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# The Distribution of Rainwater Acidity in Bandung

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**Abstract.** Acidity value (pH value) of rainwater, are influenced by the concentration of anions and cations dissolved in rainwater and it was also influenced by several sources of pollutants emitted into the atmosphere. This research was conducted to determine the sources of pollutants that affect the pH value in Bandung. Sampling locations were conducted in 10 locations, both in Bandung City and Regency. We used data monthly averages of pH value from 2006 – 2015, to see the distribution of pH values in Bandung. As for knowing the effect of pollutant sources that affect the pH value, Cipedes area was chosen to represent urban areas from the sampling location. We used data anion and cation concentrations of  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{NH}_4^+$ ,  $\text{Na}^+$  and  $\text{Ca}^{2+}$  in 2006 - 2015. The statistical method used for data process was PCA method. Result shows that pH value in Bandung fluctuated from 2006-2015, with the lowest average pH value in 2010 and 2014 was 5.2. From result of data processing with PCA gained 3 factors influencing pH value Bandung, which were Factor 1:  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{K}^+$  and  $\text{Mg}^{2+}$ , Factor 2:  $\text{Ca}^{2+}$ , and  $\text{NH}_4^+$ , Factor 3:  $\text{Cl}^-$  and  $\text{Na}^+$ .

**Keywords :** acidity,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{NH}_4^+$ ,  $\text{Na}^+$  and  $\text{Ca}^{2+}$ .

## 1. Introduction

Research on rainwater chemistry has been widely carried out by researchers around the world, because it is related to acid rain and the impact on the environment, especially human health [1]. Rain is one of the most effective ways to remove pollutants in the atmosphere. Rainwater chemistry is the result of a series of complex chemical reactions that involve the interaction between the microphysic process and cloud dynamics [2].

Rainwater composition is different for each location, because it is very difficult to control the source of pollutants derived from both anthropogenic and natural sources [3]. The level of the acidity parameter of rainwater can be used as an indicator of the pollution level of a region [4]. For example industrial areas, where industrial processes emit large amounts of sulfur and nitrogen oxides into the atmosphere, and these gases are converted in a series of chemical reactions in the atmosphere to form strong acidic compounds. When this strong acid compound is dissolved in rain water will result low acidity (pH) of rainwater [2].

According to several studies that have been carried out regarding the trend and characteristics of the pH value of rainwater, in Beijing the lowest pH value was obtained during high rainfall, i.e. between July - September [5]. In India, the pH value is strongly influenced by the presence of suspended particulate matter, which will have a neutral effect on the acidity of rainwater [6]. In the Brazilian region, the lowest pH value occurs during the summer, i.e. December, January and February, while the highest pH values occur during spring and autumn [7].

