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# Break Point Analysis of Particulate Matter

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**Abstract:** Fine particles like $PM_{2.5}$ are known to trigger or exacerbate unending ailment, for example, asthma, heart assault, bronchitis and other respiratory issues. The factors affecting the density of $PM_{2.5}$ in atmosphere are temperature, humidity and pressure. Other factors like burning fire crackers, thrashes, etc. compliments them which leads to adverse effect of $PM_{2.5}$ on mankind. We cannot control the natural activities of temperature, humidity and pressure but we can at least prevent complimenting them by knowing at what duration of a year there is sudden change in density of $PM_{2.5}$ in environment due to these factors. In this research, prediction of breakpoint of $PM_{2.5}$ density in a year with respect to these factors using segment analysis is being tried.

**Key words:** $PM_{2.5}$, break point analysis, air pollution.

## Introduction

The three basic needs of the human to survive are air, water and food out of which air is the most important (Varun Jain, 2018). But the humans are themselves destroying their survival conditions for present and future by their activities causing pollution of various type, one of which is air pollution. The air pollutants could be categorized as pollutant gases ($SO_2$, $NO_2$, CO, etc.) and suspended particles ($PM_{10}$, $PM_{2.5}$, etc.) (Ling-Jyh Chen, 2017). The $PM_{2.5}$ alludes to air particulate matter (pm) that have a measurement of under 2.5 micrometres, which is around 3% the diameter across of a human hair. Since they are so little and light, fine particles tend to remain longer noticeable all around than heavier particles. This builds the odds of people and creatures breathing in them into the bodies. Sources of $PM_{2.5}$ are: traffic-related particles (30% of the average $PM_{2.5}$), secondary particles (34%), crustal material (7%), oil combustion (11%), industrial and incineration processes (9%), reaction of gases from power plants in atmosphere and sea salt (2%) (Muggeo, 2008). The unidentified $PM_{2.5}$ fraction was 7% on the average. $PM_{2.5}$ is causing various serious health problems like lung cancer, premature death, respiratory diseases, asthma, cardiovascular diseases, etc. Moreover when combined with moisture in atmosphere it leads to smog (Sigfox, 2009).

The $PM_{2.5}$ concentrations of different places have been monitored and recorded using various IoT methodologies and instruments. $PM_{2.5}$ concentration has been monitored using COTS (commercial off-the-shelf) IOT devices which are capable of using any existing sensors capable of sensing pm (Dongyun Wang, 2016). An Ethernet air quality remote monitoring and control system has been designed (Shie-Yuan Wang, 2017). Various wireless IoT devices such as LoRa (Sigfox, 2009), SigFox (Lim SS1, 2012), and Wireless-Nand NB-IoT (Konstantin Mikhaylov, 2016) have been developed to sense $PM_{2.5}$ concentration in atmosphere (Shie-Yuan Wang, 2017).

But only monitoring $PM_{2.5}$ concentrations is not sufficient. It needs to be analyzed so that some patterns and outcomes could be obtained that can

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help in reducing the adverse effect of $PM_{2.5}$ on living things. In this research paper breakpoint analysis of $PM_{2.5}$ concentration with respect to factors affecting it is done. Breakpoint analysis is a way to obtain the sudden change in dependent variable with respect to independent variable in a relation.

### Some Natural Factors Affecting Concentration of $PM_{2.5}$ in Atmosphere

*Humidity:* Humidity and PM density are directly proportional. With increase in humidity particles are attached to water droplets, the PM particles become aggregate due to which the density of PM in atmosphere increases (Majewski, 2011).

*Pressure:* Pressure and PM density are directly proportional. With increase in pressure the intermolecular force between PM increases; hence density of PM in atmosphere increases (Majewski, 2014).

*Temperature:* Temperature and PM are inversely proportional. With increase in temperature PM density decreases because with increase in temperature kinetic energy of PM molecules increases, leading to lower density of PM in atmosphere (Nidzgorska-Lencewicz, 2015).

