Real-Time Particle Matters Monitoring Based on Mobile Sensors from Multiple Vehicles in Urban Street, Daejeon-City, South Korea

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Abstract—**Particulate matters may affect the health of the people living in metropolis. To establish appropriate health guidelines, further information is required. The purpose of this study is to visualize the spatial distribution and identify those areas of higher concentration of interesting particulate matters within the city. In this work, particle sensing device was devised to be installed on automobiles such as taxies or SUVs, and those vehicles were operated to gather particle information of every nook and corner in the city. This work presents a new technique for arrangement and refinement of the gathered data and demonstrates how it is applied to the visualization and statistical analysis. This paper provides the results of mapping spatial distribution of urban street dust concentration with visualized maps and identifies the correlation among particle matters. This work also investigates the relationship between particulate matters and metrological parameters such as temperature, wind speed, and precipitation using statistical methods like analysis of variance (ANOVA) and Principal Components Analyses (PCA). In addition the results prove that particulate matters are significantly correlated to metrological parameters.**

Index Terms—**mobile vehicles, multiple sensors, real-time monitoring, spatial distribution, urban street dust**

I. Introduction

Particulate matter of urban dust in the atmosphere is the most important factor which has a wide range of implications for climate, environment, and human health [1], [2]. In recent years the drought, which has been increasingly intensified due to climate change and desertification phenomenon in the Middle Asia, has played an important role in increasing dust [3]-[5].

The main issue of air pollution in South Korea is fine dust, which comes from neighboring countries since a substantial amount of dust is produced during a very short period of time [6], [7]. Most small particles of fine dust, which are in flowed from the Middle Asia and China, contain clay and silt since small particles are as light as air and can exist in arid or semi-arid climate. Even most percentage of small particles do not have cloud condensation nuclei, therefore it is possible for these small particles to disperse through wind or convection current [8]-[11]. In addition, small particles can be migrated very long distance and can exist high altitude in atmosphere. This phenomenon explains that particulate matters attaching to small particles of fine dust can be released on a large scale and fine dust can be considered as an important source of particulate matters [12]-[14].

In general, it is known that the larger the population, the higher the particulate matter concentration in urban street dust. Reference [15] noted a trend for higher concentrations to be found on streets where traffic was more likely to undergo stop-and-go driving in heavy traffic and frequent stop-and-start signal control of traffic lights.

According to [16], temperature, wind and precipitation are also likely to influence particulate matter concentration, retention time, and distribution. Most studies have shown that metal concentrations in dusts vary between different cities with level of development and environmental characteristics, but still lacking is a comprehensive characterization of the distribution of particulate matter levels in a large city.

There have been no similar studies specifically examining street dusts distribution across a large city. The reason, we believe, is that it is virtually impossible to install dust sensing devices on every area in a large city. Particularly, most dust sensing devices have been installed in limited area and the number of devices is not enough to collect dust information of across city. In addition, the measuring sources which dust sensing devices are installed do not have distance regularity. Even one source site is as close as several kilometers away and as far away as dozens of kilometers from the very next source. Thereby the information of street dust is not able to be correctly gathered. These kinds of problems make it impossible for proper information providing. For example, even though a district is actually not an area of influence of small particles, the residences of the district are also alerted from national administrator. In addition, when urban dust phenomenon happens, it is difficult to predict how long it will be lasted as well as to provide when outdoor activity might be fine.

In this work, we developed a new method for mapping dust distribution using street dust data set collected from

Manuscript received May 23, 2019; revised June 30, 2019; accepted July 20, 2019.
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doi: 10.18178/ijeetc.9.1.1-7

mobile vehicles. As shown in Fig. 1, several sensors such as PM1, PM2.5, PM10, NH3, CO, NO2, CH4, etc. are combined into a device.

The device was installed inside cab of taxi roof, and the taxies containing the sensing device irregularly got around across city for carrying passengers (see Fig. 2).