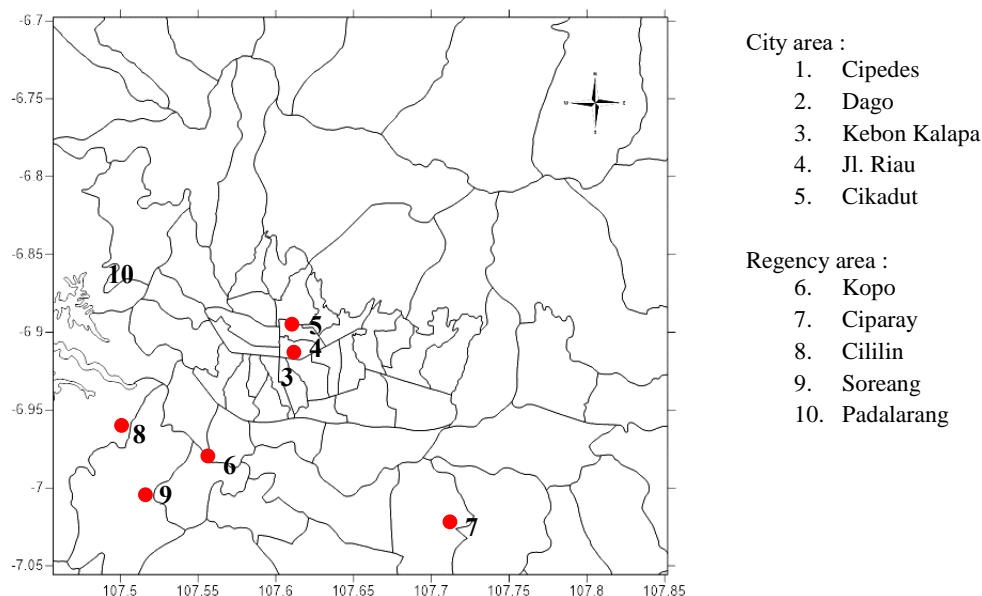


Bandung is an urban area that has a unique topography like a basin area. Bandung is famous tourism city in Indonesia with its rapid development as an urban and industrial area. Previous research on Bandung air quality related to acid deposition, shows in 2013 acid rain has been occurred in Bandung, because the pH value of rainwater was below 5.6. [8]. Based on this, the objective of the research was conducted using rainwater acidity data monitoring in a longer period, from 2006 - 2015 to see the distribution of acidity in Bandung, both the city and regency, and also to see the influence of pollutant sources on the acidity level in Bandung, especially for urban areas. This study will provide useful information for identification of potential source in rainwater and improvement of air quality in Bandung.

## 2. Data and Method

### 2.1. Sampling location and sample collection

The location of the study was conducted in 10 locations for the city and regency of Bandung. Its location were Cipedes, Dago, Kebon Kalapa, Kopo, Jl. Riau, Cikadut, Ciparay, Cililin, Soreang and Padalarang (figure 1). Cipedes, Dago, Kebon Kalapa, Jl. Riau and Cikadut were include in city area, meanwhile Kopo, Ciparay, Cililin, Soreang and Padalarang, are regency area. Bandung is a Basin area surrounded by mountains and hills, where transport of pollutants from the center of Bandung city will be carried by dominant wind then turn around due to collisions with hillsides [8]. Rainwater sampling is done every rainy day from January 2006 - December 2015 by using automatic rain sampler for Cipedes and raingauge for other locations.



**Figure 1.** Sampling location

### 2.2. Sampling analysis and quality control

Samples of rainwater are then measured in volume and placed in polyethylene bottles. Measurement of rainwater pH was done by using the pH meter Horiba F 51 with measurement control at 25°C. After measurement of pH value, the sample of rainwater filtered by using Millipore filter paper with pore size of 0.45 µm. Anion and cation concentrations in rainwater were determined using Dionex ICS 1500 ion chromatography for anions and ICS 1600 for cations. The quality of analytical data was also checked

by a cation-anion balance and by comparison of the measured conductivity with the conductivity calculated from the concentration of all measured ions and their specific conductivity refer to EANET guidelines.

### 2.3. Data analysis

We used data monthly average of pH value to see the distribution of rainwater acidity in Bandung from 2006 - 2015 for 10 monitoring locations. To see the effect of pollutant sources on rainwater acidity values in Bandung, we choose Cipedes data anion and cation concentration (representing Bandung city area) which is also in the form of monthly averages from 2006 - 2015. Data processing is done using PCA (Component principle Analysis) processed with SPSS.23 software

## 3. Result and Discuss

### 3.1. Distribution of acidity value rainwater

The acidity level of rainwater is determined by the relative amount of acids and bases dissolved in rainwater. The dominant strong acid in influencing the level acidity of rainwater, globally is sulfur, nitrate and hydrochloride and the dominant weak acids such as formic acid, acetic acid and carboxylic acids. Organic acids play an important role in the acidity of rainfall when the concentration of strong acids is low, but the deposition of organic acids is considered not important for the ecosystem because organic acids are the consumption of microorganisms on the surface of the earth.

The distribution of the acidity value rainwater for Bandung area varies from year to year. By using interpolation data from 10 sampling points both city and regency areas, contour distribution of rainwater acidity was obtained for Bandung. Based on Figure 2, in 2006 the acidity of rainwater ranged from 5.93 – 6.23 for the regency. But for the city itself, the acidity of rainwater has ranged between 5.63 - 5.73. The acidity value of rainwater is still above the reference value for acid rain, which is 5.6.

From 2007 until 2010, the distribution of acidity in rainwater showed a lower pH value, especially for city area, with a range of pH values was 4.43 - 5.32. Distribution of low pH values from the city to the southwest part of Bandung, Soreang and Cililin and suggesting acid rain events in this area were serious. Because acidity value of rainwater shows below the reference value for acid rain. This condition assumed that anthropogenic source contributed to decrease the acidity of rainwater value during this sampling period, such as fossil fuel burning, industrial and vehicular emission [9].

