PM2.5 MAPPING WITH PORTABLE SENSOR DEVICES AND LOCATION MAPPING

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KEYWORDS: Air pollution, mobile sensing, light weight device, fine particle.

ABSTRACT: PM2.5 is considered as one of the most crucial components contributing to local air pollution but so far, few studies have analyzed the role and the importance of this fine particle within micro-environment. There have been various techniques applied to monitor air quality, such as: network of fixed station, air pollution sensors or even remote sensing technology. Although these approaches have achieved certain results, they are still quite expensive, inflexible or just available for large scale study. Fine particle mapping with portable sensor device which is called Compact PM2.5 sensor might be the answer for this challenge. This equipment, that has small dimension and light weight, can provide PM2.5 concentration and GPS Position Data at the same time, thus it can be noted as a novel method in air pollution research, especially local pollutant. Objective of this study is PM2.5 mapping by this device and preliminary analysis the effects of traffic and meteorological factors like wind speed. The sampling campaign was conducted in two campuses of the University of Tokyo in Komaba, Meguro district, Tokyo for 17 days. Our findings show that the concentration of PM2.5 is surprisingly varied along time and location. Moreover, the trend that is expressed by measures from portable sensor is consistent with the ones provided by fixed station even the gap between two dataset is noted. However, the negative correlation between wind speed and value of fine particle is not clearly seen. In addition, the analysis basing on the segmentation of study area expressed the different extents that traffic influences 10 sub regions in two campuses. In near future, we plan to include this special dataset in diffusion or dispersion models for further study about the impacts of traffic and meteorological factors.

1. INTRODUCTION

1.1. Background

With nitrogen dioxide (NO2) and PM10, PM2.5 is consider as one of the most crucial components contributing to local air pollution which is the reason of causal acute effects on resident but so far, few studies have examined the role and the importance of this fine particle within the micro-environment. As a result, finding the roots of particulate matter within local scopes is an essential and urgent demand. In Japan, air pollution used to be a severe problem but thanks to strong regulations of government, air quality has improved strongly in recent decades. According to the Environment Quality Standard (EQS) of Japan which was established in 2009, the annual standard for PM2.5 is less than or equal to 15.0 µg/m3, and the 24-h standard is not higher than 35 µg/m3. In fact, the portion of emission from automobiles and the environmental concentration of PM2.5 has fallen dramatically, but still exceeds the EQS, especially in big cities like Tokyo, Osaka.

The traditional method for air pollution monitoring is basing on network of stations which provide reliable, near real time measurements but not applicable for local pollution. Similarly, satellite image with the large coverage is an emerging method in this field but their spatial and temporal resolution are too coarse for pollutant study and the accuracy is quite limited because sensors are not feasible to measure surface air quality. For short-term, timely and local monitoring goals, portable device integrating with high accuracy location technology is new trend and promising approach which can be solution for the difficulties in local pollution research. Mobile sensors used to be heavy, bulky, and expensive with low accuracy but thanks to the strong support of GNSS technology and the improvement in manufacture, at this moment they are quite potential because of many convenience: light weight, being able to measuring and mapping personal environmental pollution in real time, affordable prices and being able to produce high spatial and temporal resolution data. Consequently, a wide range of applications have been provided such as: Personal exposure monitoring and crowdsource pollution mapping, assessing the (spatial and temporal) variability and dynamics of air pollution, hot-spot identification and high resolution air quality mapping in urban environment.

As a result, this equipment is becoming increasingly popular in both of commercial aspect and research field, especially in European and American countries. Many research have taken its advantages, such as studies of Bart Elen et al (2013), Joris Van den Bossche et al (2013), Michael E. Deary et al (2015) and Admir Creso Targino et al (2016), etc. Noteworthy, Environmental Defense Fund (EDF) and Google Earth Outreach have joined in a project for mapping Hyperlocal Air Quality. They established a mobile measurement team using the Aclima platform in the cars to assess air conditions in real-time in Oakland, America. They concluded that their air pollution mapping is 100,000 times greater than the one using conventional monitors regarding spatial resolution. Although these studies have achieved certain achievements and the uniqueness, the potential of portable devices are incontrovertible as well, the number of research on application of this equipment is quite limited in quantity and quality because of some reasons. Urban air pollution is more variable than previously expected extremely, with air quality changing over time and location rapidly. Its relations with emission rate, meteorological factors and geographical features are very complex and have been the big challenges for scientists and researchers. Studies exploiting light weight sensor have ever stopped at temporary air condition mapping virtually and the further analysis about influence factors or hot spots determination with high accuracy are quite few. In this situation, big data combining with machine learning or neural network approach can be an innovative air-pollution assessments.

