Journal of Environmental Science International
28(10); 831~840; October 2019
pISSN: 1225-4517 eISSN: 2287-3503
https://doi.org/10.5322/JESI.2019.28.10.831

ORIGINAL ARTICLE

Analysis of the Correlation between Urban High Temperature Phenomenon and Air Pollution during Summer in Daegu

Eun-Ji An, Hae-Dong Kim*

Department of Global Environment, Keimyung University, Daegu 42601, Korea

Abstract

Recently, summer high temperature events caused by climate change and urban heat island phenomenon have become a serious social problem around the world. Urban areas have low albedo and huge heat storage, resulting in higher temperatures and longer lasting characteristics. To effectively consider the urban heat island measures, it is important to quantitatively grasp the impact of urban high temperatures on the society. Until now, the study of urban heat island phenomenon had been carried out focusing only on the effects of urban high temperature on human health (such as heat stroke and sleep disturbance). In this study, we focus on the effect of urban heat island phenomenon on air pollution. In particular, the relationship between high temperature phenomena in urban areas during summer and the concentration of photochemical oxidant is investigated. High concentrations of ozone during summer are confirmed to coincide with a day when the causative substances (NO2,VOCs) are high in urban areas during the early morning hours. Further, it is noted that the night urban heat island intensity is large.. Finally, although the concentration of other air pollutants has been decreasing in the long term, the concentration of photochemical oxidant gradually increases in Daegu.

Key words : Urban heat island, Heat stroke, Heat wave, Photochemical oxidant

1. Introduction

Recently, heat waves have turned into a serious problem worldwide. The primary causes of heat waves are global warming and urbanization. Therefore, these two factors must be controlled to mitigate heat waves. The industrial revolution began when humans obtained the energy required for production activities from fossil fuels. The population growth from approximately 300 million at the beginning of industrial revolution to 7.2 billion today can also be attributed to fossil fuels. Although the human race is able to lead a comfortable life due to the presence of fossil fuels, it is being done at the cost of carbon dioxide emissions, which result in global warming and heat waves (Yoshino, 2010; Kwon et al., 2018; Park et al., 2018).

The other cause of heat waves is urbanization. The main cause of urban heat islands is the disappearance of soils and greeneries due to the increase in asphalt roads and concrete buildings. Artificial structures absorb and store more solar energy during the day, which is called ‘heat capacity increase.’ Due to this, the surface temperatures of cities are always higher

Received 25 September, 2019; **Revised** 29 October, 2019;
Accepted 29 October, 2019
***Corresponding author**: Hae-Dong Kim, Department of Global Environment, Keimyung University, Daegu 42601, Korea
Phone: +82-53-580-5930
E-mail: khd@kmu.ac.kr

than those of suburbs (Hujibe, 2012). The urban heat island phenomenon is not just limited to increasing temperatures in urban areas, but is also related to changes in various meteorological elements such as wind speed, humidity, cloud cover, and solar radiation (Mizukoshi and Yamashita, 1993). The albedo of urban areas is declining due to an increase in the number of asphalt roads and buildings with low reflectivity. The presence of buildings affects the rate of heating by changing the surface albedo. Dark-colored buildings absorb more sunlight than lighter ones, and in general, urban surfaces (asphalt streets, roofing materials) have lower albedo than the natural surfaces that they replace (Aguado and Burt, 2001).

Such changes in urban weather conditions affect the frequency and intensity of air pollution. The temperature rise due to global warming accelerates ozone generation at ground level. The increase of ozone concentration appears more conspicuously in cities with dense population, high traffic, and several industrial facilities (Nishioka and Harazawa, 1998).

The study by Takahashi et al.(2008) is well known for analyzing the problem of global warming and photochemical oxidants. They investigated the relationship between the state of photochemical oxidants and temperatures, and found that the possibility of high-concentration photochemical oxidants is higher when there is a rise in temperature. However, the generation of photochemical oxidants is not just affected by temperature, but also by other meteorological elements such as wind speed and the emissions of primary pollutants. Hence, high temperatures do not necessarily cause high pollutant concentration events.