During driving, the device kept connecting to cellular networks for transmitting collected data from street. Then, whole data were saved for analysis and information provision of street dust distribution which was supposed to be provided at an interval of ten minutes. However, it requires very high expense to develop a device to sense dust information. In addition, it is hard to prepare every required sensor or device for urban environment. Therefore, if we can find any correlation of particulate matters, we can easily infer the status of particulate matters from the relationship and reduce sensing cost.

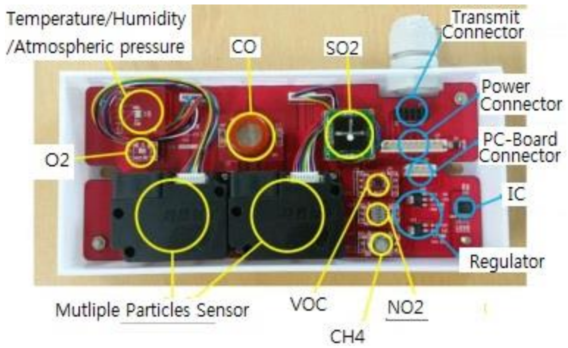


Fig. 1. Sensing device with several sensors for urban street dust.

Fig. 2. Example of sensing vehicle. The sensing device is installed on the roof and it is operated by a driver.

The aims of this study are twofold; firstly to examine and present the spatial distribution of particulate matters found in street dusts in Daejeon city using collected data from mobile vehicles. The second aim is to assess mobile sensors from multiple vehicles based analytic approach has practical use comparing to general phenomena of particulate matters to wind, humid, and temperature.

II. Method

A. Sample Area

Daejeon-city is the third largest city of South Korea and is located on the western part of peninsular. It is surrounded by mountains from west, south-east, and east. Daejeon-city is a large commercial and industrial center as well as the crossroads between North and South in South Korea. The general climate of Daejeon city is warm and humid but moderate in winter, however in summer it is characterized by high temperature, humidity, and solar radiation. Rainfall is generally intermittent. Sampling areas can be categorized according to traffic density, industrial activities, and residential districts.

B. Sampling Strategies

Street dusts were sampled during August to September in the summer after a dry spell of weather, to avoid rain washing out the particulate matters. The samples were collected every one minute from randomly moving taxi to carry passengers. The device, which multiple sensors are combined, was installed on the taxi roof (see Fig. 2). The device immediately analyzed the information from multiple sensors and produced a sample data according to following protocol as shown in Table I.

The reproducibility of the sensors installed on the sampling device were expressed as Relative Standard Deviation (RSD) for replicate analyses of the calibration standard for all measured data varied from 1.5% to 3.0%. The detection limit was calculated from the data of replicate measurements of low concentration samples and observed from their standard deviation. Since one sample site can have multiple visits by a taxi and/or by several taxies, whole data set were normalized for the preciseness of post analytical process.

TABLE I. SENSOR DATA PROTOCOL

Simbols	Data	Unit
LAT	Latitude	Decimal degree(DD.D)
LNG	Longitude	Decimal degree(DD.D)
TEMP	Temperature	°C
HUM	Humidity	$\%RH$
PM1.0	Particulate Matter 1.0	$\mu g/m^3$
PM2.5	Particulate Matter 2.5	$\mu g/m^3$
PM10	Particulate Matter 10	$\mu g/m^3$
O3	Ozone	ppm
NH3	Ammonia	ppm
CO	Carbon monoxide	ppm
NO2	Nitrogen dioxide	ppm
CH4	Methane	ppm
H2	Hydrogen	ppm
O2	Dioxygen	ppm
VOC	Volatile organic compound	ppm
TIME	Collected time	$yyyy-mm-dd$ $hh:mm:ss$
GROUP	Vehicle id	ID

C. Data Arrangement Procedure

At the first trial to map the street dust distribution, we learned that several sources of urban street dust were not correctly collected and arranged in the database (see Fig. 3).