In spite of this there are threshold values or break points after which they tend to suddenly behave inverse. And this is what the aim of this research paper to "analyze break point of $PM_{2.5}$". Here, the dependent variable in the relation for break point analysis is $PM_{2.5}$ concentration and independent variables are temperature, pressure and humidity.

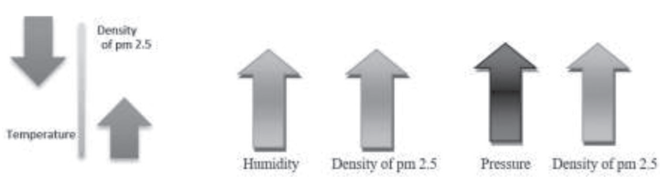


**Figure 1: Depended and independent variables for breakpoint analysis.**

## Research Objective

The whole world is suffering from types of pollution either air, water, soil, nuclear or any other which are either created by human or nature. Scientists are trying to predict how humans are going to adapt themselves in the changing environment in future. Either they will adapt or will extent. It is tough to imagine the future of human with air purifying masks all around, least exposure to open environment, relying on medicines instead of on food and water for survival and still be moving bodies with lots of diseases. They will be repaying the cost of their ancestors' careless behaviour towards the environment.

So, why not to change now rather than adapting in future. With certain measurable careful steps we could decrease the rate and effect of pollution in coming years. This research paper would help to find how to know in what particular season and condition the density or presence of $PM_{2.5}$ increases or decreases suddenly. Which could be further used to aware citizen so that in that particular time period they could avoid doing activities such as burning fuel, crackers, thrashes etc. that could compliment the harmfulness of the $PM_{2.5}$ in surrounding.

## Literature Survey

According to Global Burden of Disease Study air pollution from household caused three million deaths across the world and is fourth greatest danger to life (Juha, 2015). Enough research is done to show that this air pollution could also lead to various cardiovascular diseases (Mukesh Sharma, 2005). Because of particulate matter and benzopyrene pollutants noticeable all around, the Polish economy loses from PLN 40 to 120 billion every year, which incorporates for instance the expenses of hospitalization, lost working days and undertaking misfortunes. The low discharge decrease framework in Poland requires legislative changes (Janusz Adamczyk, 2017).

In year 2017 a research has been carried out in Krakow to analyse seasonal variation and chemicals contributing to $PM_{2.5}$ concentration. Six sources affecting the $PM_{2.5}$ concentration using the PMF model were identified: secondary sulfate, secondary nitrate, combustion, biomass burning, steel industry/soil dust and traffic. Highest seasonal variation was observed for the combustion source (from 0.17 to 27 μg $m^{-3}$)—in winter months, the contribution of this source to total $PM_{2.5}$ mass was about 40% (Lucyna Samek, 2017).

In years 2016 and 2017 first study to $PM_1$ and $PM_{2.5}$ was done in Krakow to observe $PM_1/PM_{2.5}$. The concentrations of $PM_{2.5}$ were 12 mg/$m^3$ in summer and 60 mg/$m^3$ in winter and for $PM_1$ it was 6.9 mg/$m^3$ and 17.3 mg/$m^3$, respectively. The ratio of $PM_1$ and $PM_{2.5}$ are 0.58 and 0.29 in summer and winter respectively. Chemical species (K, Fe, Cu, Zn, Br, Pb, Cl, $SO_4^{2-}NO_3^{-}$ and $NH_4$) concentration, for both fraction, had also significant seasonal variation. The biggest variation were observed for $Cl^-$, $NO_3^-$ and $NH_4$ (Janusz Adamczyk, 2017).

According to a study that analyzed hourly mass concentration observations of $PM_{2.5}$ (particulate matters with diameter less than 2.5 μm) at 512 stations in China from December 2013 to May 2015, it was found that the mean concentrations of $PM_{2.5}$ during the winter and spring of 2015 (Dec. 2014 to Feb. 2015 and Mar. 2015 to May 2015) decreased by 20% and 14% compared to the previous year, respectively. Comparison of the climatic diffusion conditions during these two years and to know the change of air quality amid the principal half of 2015 over China (Xiaoyan Wang, 2016).