In this context, our study investigates the seasonal temperature rise tendencies over recent 10 years in Daegu, South Korea and examines the effects of meteorological elements on the occurrence of high-concentration ozone events at ground level. The obtained results can be used as the basic data for promoting plan establishments for mitigating urban heat islands as well as high ozone concentration at ground level.

2. Materials and Methods

The study used the air pollutant concentration data (from nine sites) collected by the Daegu Regional Office of Meteorology and Daegu Health and Environment Research Institute for 10 years (2008 – 2017). Fig. 1 shows the nine air pollution observation sites and the meteorological observation sites of the Daegu Regional Office of Meteorology. Table 1 provides the detailed information about each site shown in Fig. 1.

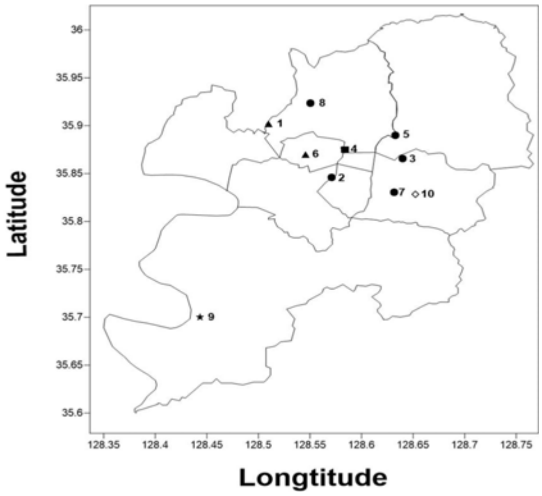

Fig. 1. The locations of air pollution observation sites and geographical characteristics in Daegu.
●, Residential area; ■, Commercial area; ▲, Industrial area; ★, Green area; ◇, Automated Synoptic Observing System.

The air pollution data used for analysis give 1-hour average concentrations of NO_2 and O_3. For the study, we analyzed the seasonal distribution and temporal change characteristics of the excess frequency of environmental standards for ozone concentration that is gradually increasing among the general air

Table. 1. The locations of air pollution observation sites and weather station

No.	Site	Location
1	Nowon	31, 3gongdan-ro 14-gil, Buk-gu
2	Daemyung	55, Seongdang-ro 30-gil, Nam-gu
3	Manchon	1000, Gukchaebosang-ro, Suseong-gu
4	Suchang	30, Dalseong-ro 22-gil, Jung-gu
5	Sinam	92, Ayang-ro 37-gil, Dong-gu
6	Ihyeun	135, Gukchaebosang-ro, Seo-gu
7	Jisan	209, Muhak-ro, Suseong-gu
8	Taejeon	56, Chilgokjungang-daero 52-gil, Buk-gu
9	Hyeonpung	147, Hyeonpungseo-ro, Hyeonpung-eup, Dalseong-gun
10	ASOS	10, Hyodong-ro 2-gil, Dong-gu

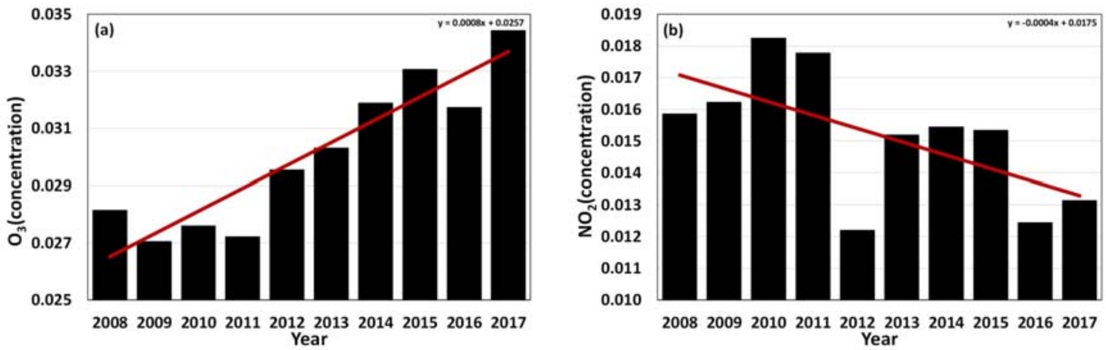

Fig. 2. Trends of annual average O_3 (a) and NO_2 (b) concentrations at 9 observation sites.