In 2011 until 2014 it was seen that the spread of low pH values was still to the west of the city area with a range of pH values between 4.43 - 5.33. The distribution of rainwater acidity in 2015 showed that the most locations in Bandung regency had a condition low pH values. But it's different from some locations in the city, where the pH value ranges from 6.03 to 6.33. According to the research that has been carried out the existence of  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{NH}_4^+$  which is dissolved in rainwater has a great influence on neutralizing the acidity of rainwater for the area of Bandung [10]. Acidic pH reveals the presence of strong acids while neutral or alkaline pH indicates neutralization of acids by carbonates, mineral dust or by ammonium. This may be due to the reaction of sulphuric and nitric acid absorbed in the aerosols with alkaline carbonates in the particulate matter [2].

An average pH value has been carried out for 10 locations, showing that since 2008 acid rain has been occurred in Bandung. Based on Figure 3, from 2006 until 2015, there were two valleys which stated the lowest value of rainwater acidity in Bandung, it was in 2010 and 2014, with pH value around 5.2. Fluctuations in pH values correlate with fluctuations in the content of ions dissolved in rainwater. When concentration of  $\text{SO}_2$  and  $\text{NO}_2$  in air is high, and then they are dissolved in rain water it forms  $\text{SO}_4$  and  $\text{NO}_3$ , then the pH value of rainwater will be low [11].