1.2. Objective

Significant factors that have been proven to influence the spatial extent of local air pollution is: local and regional geographical features, the source of pollution, kind of pollutant, background concentration, emission rate, and meteorological factors [12] In many research, emission rate has been quantified by a number of proxies such as distances to the main road, traffic counting and road pattern. Meanwhile, meteorological factors relating to local pollution include air movement, wind speed and direction, temperature, humidity, rainfall and solar radiation. The role of these micro climate components were considered in simple Gaussian equation which calculates the downwind concentrations for an inert pollutants: $C = \frac{2Q}{\sqrt{2\pi} U \sigma_z}$ [10] In which C is the downwind concentration (µg/m^3), Q is the source strength per unit distance (µg/(m.s)), U is the average wind speed (m/s), and σ_z is the vertical dispersion coefficient (m). So this equation implied that a decrease in wind speed couples with an increase in pollution level.

In 2016, Mitsubishi Electric Corporation introduced High-precision Air-quality Sensor for PM2.5 and they called it "World's first air quality sensor can distinguish PM2.5, pollen and dust". With the dimension of 67mm x 49mm x 35mm, this device measures the scattered light from PM2.5 particles by unique double-sided mirror design [14]. Besides, there has been another light weight compact PM2.5 sensor developed by Nagoya University and Panasonic Corp. The objective of this study is to map PM2.5 by this device and preliminary analysis the impacts of traffic and meteorological factors like wind speed on PM2.5 concentration with hypothesis are:

- Light weight device is able to map PM2.5 values along time.
- The concentration of PM2.5 and wind speed have inverse relationship
- Traffic cause the increase in PM2.5 value.

2. METHODOLOGY

2.1. Study area

To conduct the experiment, University of Tokyo campuses in Komaba, Meguro district, Tokyo (including Komaba I and Komaba II campuses) were chosen to be study site. The area of Komaba I campus is around 30ha, Komaba II is 10 ha approximately and there are different roads interleaved with resident area surrounding two campuses. We measured PM2.5 while walking, and covered two campuses from August 10th to September 10th on non-rainy days with the same route and in the same time frame (from 8.30 to 10.30 am in the morning and from 14.30 to 16.30 in the afternoon). And apart from 17 days of measurement (Tab. 1), we took advantages of hourly meteorology data and PM2.5 concentration provided by fixed monitoring stations (Himonya, the nearest station in the same district, about 4.5 km away from campuses) which is published by Ministry of Environment of Japan via this link: http://soramame.taiki.go.jp/Index.php

2.2. Instrument and data processing

In this research, we used compact PM2.5 sensor which is developed by Nagoya University and Panasonic Corp. Basically, this device comprises PM2.5 sensor and wifi transmitter with power bank is mobile battery. With the dimension of 52 x 45 x 22 mm, quite light weight, the equipment uses photo-detector, stray light and LED Light to estimate PM2.5 concentration basing on the radiation scattered by the particle (Fig.1) Regarding the reliability, this sensor was verified by comparing with Beta attenuation monitoring (BAM) instrument data in Tokyo Metropolitan Research Institute for Environmental Protection for 7 months (24h average, Sept. 2016 - March 2017) and its result expressed quite high correlation (R^2= 0.911) [11] In terms of geo location data, it uses application working on Android platform named GPS logger to log latitude, longitude with a temporal resolution of 10s. The time interval of PM2.5 sensor and GPS logger are assimilated and data were transmitted to computer via blue tooth connection. So in compare with other portable sensors mounted in cars or bicycles, this device has advantages of small dimension, light weight so it is very convenient to be carried personally.

The value of PM2.5 and geo location data were synchronized by coincident time stamps. Moreover, to analyze the impact of roads surrounding campuses, we segmented study area into 10 sub regions by 100 m buffer around each road (Fig.2). The buffer method is one of the most popular approach regarding GIS analysis in air pollution research. The distances to nearby road were used for buffering in many studies are usually within 100, 300, 500 and 1000 m [8] In this study, due to the area of study site, we created the buffer zone of 100m around the roads. Among 10 regions, K1a is corresponding to the outer patch of Komaba 1 Campus, which is next to the small street named Komaba. Meanwhile, K1b is the northern area influenced by the main road and its western part is very close by this road. K1c is located between campus and the biggest two-way road names Yamate and K1d is the segment which is next to small path in the South East of campus. Likewise, Keio railway passes by K1e region and K1f is the innermost part of Komaba1. Regarding Komba2, in the Northern area of campus - K2a, the measurements conducted are pretty far from the main road. Besides, K2b is responsible for the patch next to another small street named Komaba also. K2c is the nearest segment of this campus from the railway and K2d is kernel region of Komaba2. More specifically, in Komaba1, some areas in the border such as K1a, K1b are covered by sport yards while other patches has different types of buildings and infrastructure, especially the innermost parts. Additionally, apart from the roads, campuses are surrounded by resident area interleaved with scatter vegetation, typically in K1a, K1c, K2c and K2d.

