises some missing observations and was estimated using the nearest neighbor method in the XLSTAT 2019 software. The missing values amounted to 2231 (5.6%), which gave a total of 39684 (6614 observations x 6 parameters) data sets used for the analysis. The 2018 health data for tuberculosis and pneumonia in adults and children were collected from community health centers and hospitals in Makassar, Indonesia without any missing observations. A total of 464 pneumonia cases and 5485 tuberculosis data were also utilized. The data were used as provided due to their reliability to identify their relationship with the air quality data, their spatial occurrence, and temporal variations.

2.4 Method of analyses

Air quality and health data collected were subjected to different analyses to simplify, describe and interpret their complex and dynamic behavior. The following statistical techniques are proposed.

2.4.1 Principal component analyses (PCA)

PCA will be used to establish a minimum component that can be used to describe the maximum variance possible in a data set (Singh et al., 2005; Wang et al 2014). It is a pattern recognition technique that can analyze complex data [16]. It will be applied to extract the most significant parameters by eliminating the less significant parameters with minimal loss of the original variables [17]. The major possible source of pollution will be identified using PCA.

The equation is expressed as:

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + ... + a_{im}x_{mj} \quad (1)$$

Where *z* represents the component score, *a* takes the component loading, *x* is used as the measured value of variables, the component number is represented by I, the sample number is represented by *J* and *m* is the total number of variables.

2.4.2 Geographical information system (GIS)

GIS provides a spatial visual presentation in maps. In this study, GIS will be used to provide the spatial occurrences of health incidences due to air pollution to identify areas of high, medium, and low effects. It will also be used to map out traffic flow and pollutant concentrations.

2.4.3 Hierarchical agglomerative cluster analyses

HACA is an unsupervised pattern recognition technique used to aggregate a similar group of entities that portrays a strong internal (within-class) homogeneity and strong external (between classes) heterogeneity [17]. It is used to aggregate a group with identical characteristics in a sequential manner with the aid of a dendrogram that measures the degree of risk homogeneity through Ward's method and Euclidean distance [18]. A dendrogram highlights a reduction in the dimensionality and complexity of the data sets. It also provides a visual representation of the level of uniformity in the pattern of observed parameters [19]. In this current study, HACA was used to extract the pattern of air pollutants that can be used as a guide for future sampling.

3 Results and discussion

3.1 Data availability and quality

Data availability is a priority in air pollution management and its impact on human health. Data provided from city offices are usually associated with outliers and noisy observations. These variations may require a series of data treatments and standardization to achieve a realistic result. The error may be due to the method of sensor calibration, staff skills, and other technical shortcomings. A better calibration technique may be adopted coupled with staff training to enhance skills in routine data collection. Deploying real-time sensors for air quality monitoring will improve quality data availability for proper analysis. It is also important to improve on the digitization of health data to enable easy accessibility for regularly monitored data. These will improve reliability and minimize errors.

3.2 The relative contribution of measured air pollutants to air quality

PCA was used to identify the factors with strong positive loading that can be used for source profile identification. Factor loading from 0.7 was selected as a threshold used to identify the possible spatial sources of the air pollutants. Three factors were obtained based on eigenvalues greater than one, which account for 83% of the total variance in the data set. Table 2 describes the factor loadings after varimax rotation, eigenvalues, and cumulative variance. Fig. 3 represents the PCA loading and scree plots where factor loadings are selected.

Varimax factor 1 (VF1) shows a strong positive loading for CO (0.773), NO_2 (0.793), and O_3 (0.802) which account for over 42% of the total variance in the data set as described in table 1. CO and SO_2 are by-products formed from the incomplete combustion of fuel in automobiles. Within the study area, these pollutants are emitted from automobiles especially during the early hours of the day and towards traffic peaks in the evening, as such these pollutants are associated with vehicle emission. The high association with CO and NO/VOC (via O3) may suggest that this is a factor associated with traffic pollution as vehicles will emit CO, NO, and VOCs. And then the NO/VOC would convert to NO_2 and O_3.

VF2 contributes 22% of the total variance in the data set indicating a strong impact contributed by $PM_{2.5}$ (0.708) and a moderate loading for PM_{10} (0.506). PM_{10} and PM2.5 may be associated with harmful trace elements that trigger respiratory, cardiovascular diseases and increase mortality rate by 1% for every increase in 10µg/m^3 (Yubero et al. 2011). These pollutants mostly originate from bush burning, industrial smoke, and urban dust (Shakir et al 2011).