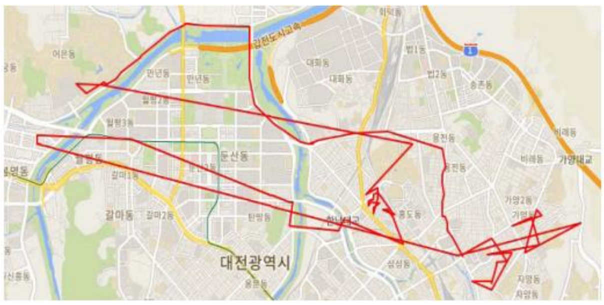


Fig. 3. An example of wrong data set.

One of examples is that there were several unusual jumps which might be caused from the error of GPS sensor or driver's mistake like driving without power-on of the device. Another one is that a missing or abnormal sensing data from some sensors. It happened on very hot day and we believed that hot weather caused malfunction of some sensors. It is assumed that operational environment was extremely degenerated. Thereby, it was required to arrange the whole data set to determine the precision of data analysis. In this work, any data set showed wrong results like above explanation were eliminated. Resultingly, it made blanked sampling sites. Next, any blanked data set were interpolated and connected by polynomial method with data sets of adjacent three sites within 1km (see Fig. 4).

The reason that we chose the adjacent three sites within 1 km range is that the vicinity of the corresponding site within 1 km does not severe differences in preliminary experiments.

However, it was not always able to get interpolation of any blanked site. In this case, we eliminated the data itself. We examined how the data represented some interesting parameters such as PM1.0, PM2.5, NH3, NO2, etc. as shown in Fig. 5.

The results shown in Fig. 5 are not applicable for generalization of urban dust distribution since the example data does not have enough density and regularity. For the purpose of analysis, we developed a new analytic approach to urban dust data set.

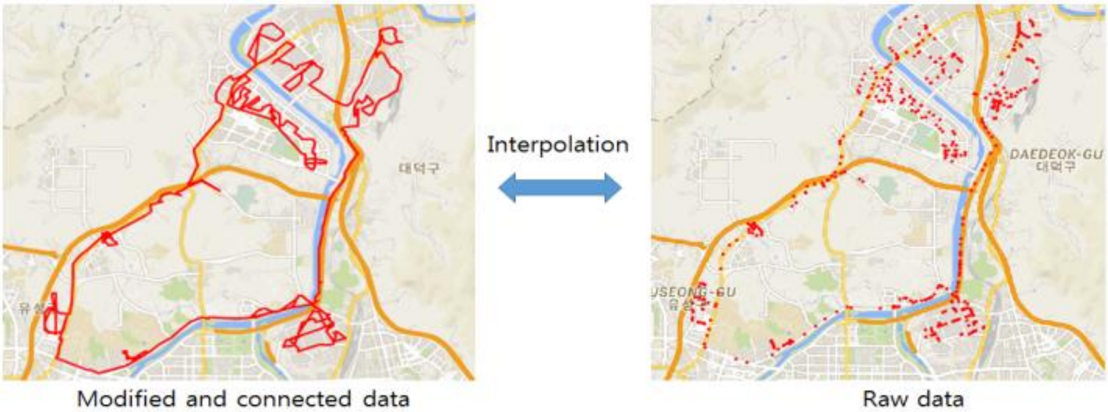


Fig. 4. An example of modified data set.