3. RESULTS AND DISCUSSIONS

3.1. PM2.5 mapping

For further analysis, we removed the outliers of datasets and estimated the daily spatial average values. At the same time, only measurements conducted inside the campuses were considered. Fig.3 showed PM2.5 map for two campuses on September 6th in the morning. So via this map, the hot spots of air pollution and the spatial distribution of PM2.5 within 2 hours can be seen clearly. However, the concentration of PM2.5 varied greatly among sampling days and between the morning - afternoon as well (Tab.2). Within measuring time, value of fine particle continuously changed also, the high standard deviations (SD) are indicators for large variability in our datasets. For example, in the morning of September 3rd, PM2.5 concentration was 11.32 ± 6.1 μg/m3, implying that SD value accounted for more than 50% of mean. Notably, according to EQS of Japan, the daily standard is 35 μg/m3, but sometimes the measurements exceeded this threshold like September 7th and September 8th, so the frequent monitoring and long term research on local pollution is still necessary. Furthermore, the average of PM2.5 concentration provided by fixed station was compared with the ones measured by portable sensor which were represented by daily mean values also (Fig.4) The results expressed quite strong positive correlation with high R coefficient (R=0.8019), thus the exploiting this source of information to estimate the background pollutant is potential. However, the gaps between two dataset were noted. The reason of this phenomenon is the different in monitoring approach between traditional fixed station and portable device, so the verification of concentration which small sensor provides by values obtained from fixed stations needs to be considered very carefully. However, it can be said that the pattern of daily change in PM2.5 concentrations that compact sensor provided is consistent with the trend obtained from monitoring station.

3.2. The impact of wind and traffic

According to Gauss's equation, the downwind concentration of fine particle has linear negative relation with wind speed so we conduct the direct comparison between two datasets but R value is low, just 0.3024 (Fig.5). Some days, in calm wind condition, the values of PM2.5 were not so high, like September 9th and September 6th but on August 24th, when wind speed suddenly gets high, their inverse link was clear (Tab.1). This results shows that the actual mechanism is much more complex, not follow the linear correlation and the influences of other factors like wind directions, air flow or air temperature should be considered. Accordingly, the dispersion model proposed by Gauss needs to be improved and included more input.

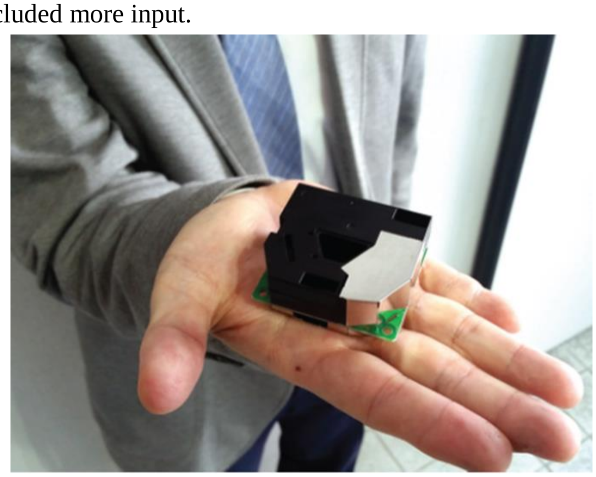


Figure 1. Compact PM2.5 sensor provided by Nagoya University

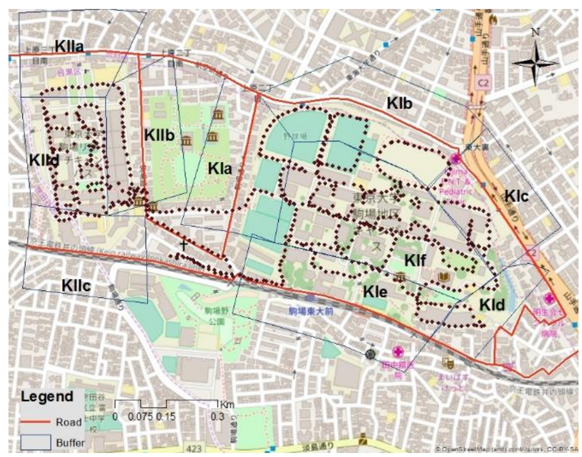


Figure 2. Study site and 10 sub regions after segmentation by buffering 100m from roads.