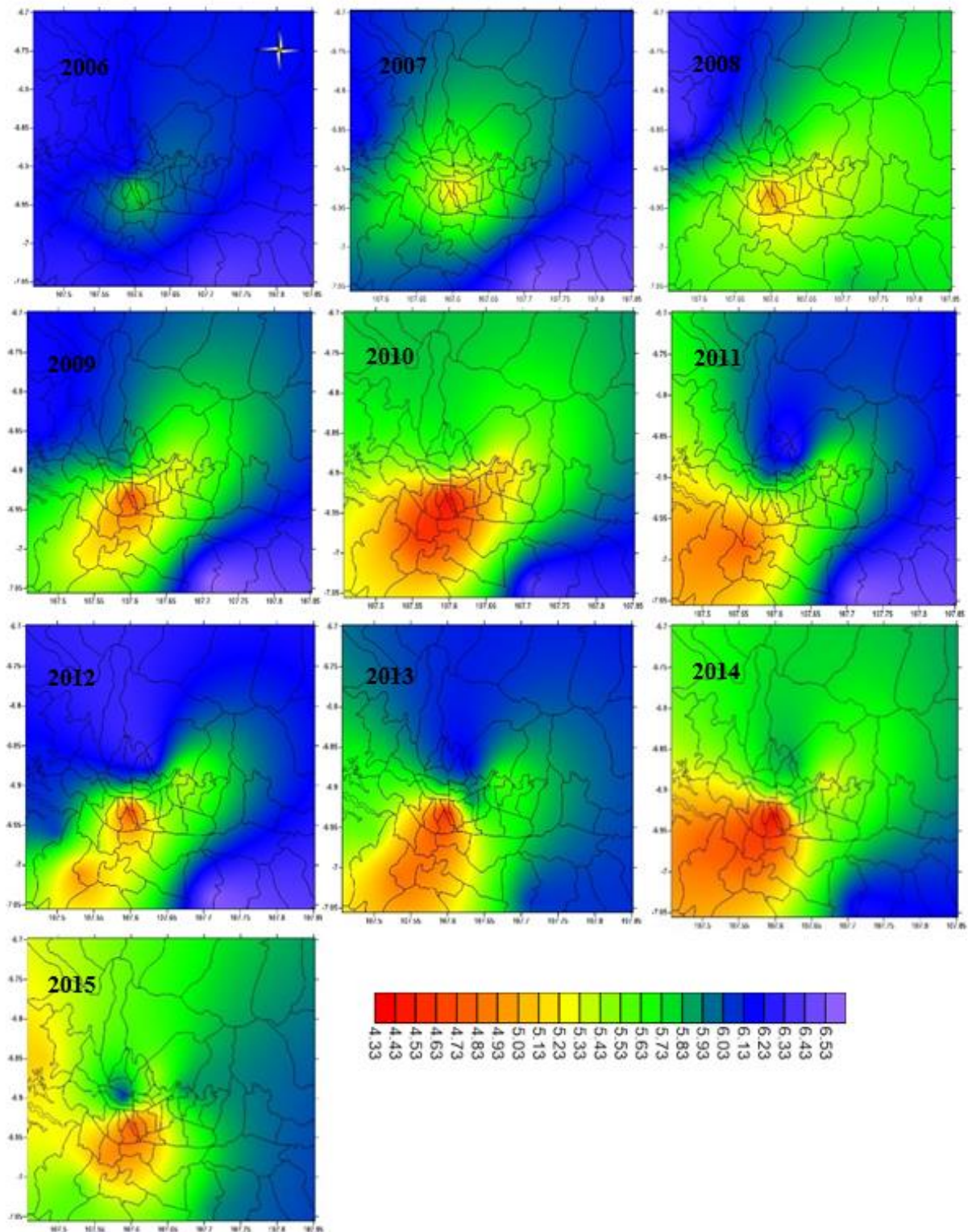


Figure 2. Distribution of pH value Bandung 2006 – 2015



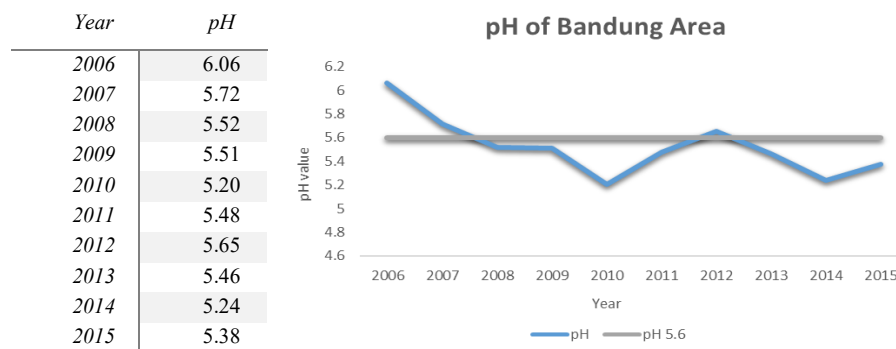


Figure 3. pH value Bandung 2006 – 2015

### 3.2. pH and rainfall

Rainfall volume is related to the process of washing pollutants in the atmosphere which will ultimately affect the chemical content of rainwater, especially the acidity of rainwater. During the dry season, the tendency to wash pollutants in the atmosphere does not run optimally, because of the large amount of pollutants in the atmosphere and the least rainfall. Several studies have been carried out related to the relationship between pH value and rainfall, it was found that if rainfall is high, especially in the rainy season, the pH value will be low, whereas when rainfall is low, the pH value will be high [5]

However, based on research conducted [4] there was no correlation between rainfall and pH value. In addition, [12] in his research was found that rainfall does not directly affect the acidity of rainwater, but there is a tendency of pollutant dispersion during heavy rain the previous day or the same day, the pH value will be low (acid).