VF3 has a strong positive loading for SO_2 (0.882) accounting for over 18% of the total variance in the data set. This could be attributed to industrial emissions due to gasoline and diesel fuel combustion during manufacturing processes.

Table 2: Factor loadings after varimax rotation

Parameters	VF1	VF2	VF3
CO	**0.773**	0.002	0.174
SO_2	0.009	0.001	**0.882**
NO_2	**0.793**	0.006	0.081
O_3	**0.802**	0.001	0.074
PM_{10}	0.057	0.506	0.074
PM_{25}	0.041	**0.708**	0.012
Eigenvalue	2.551	1.313	1.133
Variability (%)	42.516	21.885	18.879
Cumulative %	42.516	64.401	83.280

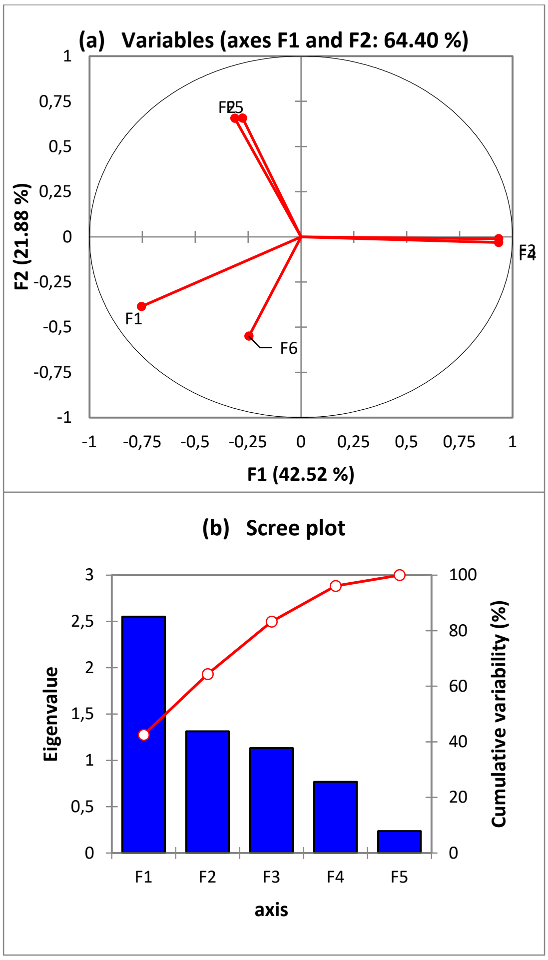


Fig. 3. (a) PCA loading and (b) scree plot diagram after varimax rotation

3.3 Spatial cases of tuberculosis and Pneumonia using GIS

The spatial variability and distribution in the pattern of tuberculosis (TB) and pneumonia (PE) in Makassar Indonesia were mapped out using geographical information system (GIS) in Fig. 4. The patter portrays a dominance in the occurrence of Pneumonia due to the impact of air pollution in the environment. Air pollution is a primary cause of TB and PN both in children and adults [6], [20].

Fig. 4. Spatial pattern of tuberculosis and pneumonia cases in Makassar

3.4 Similarities and dissimilarities among the sampled air pollutants

In this study, hierarchical agglomerative cluster analysis was used to identify the general and monthly pattern of the similarities and dissimilarities among the sampled parameters based on the dendrogram. The essence is to understand the parameters that fall within the same class of pollution level and those that have different characteristics in each month. Fig. 5 denotes a dendrogram cluster for sampled air quality data from July to December 2018 while Fig. 6 represents the monthly homogeneity and heterogeneity of the parameters based on their concentration. From Fig. 5, CO displays a different pattern from other pollutants due to its distinct emission sources especially from automobiles during the early traffic morning hours and late traffic evening. This is because CO is released from incomplete combustion that affects the air quality pattern from July to December within the study area.

NO_2 and O_3 have the same monthly pattern from July to December because O_3 is formed when solar Ultraviolet radiation reacts with nitrogen oxides and reactive hydrocarbon is the principal component of photochemical smog. NO_2 can act as a precursor in the formation of O_3 giving them a close interrelationship within the pollution spectrum. SO_2, PM_{10}, and $PM_{2.5}$ have a similar pattern within the same cluster due to their interrelated pollution sources. SO_2, PM_{10}, and $PM_{2.5}$ are emitted mostly from industrial activities, bush burning, construction sites, etc.