Therefore, analysis should be performed on these basic natural factors effecting concentration of PM in environment.

## Implementation

The air quality data of twelve months of city of Krakow of Poland has been taken from https://www.kaggle.com/datascienceairly/air-quality-data-from-extensive-network-of-sensors/data in which air quality data of 150 places has been recorded using air quality sensors network in which date, time, humidity, temperature, pressure, $PM_{2.5}$, $PM_{10}$, $PM_1$ of respective 56 places has been recorded. In this research paper only one place's twelve month data with only $PM_{2.5}$ values has been analyzed for break point value.

This dataset comprises air quality information (the convergences of particulate issue $PM_1$, $PM_{2.5}$ and $PM_{10}$, temperature, gaseous tension and mugginess) from 2017 created by system of 56 ease sensors situated in Krakow, Poland. Each had its own particular area (6 of them were replaced during this time period and have almost the same latitude and longitude). Estimations are assembled in 12 records, one for every month. Resolution is 60 minutes.

1. One place data from Kaggle's complete data set is extracted. The extracted date set of PM with temperature, humidity and pressure respectively are shown in Table 1.
2. Load all the data sets to the R.
3. Define the broken line relationship between $PM_{2.5}$ and temperature, pressure and humidity respectively to be fitted in estimated standard GLM.
   ```
   >fit.glmt<- glm(X142_PM25~X142_temperature, weight = X142_PM25, data = temperature)
   >fit.glmp<- glm(X142_PM25~X142_pressure, weight = X142_PM25, data = pressure)
   >fit.glmh<- glm(X142_PM25~X142_humidity, weight = X142_PM25, data = humidity)
   ```
4. Define the piecewise relationship on pressure, temperature and humidity respectively with respect to $PM_{2.5}$ and guess the estimated breakpoint values where there could be sudden change in $PM_{2.5}$ concentration in atmosphere either positive or negative due to change of temperature, humidity or pressure.
   ```
   >fit.segh<- segmented(fit.glmh, seg.Z = ~X142_humidity, psi = c(31,43))
   >fit.segt<- segmented(fit.glmt, seg.Z = ~X142_temperature, psi = c(31,43))
   >fit.segp<- segmented(fit.glmh, seg.Z = ~X142_pressure, psi = c(101773,101348,101528))
   ```
5. Plot the relations and observe the actual breakpoint values of $PM_{2.5}$ in accordance with temperature, pressure and humidity. This will provide the actual temperature, pressure and humidity values in a period of a year that could lead to sudden change in $PM_{2.5}$ concentration.

The results are shown in Figures 3, 4 and 5.

As per the graph in Figure 3, the first break point of $PM_{2.5}$ concentration with respect to humidity is at humidity value 58. After this break point the concentration of $PM_{2.5}$ increases with a sudden high rate. But when humidity value reaches at 60 which is second break point the $PM_{2.5}$ concentration starts decreasing and at humidity value 63 the rate of decreasing concentration of $PM_{2.5}$ slows down.

As per the graph in Figure 4, the first break point of $PM_{2.5}$ concentration with respect to temperature is obtained at temperature value 261 K. After this $PM_{2.5}$ concentration starts decreasing but after second break point at temperature value 264 K the rate of decreasing $PM_{2.5}$ concentration is higher. After 266 K which is the third break point the decreasing rate of $PM_{2.5}$ concentration again decreases.