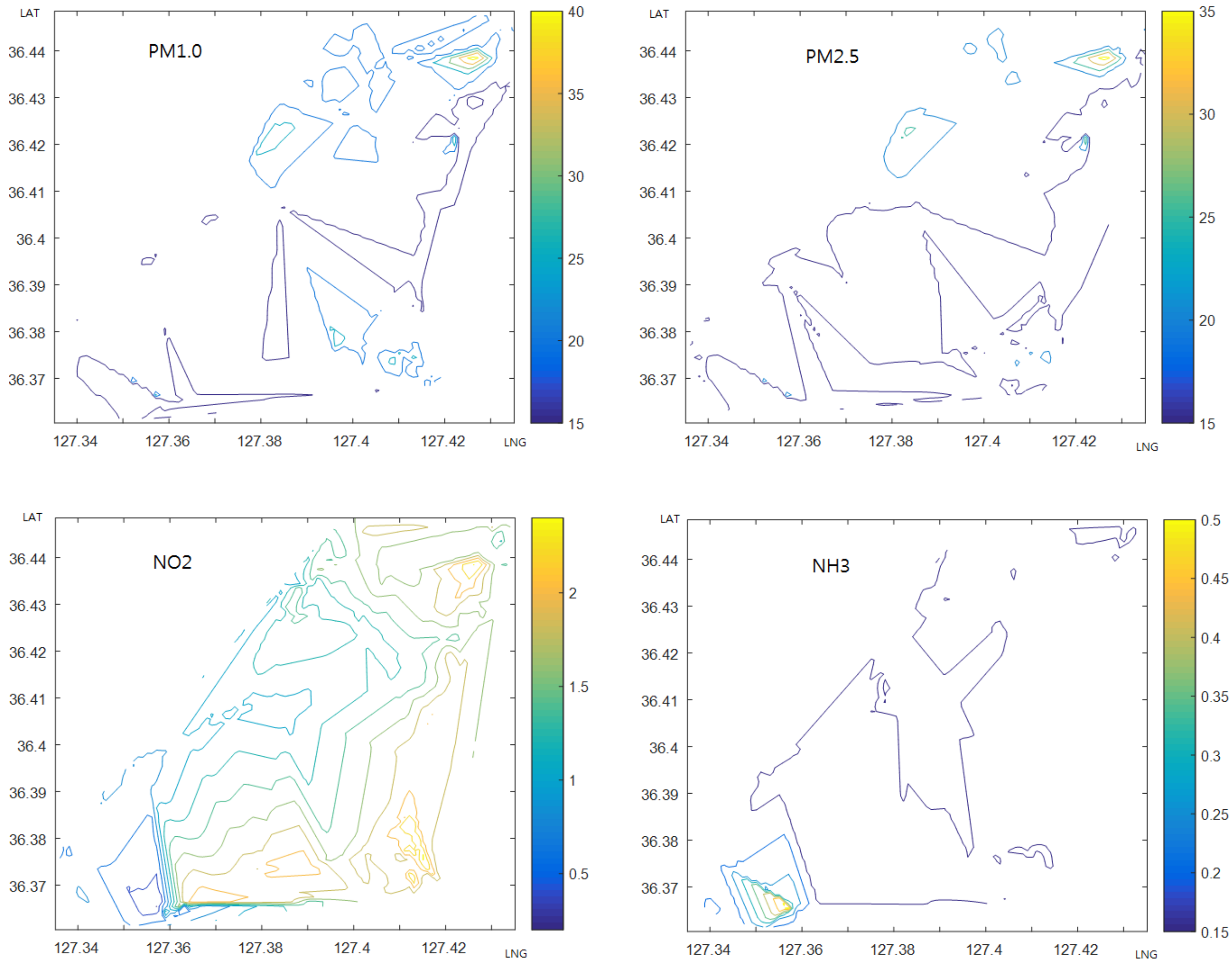


Fig. 5. An example of spatial distribution from modified data set.