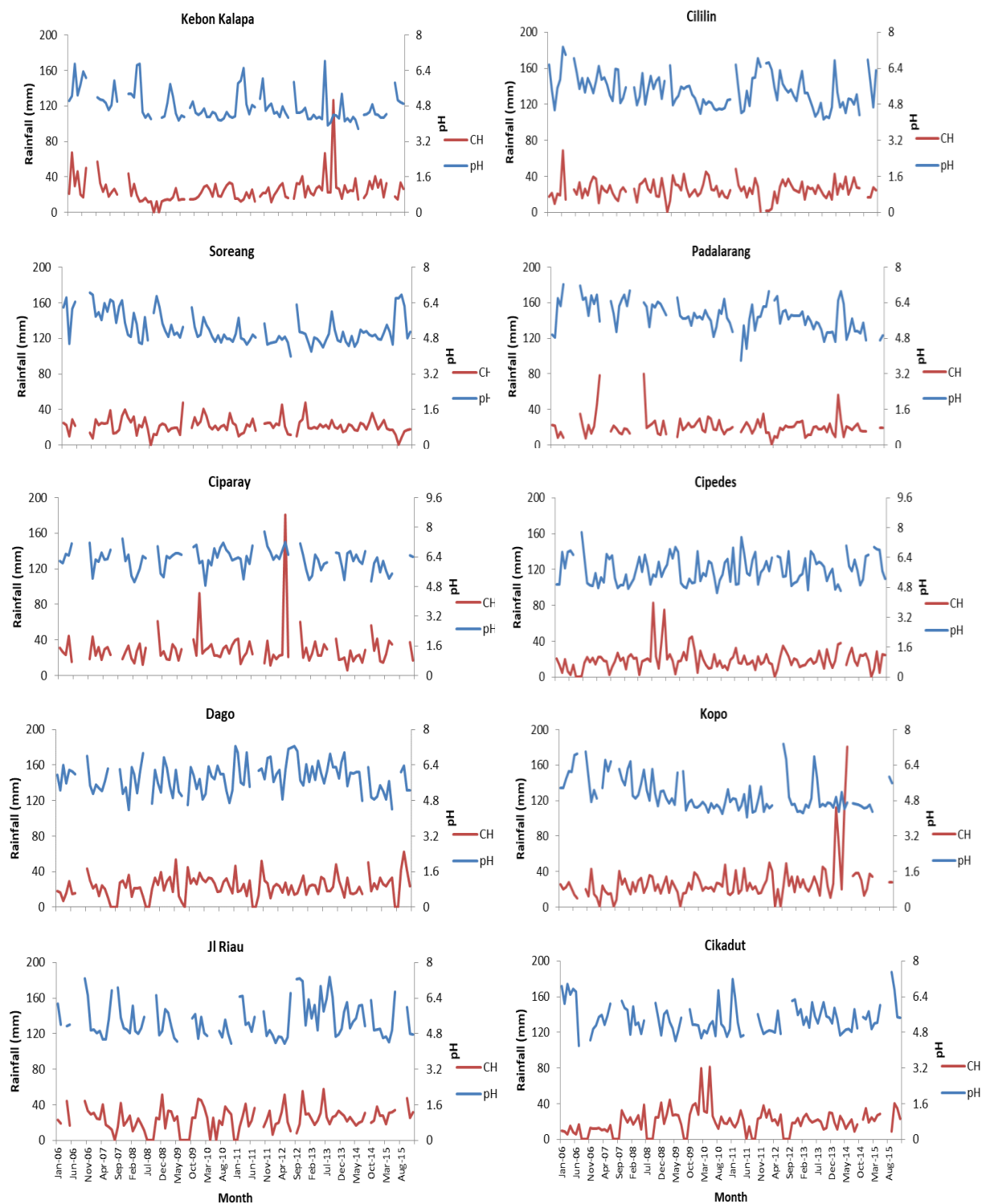
In Figure 4, it can be seen that in each sampling location, the relationship between rainfall and the acidity of rainwater does not provide a significant correlation. In certain months it shows when the rainfall volume is low, the pH value will be high, and vice versa. From the calculation of correlation for several locations shows the significance of the relationship between rainfall and pH value with a negative relationship, while other locations do not provide a significant relationship. Some researches were needed regarding the effectiveness of washing the atmosphere carried out by rainwater against air pollution, especially in Bandung, which is correlated with the value of dissolved ion concentration also the acidity of rainwater.

### 3.3. Analysis of PCA

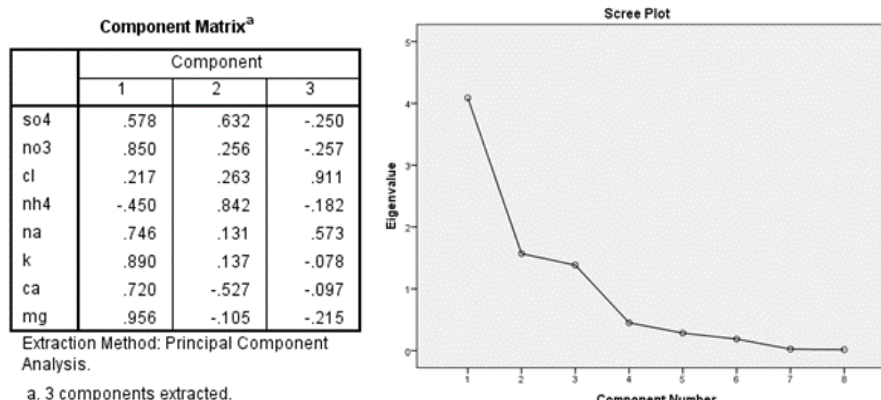
Data processing was performed using PCA statistical analysis method to identify the influence of anthropogenic sources and natural sources on the value of rainwater acidity in the Bandung basin and for the location we choose Cipedes represents for urban location. The variables used are the values of the concentration of rainwater anions and cations such as  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{NH}_4^+$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ .