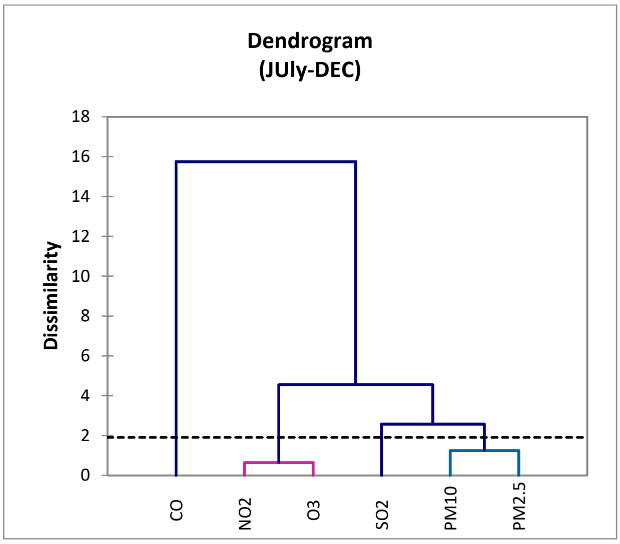
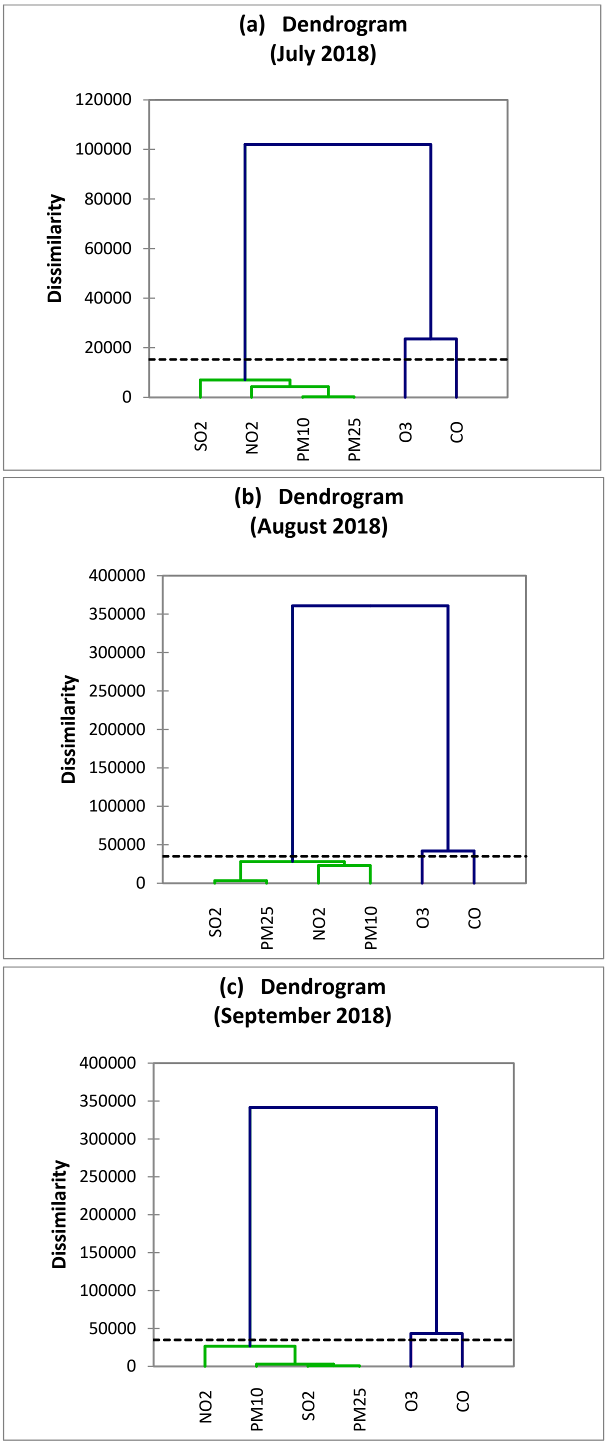


Fig. 5. Variation in the characteristic of the parameters

The monthly pattern of the studied pollutants was also described with a dendrogram in Fig. 6 which relates to the monthly climatic conditions observed in Makassar. The dendogram for July, August, and September 2018 shows similar behavior in the occurrence of NO_2, SO_2, PM_{10}, $PM_{2.5}$, O_3, and CO. This is because Makassar has a tropical climate with the driest months in July, August, and September. This makes the pollutants exhibit similar patter during this period of the year as described in dendrogram a, b, and c. Dry season experiences less rainfall which provides a favorable climatic condition for more pollutant concentration. More so, farmers engage more in bush burning in preparation for the rainy season to plant crops. This portrays a similar pattern in pollution level due to the homogenous bush burning activities.