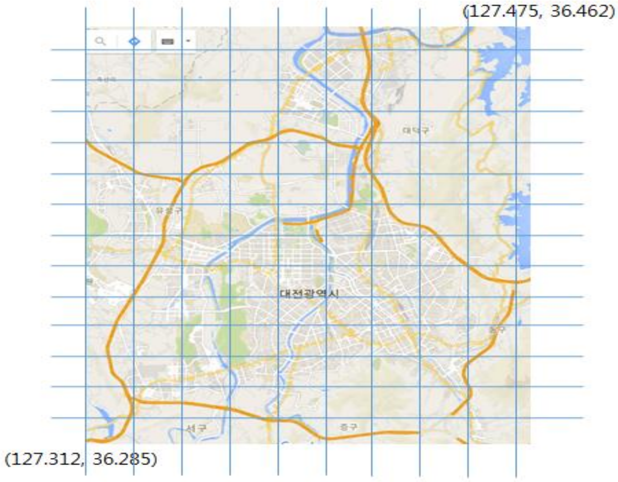


Fig. 6. An example of conceptual divided map.

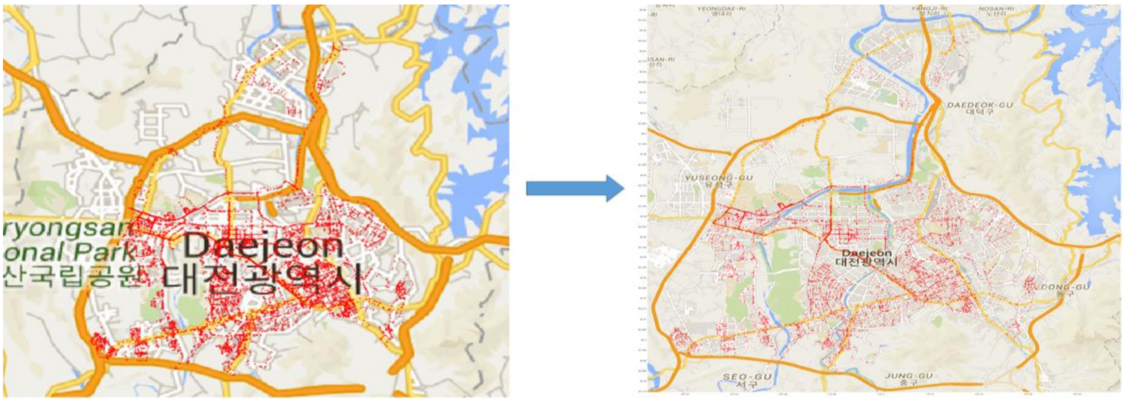


Fig. 7. Left side is the data distribution before normalization and right side is the data distribution after normalization.

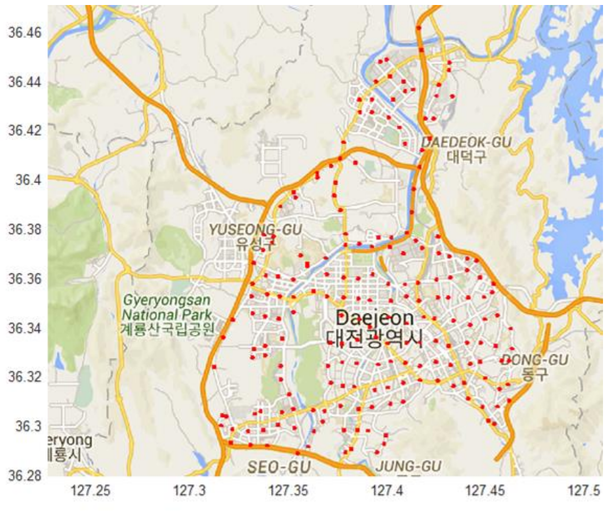


Fig. 8. The finalized data represents the urban street dust on the centroid of each sector.

Firstly, we set the ROI (region of interest); longitude is from 127.312 to 127.475 (about 20 km) and latitude is from 36.285 to 36.462 (about 24 km). Then, we equally divided the area to be unit square (e.g., $1km^2$) for easier management of sectors (see Fig. 6). Totally, the map was divided into 441 cells.

We re-examined whether there is any outlier from ROI and incorrect data such as too higher or lower, and unusual data, etc. Then, we normalized the data since some sectors have one or two visits by vehicles and others have over four times. For the purpose of data consistency, each sector has normalized data. This process reduced the number of data set from 288 million to 28.6 million. Though, as shown in Fig. 7, the data set became enough density for each sector, it was still inconsistent.