Regarding the impacts of roads on air quality inside the campuses, Fig.6 showed the spatial mean values of PM2.5 concentration for 10 sub regions in the morning of 10 days (from Aug. 25th to Sep. 10th) and in the afternoons of 2 days (Aug. 21st and Aug. 17th)(the afternoon is marked by blue frame and weekends are marked by brown frames) Firstly, on some days, fine particle values are quite varied among different areas such as Aug 21st, Aug 25th, Aug 30th, Sep 3rd, Sep 7th and Sep 8th. And the higher PM2.5 concentration is, the bigger gaps among parts are observed like Sep 7th and Sep 8th. However, the sudden high patterns in all the segments which were observed on these two days are consistent with high concentrations that are provided by fix station. Consequently, it is not supposed to be the result of local effects, so it is not discussed here. Noteworthy, K1b emerged like a hot spot while K2d, K2c, K2b expressed the lowest values of PM2.5 on many days.

No	Date	Mean of PM2.5 (µg/m3)	Standard deviation of PM2.5 (µg/m3)	Air temperature (℃)	Wind speed (m/s)
1.	10-Aug Afternoon	32.955	6.89	28	5.1
2.	17-Aug Afternoon	8.78	2.589	27	3.6
3.	21-Aug Afternoon	26.74	6.365	30	3.1
4.	23-Aug Afternoon	8.396	4.579	32	4.6
5.	24-Aug Afternoon	16.162	4.399	33	7.2
6.	25-Aug Morning	29.19	5.9	32	3.6
7.	28-Aug Morning	18.48	1.1844	28	3.6
8.	29-Aug Morning	12.79	3.63	31	4.8
9.	30-Aug Morning	32.46	4.657	32	1.4
10.	1-Sep Morning	6.49	3.28	25	3.7
11.	3-Sep Morning	11.32	6.1	26	3.9
12.	5-Sep Morning	18.25	4.617	26	3.2
13.	6-Sep Morning	22.58	3.1779	23	1.3
14.	7-Sep Morning	70.971	23.663	24	1
15.	8-Sep Morning	75.866	24.726	26	2
16.	9-Sep Morning	14.7413	3.721826	27.5	1.5
17.	10-Sep Morning	18.050	8.6682	26	2

Table 1. Summary of measurement results and the meteorological conditions during the sampling days