The rainfall pattern in Makassar increases from the month of October to December. December experiences a high rain pour of about 552 mm within the last six months of the year. These change in rainfall and temperature pattern is responsible for modifying the pollutant behavior in Makassar especially towards the end of the year. Heavy rainfall may help to settle down the suspended pollutants in the atmosphere.



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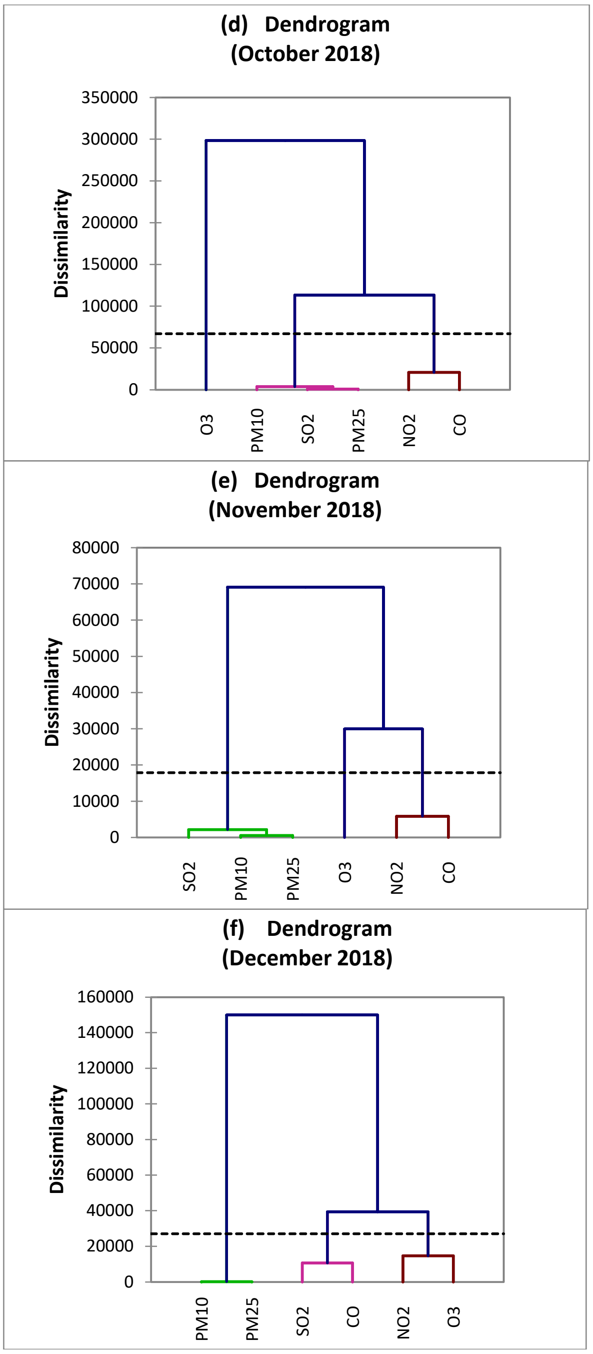

Fig. 6. Monthly variation in the characteristics of the sampled parameters

3.5 Air pollution trend analyses and variability in the pattern of health cases in Makassar

Ambient air pollutants that include PM_{10}, $PM_{2.5}$, O_3, CO, NO_2, and SO_2 have a direct or indirect effect on lung functions which can increase the occurrence of pleural effusion caused by the excess accumulation of fluid between the visceral and parietal flexural of the lungs. This shortfall inhibits lung expansion thereby causing serious health challenges that may lead to a series of hospital admission and finally death [21]. From Fig. 7, PM_{10} happens to be the most highly occurred pollutants followed by NO_2 due to bush burning and emission from industrial activities especially during the month of July, August, and September. This is evident in the cluster analysis displayed in the dendrogram in Fig. 6 which shows PM_{10} and NO_2 in the same cluster. This high concentration is controlled by the dry climatic season experienced in July, August, and September which provides favorable conditions for pollutant occurrence. During these months, farmers practice bush burning to clear their farmland in preparation for high rain pouring in November and December. However, less pollutant concentration is found in November and December due to the rainfall that beats and settles the pollutants. During this period there is less bush burning which reduces the number of pollutants in the environment.