Next stage, we determined the centroid data that comes as close as possible to the center point of each sector. Then, each data re-calculated for Euclidian distance (ED) from each centroid data, and any data within ED $<$ 0.001 from a centroid data was accepted as the same group.

We determined ED value for standard deviation to maintain statistical significance such as less than 0.001 [17]. Then the data within a group got together, re-normalized, and reflected into the centroid data. Finally, we successfully extracted 250 representatives from 28.6 million data which are normalized into a centroid of sector and to represent urban street dust information at the corresponding location.

From above analytical data process, we believe that the data from moving vehicles are changed into a kind of static data which represents urban street dust of a localized sector.

We first examined the descriptive statistics of average concentration in Daejeon-city. Table II describes overall concentration of urban dust. We performed correlation analysis using dendrogram for clustering of dust elements which present similar patterns. Finally, we compared with correlation coefficient values between total dust and metrological parameters such as temperature and humidity.

III. Experiment Results

Descriptive statistics for urban street dust are presented in Table II which shows the wide range of values found for each element.

TABLE II. DESCRIPTIVE STATISTICS OF AVERAGE CONCENTRATIONS OF PARTICULATE MATTERS IN URBAN DUST

Head	TEMP	HUM	PM1.0	PM2.5	PM10	O3
Mean	33.67686	34.27289	18.54312	32.11089	34.27843	97.08369
STD	4.008495	9.331403	27.25998	51.23184	51.53775	48.46878
Head	NH3	CO	NO2	CH4	H2	O2
Mean	1.86364	2.116853	1.782683	68.73732	0.250286	19.40835
STD	0.049594	0.568868	0.745513	69.69198	0.106866	2.011157

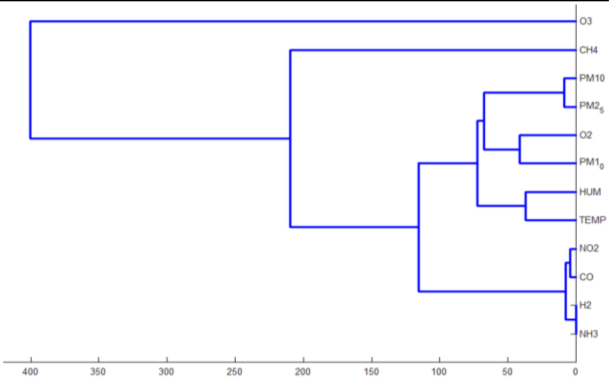
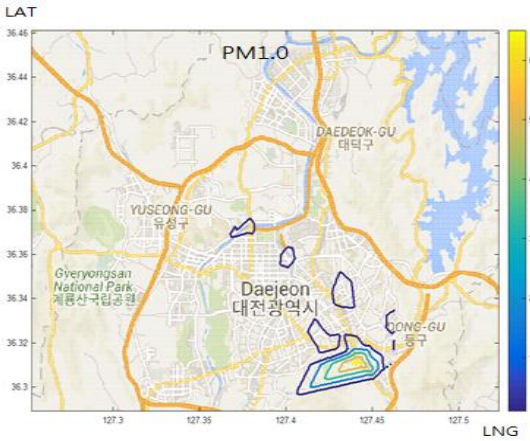
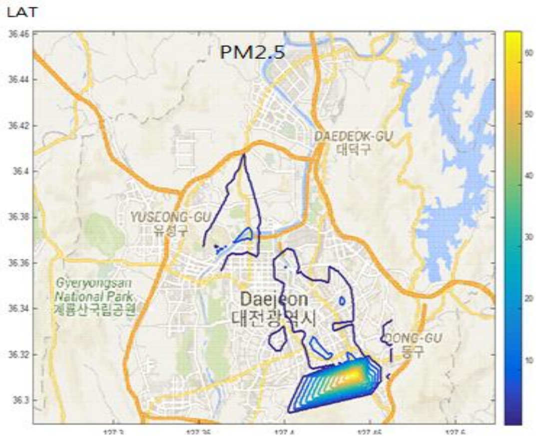


Fig. 9. Dendrogram of clustering analysis, the average concentrations of particle matters in urban street dust.