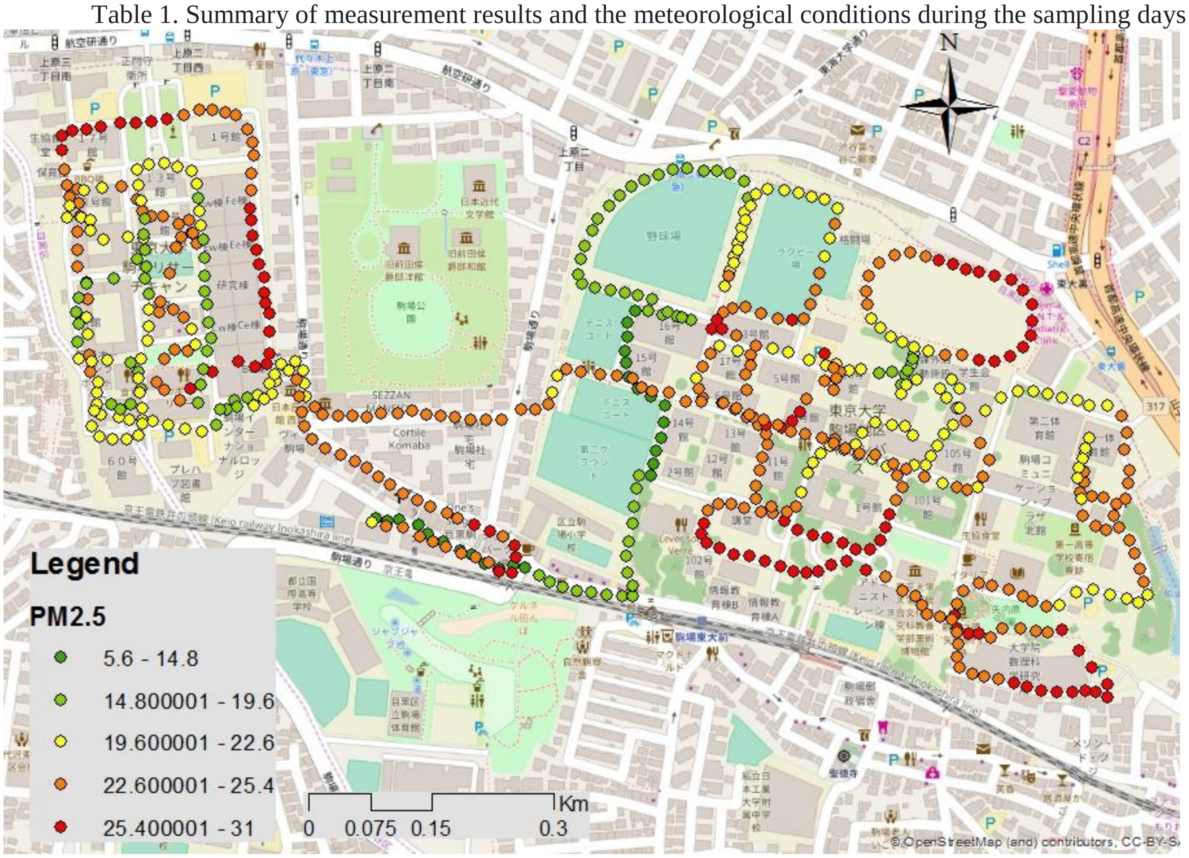
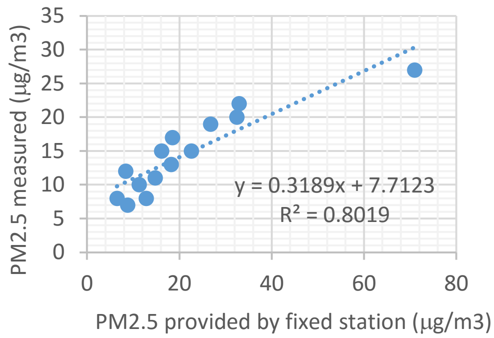


Figure 3. PM2.5 map for Komaba campus on September 6th (µg/m3)

This phenomenon is easy to understand. As mentioned above, K1b is the patch which is very close by the main road. Furthermore, its land cover is yards mainly, so the absence of high building leads to stronger impact of traffic on air quality in this zone. K2d is innermost region of Komaba 2 campus, so it explains why the concentration of PM2.5 here is lower. In terms of K2c, where railway crosses by, and the measurements are conducted not so close to the railway, thus somehow the air quality is better than other areas also. Likewise, K2b is the part which is influenced by the small street named Komaba where traffic flow is much lower than main road, so in the graph, its curve is one of the lowest, and lower than K1a, where a similar street passing by. The difference in land cover between these two segments can be the answer.

The dominate cover in K1a is sport yards, like K1b, but in K2b, there is a tall building located between the street and small path inside the campus where data were collected.



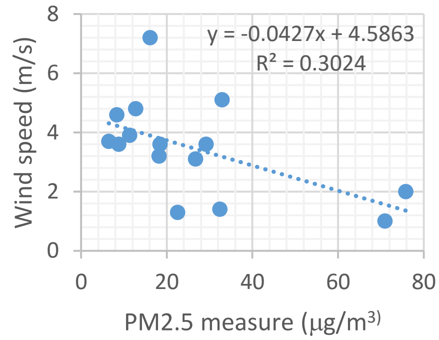


Figure 4. The correlation between PM2.5 measured by portable sensor and PM2.5 obtained from fixed station.

Figure 5. The correlation between PM2.5 measured by portable sensor and wind speed

In the weekend, not so high value of fine particle recorded somehow implies that the air quality is better than almost of weekdays. Specifically, the first Saturday and Sunday of September show fairy consistent concentrations among 10 segments. Accordingly, this change is the result of the difference in human activities between weekdays and weekend which leads to their inconsistent impacts on air quality inside the campus. Besides, the pattern of PM2.5 concentrations in the afternoon does not show the distinction from the ones measured in the morning.