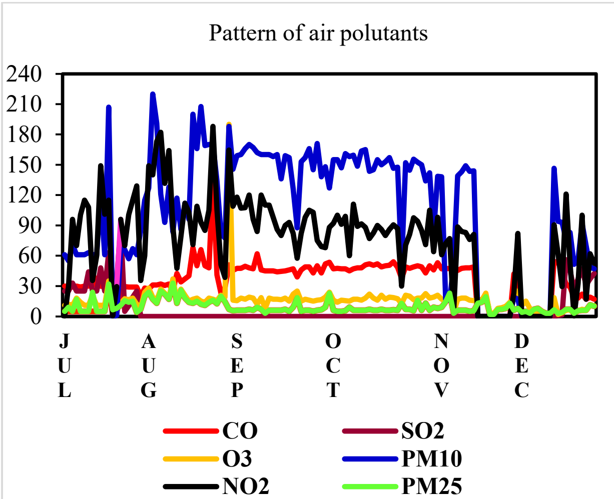

Fig. 7. Trend pattern of monthly air pollutant concentration

3.6 Cases of tuberculosis (TB) in adults and kids in Hospitals and community health centers

Ambient air pollution is among the frequent cause of respiratory infectious diseases globally. Despite the effort put towards reducing the trend of TB cases, it has continued to pose threat to the health of people in developing countries. Recent evidence has shown that exposure to ambient air pollution could increase the incidence of pulmonary TB [21-22]. This risk is obvious due to the dispersion of contaminated air, ventilation, and clinical cases in Makassar hospitals and community health centers as described in Figs 6 and 7. These pollutants may be associated with complex mixtures containing bacteria and other pathogens forming a composition that can affect the immune system and respiratory organs [23-24]. In 2018, the highest adult hospital TB cases in Makassar are 142, 134, 133, 131, and 130. For children's hospital cases, the highest incidence is recorded in 112, 92, 89, and 85. These numbers are of serious concern and require urgent interventions.

More so, community health centers have recorded several TB cases for adults and kids in 2018. For adults, the highest incidence is 215, 167, 159, and 148, while children's cases in different hospitals are in the range of 10, 8, 7, and 6.