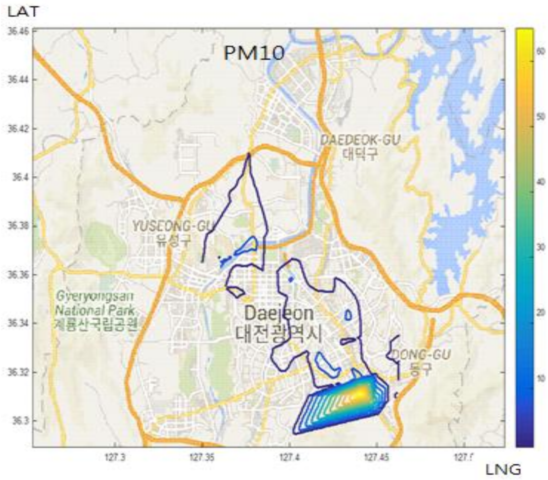


Fig. 10. Spatial distribution of the concentrations of PM1.0, PM2.5 and PM10 in urban dust of Daejeon-city.

Fig. 9 shows a dendrogram of studied variables using cluster analysis. The distance of clusters represents the correlation between the variables. A short length indicates strong correlation and long distance implies weak correlation between the variables. From the dendrogram, it can be drawn that variables are placed in three major groups. The first group consists of NH3, H2, CO and NO2. The second group of metals includes PM1.0, PM2.5 and PM10, and the third group has Temperature, humidity and O2. O3 has considerable relation to all groups.

From the result of clustering analysis, we presumed that there might exist principal components which represent the status of other elements of urban dust since some elements show very strong relationship. Thereby, we performed the principal components analyses (PCA), and PM1.0, PM2.5 and PM10 are very strong component (about 56.1% of the total variability, and justified about 99.8%).

The maps of Fig. 10 show that the south-eastern area of Daejeon-city has the highest concentrations of PM1.0, PM2.5, PM10, specifically near the backward region which has lots of dilapidated dwelling as well as deficiency of infrastructure and environment facilities such as green spaces and well-constructed road networks.

In this work, the collection of urban street dust was performed during summer season. It is not enough for finding any correlation between urban street dust and metrological parameters such as temperature, humidity, wind speed and precipitation. Therefore, we needed more long term data to see any significant variation of urban street dust according to metrological conditions.

Additional wind speed data for twelve months (Jan. to Dec.) were achieved from the national metrological environment service in Korea and urban street dust data were gathered for corresponding period from the national statistics office [14].

According to Table III, the correlation between the total street dust concentration and temperature, wind and precipitation is significant, but between the concentration and humidity is not significant.

TABLE III. CORRELATION ANALYSIS BETWEEN URBAN STREET DUST CONCENTRATION AND METROLOGICAL PARAMETERS

Correlation	R	P-value
Street dust concentration		
Temperature	-0.425	0.028
Humidity	0.231	0.363
Wind	-0.363	0.029
Precipitation	0.725	0.032

According to the analysis results obtained from the urban street dust in this research, the average concentration of PMs in overall 2 months of sampling was 27.97 (ug/m2) for PMs. It is very lower than the standard AQI (Air Quality Index). Other elements have also lower than AQI or satisfactory level except CO.

By using the one-way analysis of variance (ANOVA) test, it was drawn that there is a meaningful deference between various times of sampling. The highest concentration was corresponded to winter season and the least was related to summer. As compared to Korea government opened information, the results are quite meaningful (see Fig. 11).