The result from PCA analysis shows the Barlett's test of sphericity for the overall significance of all correlations in a correlation matrix, which is characterized by significance (p value <0.05). There is a significance level of 0.00 (p value <0.05). To measure the adequacy of sampling, by comparing the magnitude of the correlation coefficient observed with a partial correlation coefficient, the KMO (Kaiser-Meyer-Olkin) value shows a value of 0.218 (KMO value <0.05), this means that the correlation between pairs of variables can be explained by other variables.

From the total variance explain result (figure 5) there are 3 factors that will explain the sources that affect the pH value in Cipedes. Of the three variables can explain the variance of 8 items by 87.99%. This value is quite good, because it is proven to explain more than 50% of the variance of the variable.



**Figure 4.** Rainfall and pH value



**Figure 5.** The results of component matrix and screen plot

Rotation analysis is then carried out to explain clearly the distribution of variables, where the results show 3 rotations of the matrix component, according to the number of factors obtained. There are 3 variables that are highly correlated. Factor 1 explained about 51.11% of the total variance with strong positive loading for  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{K}^+$  and  $\text{Mg}^{2+}$  (0.849; 0.902; 0.817 and 0.813). Showing the pH value is influenced by transportation factors, where the source of pollutants comes from motorized vehicles which contribute to the concentrations of  $\text{SO}_2$  and  $\text{NO}_x$  in the air, while  $\text{K}^+$  and  $\text{Mg}^{2+}$ , indicate the source of soil (dust) from the road and the flying land into the air. The loadings of all ions in factor I give some result that industrial activity gives way to vehicular activity which causes stirring of soil dust raised by the convective activity coupled with the dust raised by vehicles themselves [12].

Based on data from the Central Bureau of Statistics in Bandung Municipality in Figure 2007 and 2012, the number of motorized vehicles was 699,320 units in 2006, and increased by 1,252,230 units in 2011. Based on this, it is seen that transportation is indeed the main factor that contributes to the acidity of rainwater Bandung. Besides that, since the opening of Cipularang Toll Road, which made it easy for tourists to visit Bandung, they also contributed to the source of vehicle emissions, especially during holidays. Recorded in 2009 the number of vehicles entering Bandung via Pasteur Toll Gate was 9,999,213 vehicles and increased by 11,035,023 vehicles in 2011.

Factor 2 which explained 19.60% of the total variance has strong positive correlated with  $\text{Ca}^{2+}$ , and negative correlation with  $\text{NH}_4^+$ .  $\text{NH}_4^+$  has a negative correlation of 0.964, while  $\text{Ca}^{2+}$  is 0.809. This result showed pH value more influenced by limestone which contributes  $\text{Ca}^{2+}$  to the air and  $\text{NH}_4^+$  in urban area produce from industrial processes, vehicular emissions and volatilization from soil [13] and commonly associated to biomass decomposition [7]. Negative loading for  $\text{NH}_4^+$  means concentration of  $\text{NH}_4^+$  greatly affects the acidity value of rainwater in Bandung in the opposite direction of correlation. Factor 3 with strong positive loading 17.28% for  $\text{Cl}^-$  and  $\text{Na}^+$  (0.970 and 0.778), both of them are very strongly influenced by sea resources (sea salt breeze) [7].

Based on research conducted by Xiao, 2016, using PCA to identify sources of pollutants that affect air quality in Xi'an, China. The results showed there are two factors that affect air quality in Xi'an, China, the first was affected by mixed source such as crustal, anthropogenic and marine origins, possibly transported over a long distance and the second factor were from neutralization process which is also from anthropogenic source that release fluoride contents. In another research, done by Cerqueira et al, 2014 was found 4 factors that affect the concentration value of anion and cation in rainwater. There are soil and road dust, anthropogenic source, sea salt and from agricultural and cattle farming.

#### 4. Conclusion

Acid rain results from human activities that affect the environment. The distribution of rainwater acidity value for the Bandung area has shown the distribution of acidic pH values to the city and regency of Bandung in 2015. However, there are conditions where the city area has a pH value > 6.0 which is



thought to be due to neutralization by the presence of  $\text{Ca}^{2+}$ ,  $\text{Na}^+$  and  $\text{NH}_4^+$  ions . By using PCA, obtained variables that affect the high and low pH values for Cipedes , were vehicles, street dusts and also the influence of marine sources.

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