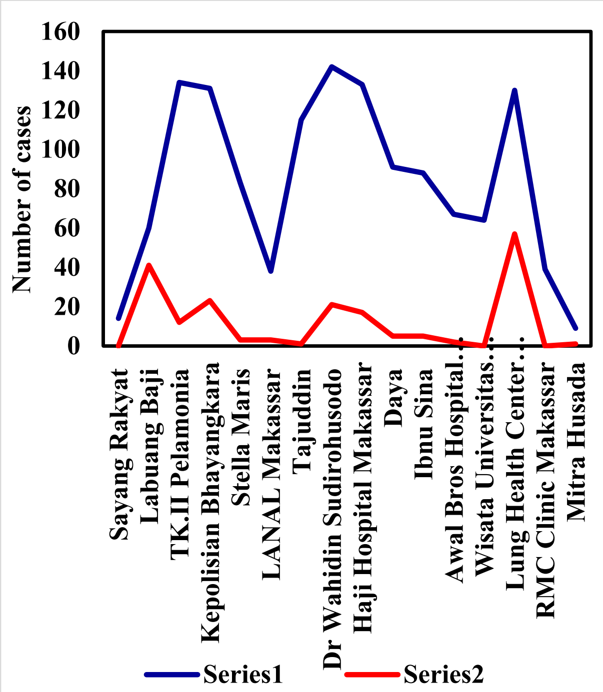

Fig. 8. Hospital Cases of TB in Kids and Adults

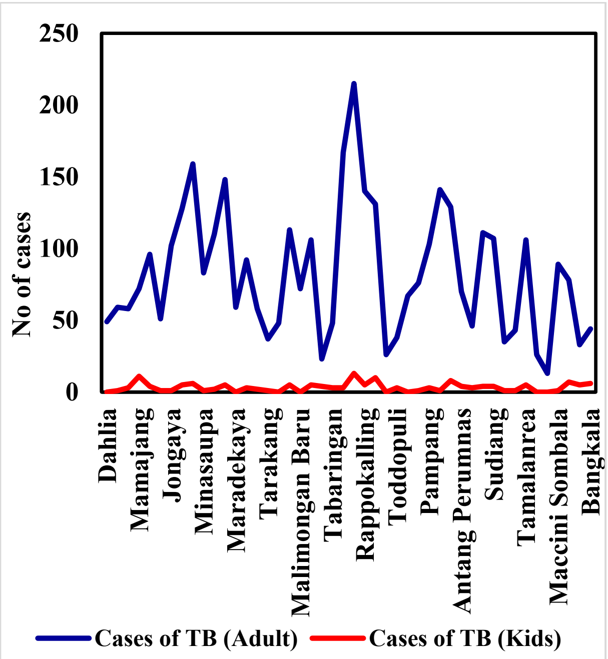

Fig. 9. Community Health Center Cases of TB in Kids and Adults

3.7 Pneumonia cases in Makassar Indonesia

The pattern of pneumonia cases in male and female children within the age of 0-4 years in Makassar was also analyzed. The result as described in Fig. 10 shows a similar but slight difference in trend between the male and female children. This indicates that air pollution affects pediatric pneumonia due to their weak immune system and other defense mechanisms [25]. From Fig. 10, the male children between the ages of 0-4 years have the highest occurrence case of 30, 29, and 28. Other cases display a similar effect for male and female children.

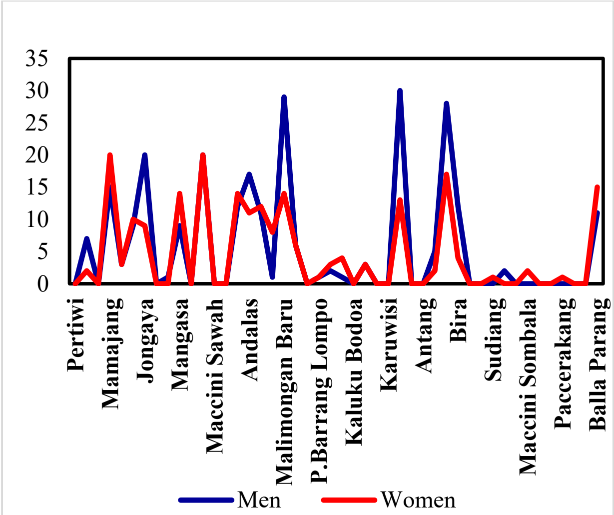

Fig. 10. Pneumonia case for male and female children (0-4 years)

4 Conclusion

This study aims to identify the major possible sources of air pollution, their trend, classification, and health impact in Makassar, Indonesia. Air quality data from July to December 2018 such as CO, SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ alongside tuberculosis and pneumonia data from hospital and community health centers were used. The result for the PCA produced three varifactors with eigenvalues greater than one which explains 83% of the total variance in the dataset. The first varifactor has a strong positive loading for CO, NO_2, and O_3 could be associated with vehicle emission. Strong positive loading of PM_{10} and $PM_{2.5}$ is also observed in VF2 accounting for 22% of the total variance in the dataset. The source of these pollutants is linked with bush burning, frequent urbanization and construction, industrial emission, vehicle emission, and re-suspension of soil dust. SO_2 has a strong positive loading in VF3 accounting for over 18% of the total variance in the data set. Industrial emissions from gasoline and diesel fuel combustion during manufacturing processes may contribute to this emission. July, August, and September are the months with the highest concentration of pollutants due to the presence of dry sky which provides a favorable condition. During these months, these pollutants are associated with complex mixtures that lead to several clinical cases of pneumonia and tuberculosis. Kaluku Bodoa, Jumpandang Baru and Rappokalling, Kassi-kassi, Tamamaung, Malimongan Baru and Antara areas are associated with highest clinical pulmonary cases. These locations have busy traffic, highway, and shipyard activities and some are also slum areas. GIS was also used to map out the spatial distribution in tuberculosis and pneumonia cases. The dendrogram was used to understand the general and monthly pattern of air pollution based on the climate. However, several hospitals and clinical admission cases in adults and children were presented. Urgent measures should be taken by the government to reduce the level of pollution which will, in turn, minimize the level of clinical cases in Makassar. The research findings show that serious and urgent interventions need to be taken to save public health by reducing transport and industry emissions. Stringent enforcement of policy and regulations is needed urgently as well.

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