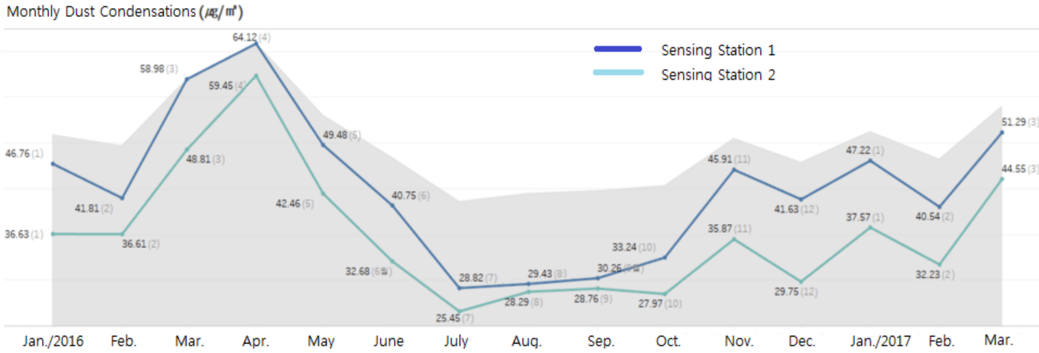


Fig. 11. Spatial distribution of the concentrations of PM1.0, PM2.5 and PM10 in urban dust of Daejeon-city (Courtesy by Korea Environment Office).

The correlation factor between urban dust concentration and temperature (*r*=–0.425), indicates the invert association between them. It means that when temperature increases, the amount of urban dust concentration decreases and vice versa. As can be seen, the highest concentration during March and April was appeared and severely increased.

It might be due to the start of educational programs, and therefore an increase in transportation might raise urban street dust concentration.

As a car runs, friction between the tires and road produces dust and the brake pad is worn each time the brake is applied. Dust like rubber shavings from tires, emissions of vehicles, resuscitation of urban dust, and particles along with road traffic in urban areas are the most important sources of urban dust concentration.

The second semester is started for two weeks from the last week of Aug and the first week of Sep. However, as shown in Fig. 11, it is very windy in autumn season (Sep to Oct) in South Korea and that is the reason for lower urban dust concentration for that period. It is also well-matched with the correlation of wind speed (see Table III).

In a study which was performed in [18], a negative meaningful association was observed between dust falls and windy autumn season. However, three stations reported cold wave (defined as a temperature drop over 10℃within 24 hours or over 12℃ within 48 hours) in the first week of Oct. Such cold air masses from the North Pole and when cold air breaks out from the North Pole, moves southwards, and meet a warm air mass. This phenomenon generally followed by fierce winds and a fall in temperature. It leads to a vigorous convection in the atmosphere and eventually creates strong gusty winds which is an important factor for dust storms to occur [19]. Therefore, it is possible to explain the reason for rising of dust concentrations from Oct.

IV. CONCLUSION

In this paper, we described the spatial distribution of urban street dust concentration in Daejeon-city and identified those areas of higher concentration of interesting particulate matters within the city using sensing data which have been gathered by multiple sensors which are installed on mobile vehicles.

Since the raw data set was not enough for data analysis with a certain of consistency, this work proposed a new technique for arrangement and refinement of the data. The spatial distribution of the urban street dust has several trends: higher concentrations in near industrial areas and lower concentrations in residential areas and parks.

We also investigated with one-way ANOVA test to find any correlation between metrological parameters and urban street dust concentrations. There are significant association between variables such as temperature, wind speed, precipitation and urban street dust concentration. Finally we suggested these correlations have similar trends with respect to official information from a national information service institute.

The proposed approach can be used for a regular monitoring system to assess the street dust quality and if IoT based sensor devices will be developed and installed to the vehicles, the information of air pollution status across the city will be provided in real time.

ACKNOWLEDGMENT

This research was funded by a 2019 research Grant from Sangmyung University.

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