**Figure 2: The complete process flow.**

**Table 1: Temperature and $PM_{2.5}$ (left), Pressure and $PM_{2.5}$ (centre) and Humidity and $PM_{2.5}$ (right)**

| 1 | 142_temp | 142_pm25 |
|---|---|---|
| 2 | -4 | 127 |
| 3 | -5 | 116 |
| 4 | -5 | 121 |
| 5 | -5 | 118 |
| 6 | -5 | 123 |
| 7 | -5 | 143 |
| 8 | -5 | 132 |
| 9 | -5 | 138 |
| 10 | 0 | 140 |
| 11 | 3 | 114 |
| 12 | 4 | 112 |
| 13 | 7 | 80 |
| 14 | 8 | 58 |
| 15 | 6 | 65 |
| 16 | 0 | 90 |
| 17 | -1 | 108 |
| 18 | -3 | 195 |
| 19 | -3 | 178 |
| 20 | -4 | 201 |
| 21 | -5 | 172 |
| 22 | -5 | 142 |
| 23 | -5 | 98 |
| 24 | -4 | 90 |
| 25 | -5 | 102 |
| 26 | -5 | 92 |
| 27 | -5 | 94 |
| 28 | -6 | 98 |
| 29 | -5 | 93 |
| 30 | -5 | 89 |
| 31 | -5 | 85 |

| 1 | 142_press | 142_pm25 |
|---|---|---|
| 2 | 102279 | 127 |
| 3 | 102228 | 116 |
| 4 | 102149 | 121 |
| 5 | 102097 | 118 |
| 6 | 102047 | 123 |
| 7 | 102021 | 143 |
| 8 | 101984 | 132 |
| 9 | 101977 | 138 |
| 10 | 101965 | 140 |
| 11 | 101927 | 114 |
| 12 | 101846 | 112 |
| 13 | 101770 | 80 |
| 14 | 101700 | 58 |
| 15 | 101669 | 65 |
| 16 | 101634 | 90 |
| 17 | 101583 | 108 |
| 18 | 101561 | 195 |
| 19 | 101552 | 178 |
| 20 | 101539 | 201 |
| 21 | 101528 | 172 |
| 22 | 101491 | 142 |
| 23 | 101442 | 98 |
| 24 | 101396 | 90 |
| 25 | 101348 | 102 |
| 26 | 101303 | 92 |
| 27 | 101261 | 94 |
| 28 | 101207 | 98 |
| 29 | 101158 | 93 |
| 30 | 101123 | 89 |
| 31 | 101111 | 85 |

| 1 | 142_pm25 | 142_humidity |
|---|---|---|
| 2 | 127 | 68 |
| 3 | 116 | 68 |
| 4 | 121 | 66 |
| 5 | 118 | 66 |
| 6 | 123 | 65 |
| 7 | 143 | 66 |
| 8 | 132 | 65 |
| 9 | 138 | 64 |
| 10 | 140 | 45 |
| 11 | 114 | 37 |
| 12 | 112 | 36 |
| 13 | 80 | 31 |
| 14 | 58 | 26 |
| 15 | 65 | 29 |
| 16 | 90 | 43 |
| 17 | 108 | 51 |
| 18 | 195 | 58 |
| 19 | 178 | 59 |
| 20 | 201 | 62 |
| 21 | 172 | 67 |

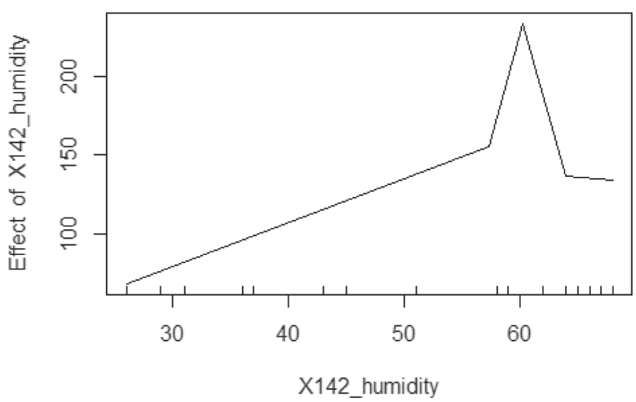


**Figure 3: Relation between humidity and $PM_{2.5}$ concentration.**

As per the graph in Figure 5, the first break point is obtained at pressure value 101550, after which $PM_{2.5}$ concentration increases at high rate. But after pressure value 101565 which is second break point value the $PM_{2.5}$ concentration decreases suddenly at high rate. At third break point pressure value 101690 the $PM_{2.5}$ concentration again increases but its rate is slower than before. After fourth break point at pressure value 101990 the $PM_{2.5}$ concentration decreases but at much slow rate than before.