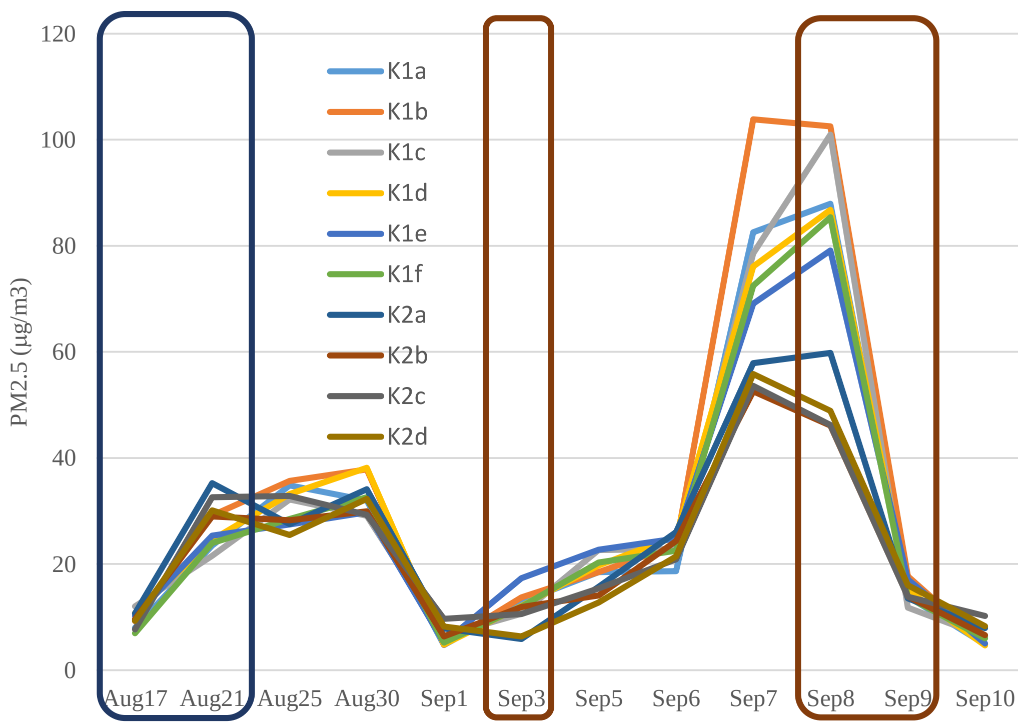


Figure 6. Mean values of PM2.5 concentration in 10 sub regions in the morning of almost one week (from September 3rd to September 9th) and in two afternoons on Aug. 21st and Aug. 17th.

4. SUMARY AND CONCLUSIONS

The result proved that compact PM2.5 sensor was successful in PM2.5 mapping within two campuses. Similar to other research on air pollution in micro environment, our findings show the high extent of variability in fine parrticle concentration along time and location. Besides, the results of this study express the similar trend with the measurements that obtained from traditional monitoring station with high correlation index, even the gap between two data set is observed. However, the negative relationship with wind speed which is considered as the main meteorological factor influencing to local pollutant is not clear. On the other hand, the analysis basing on segmentation expressed the effects of road on air quality inside the campus. On weekdays, K1b is the region where the high concentration of PM2.5 were recorded often. The reason is: this area is quite close to the biggest street. Other parts having the lowest values of fine particle are either innermost segment or the one not so close to the main road or the zone having railway passing by, not the streets having many vehicles. In addition, the different in land cover somehow explain the change in the impact of traffic on air quality inside two campuses. Accordingly, the patches where sport yards are dominate land cover show the clearer effects of surrounding roads which are assumed as the main source of local pollution.

In near future, we plan to conduct more measurements for further time series analysis of air quality within micro environment. More daily and more frequent data will facilitate the hot spots detection in weekdays and weekend with higher accuracy. In addition, the exploiting our data set in diffusion models or dispersion models with other kinds of inputs in terms of meteorology, land use/ land cover and traffic is expected to quantify the impacts of these factors on local air quality. Again, the influence level needed to be discussed more because of some reasons. Firstly, air quality depends on not only traffic and road pattern. Inside the campus, many other factors can change the pollution like the distribution of buildings, the ventilation of buildings and several mobile pollution sources as well. Moreover, because the human activities inside the campus are not the same between weekdays and weekend so this difference should be explored in a deeper and more comprehensive way also. And another direction that we want to study in next step is finding the method for verification these findings, although the preliminary results sounds quite promising and potential.

Acknowledgement

This research used light weight compact PM2.5 sensor provided by Nagoya University so the authors thank Prof. Yukata Matsumi, Nagoya University for his help with device.

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