pollutants. Further, the increasing trend of ozone concentration with an increase in temperature was analyzed and the correlation-regression relationship between them was examined. Furthermore, the correlation-regression relationship between temperature and ozone concentration while excluding the effects of wind speed and cloud cover, which are representative meteorological factors, was investigated to determine their effects.

3. Results and Discussion

3.1. Annual change trends of ozone concentration

Fig. 2 shows the ozone concentrations and the annual average concentration of NO_2, known as the precursor of ozone, measured at the nine sites for recent 10 years. It is worth noting that the concent -ration of NO_2 shows an increasing trend from 2008 (0.028 ppm) to 2011 with high concentration, whereas the ozone concentration is low and shows a slightly decreasing trend each year.

However, the ozone concentration changes to an increasing trend from 2012 onward, while the NO_2 concentration begins to decrease. In 2012, the ozone concentration increased sharply to approximately 0.0295 ppm and then, showed a gradually increasing trend every year. The annual average ozone concentration in 2017 was 0.0344 ppm.

Therefore, it can be understood that there is another factor apart from the concentration of the precursor of

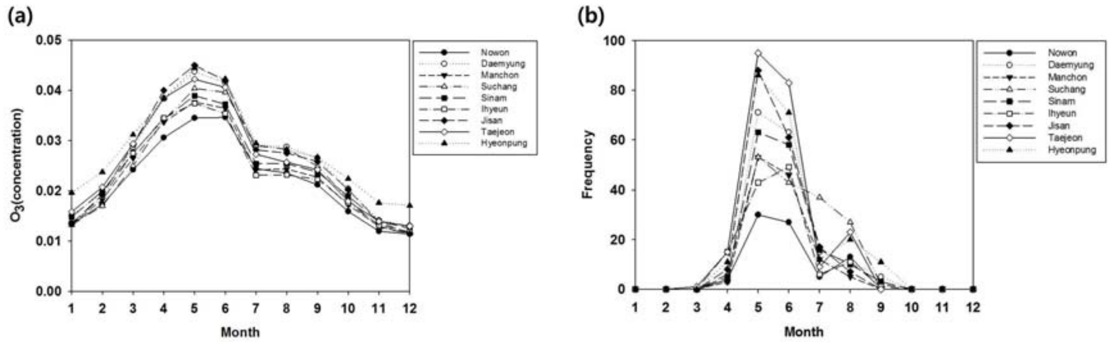

Fig. 3. 10-year average of ozone concentrations by region and month (a) and excess frequency of environmental standards (b).

ozone that causes the increasing trend of ozone concentration contrary to the decreasing trend of NO_2 concentration.

The increase in the ozone concentration, along with the high temperature phenomenon, during summer is emerging as critical environmental problems. To examine the seriousness of the ozone concentration in Daegu, the 10-year average monthly ozone concent -rations by site and the excess frequency of environ -mental standards are analyzed, as shown in Fig. 3.