In this research, data of Poland's Krakow city's $PM_{2.5}$ concentrations in a place with code value 142 has been analyzed for break point value of $PM_{2.5}$ with respect to temperature, humidity and pressure. It could help the government and citizens of that place to take measures so that any other human factor can't contribute to sudden change in $PM_{2.5}$ concentration. For the analysis R tool has been used. Segmented package of R has been used for break point analysis of $PM_{2.5}$.

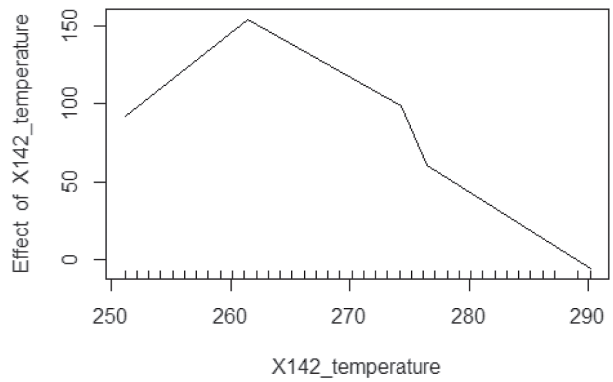


**Figure 4: Relation between temperature and $PM_{2.5}$ concentration.**

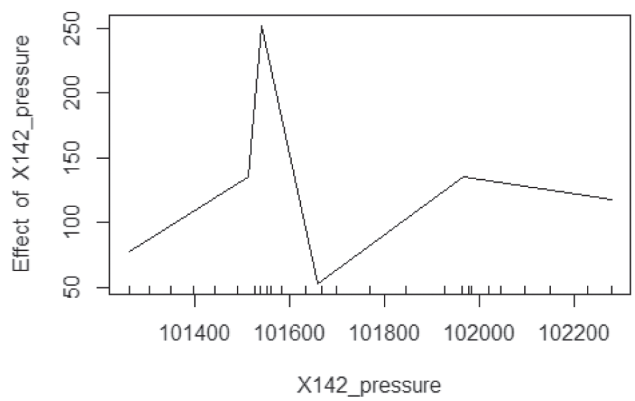


**Figure 5: Relation between pressure and $PM_{2.5}$ concentration.**

## Conclusion and Future Scope

Sudden change in $PM_{2.5}$ concentration in atmosphere leads to various health and visibility disorders. Study reflected that the natural climate factors like temperature, pressure and humidity play significant role in determining the presence of particulate matter in atmosphere. As observed through calculations with variation of these climate factors the amount of particulate matter changes. Usually this change is gradual but at certain value there is marked difference in presence of $PM_{25}$ matter. The break point analysis helps to predict the amount value of temperature, pressure and humidity at which sudden change in $PM_{2.5}$ concentration in atmosphere is reached. In this research such break point values of $PM_{2.5}$ concentration in atmosphere of a Krakow city's place with respect to temperature, humidity and pressure has been analyzed. Along with the climate factor the chemical and photochemical reactions result in development of smog. The current study is done on the secondary data and can be extended to evaluate the cumulative effect of climate factors and reactions of chemical reactions. The study will help to forecast when the smog will outburst. Same analysis could be performed on $PM_{2.5}$ concentration in India's atmosphere that could help Indian government and citizens to take corrective actions such as lesser burning of fuel, release of minute waste particles by industries etc. especially when climatic conditions are favouring in creating the smog. Thus the combined effort of technological predict and human awareness could contribute towards better air quality and health conditions.

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