During the examination of the ozone concentration level at each site, Hyeonpung showed the highest concentration of 0.0286 ppm and Nowon showed the lowest concentration of 0.0219 ppm. When the sites are listed in descending order of 10-year average ozone concentration, we get Hyeonpung > Daemyeong > Jisan > Taejeon > Suchang > Sinam > Ihyeon > Manchon > Nowon. For the 10-year average of monthly ozone concentrations, the month of May showed the highest average of 0.0405 ppm, and the concentrations ranged from 0.0345 ppm to 0.0450 ppm. The month of December showed the lowest average of 0.0126 ppm, and the concentrations ranged from 0.0170 ppm to 0.0114 ppm. Hyeonpung showed the highest 10-year average, but Jisan showed the highest monthly ozone concentration. The reason for the high ozone concentrations in Jisan and Hyeonpung can be attributed to the large discharge of natural volatile organic compounds owing to the several forests in these areas. Large amounts of catalysts (hydrocarbons) are emitted from suburban areas where forests and agricultural lands are abundant, enabling ozone generation. Therefore, ozone concentrations are often higher in suburban downtown areas (Kim et al., 2014).

The atmospheric environmental standard of ozone concentration is 0.1 ppm or lower for 1 hour, on average. Fig. 3(b) shows the excess frequency of this standard at each site. The month that had the largest excess frequency of the environmental standard for 1-hour, on average, was May, where the average frequency was 65 times the average for all observation sites, followed by June. The observation site that showed the highest frequency in May was Taejeon with 95 times the average, while Nowon showed the lowest frequency with 30 times the average. In June, Taejeon also showed the highest frequency of 83 times the average, while Nowon showed the lowest frequency of 27 times. From October to February, in the following year, when the temperatures was low, there were no cases exceeding the environmental standard for 1-hour average ozone concentration. The site that exceeded the environmental standard of 1-hour average the most during the 10 years duration was Taejeon with 226 times the average in total. By contrast, Nowon showed the lowest frequency of 79 times the average in total.

In July and August, when the temperatures are the highest, the excess frequency of the environmental standard for 1-year average was much lower than that of May and June, but the concentration was significantly high (grades 1 or 2 in Table 2).

To examine the differences in the increasing trend of ozone concentration in Daegu, the year-to-year changes of the ozone concentration at nine sites observed in summer (June to August) in Daegu for recent 10 years are analyzed, as shown in Fig. 4. It can be seen that the ozone concentration increased at all the target sites. Suchang, which is a downtown area, showed the largest increase in the ozone concentration. The annual average ozone concentration in Suchang increased from 0.030 ppm in 2008 to 0.0397 ppm in 2017. In contrast, Nowon, which is an industrial complex site, showed the smallest increase in ozone concentration, from 0.025 ppm in 2008 to 0.0306 ppm in 2017. When the sites are listed in descending order of increasing rate, we get Suchang > Sinam > Daemyeong > Jisan > Ihyeon > Taejeon > Manchon > Hyeonpung > Nowon.

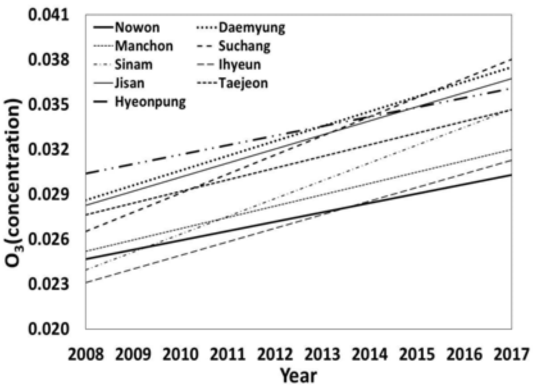

Fig. 4. Annual change of ozone concentrations at the 9 sites observed in the summer season (June-August) of Daegu for the recent 10 years (2008-2017).

3.2. Relationship between ozone concentration increase in summer and urban high temperature

To examine the relationship between urban high temperatures and ozone concentration, the monthly temperature change characteristics during summer in Daegu for recent 10 years are analyzed, as shown in Fig. 5. The daily average highest temperatures are shown in Fig. 5(a), daily average lowest temperatures are shown in Fig. 5(b), and daily average temperatures are shown in Fig 5(c). Even though the year-to-year changes are large, in terms of the simple temporal trend, the increase in daily highest temperature is larger than the daily average and lowest temperatures. The daily highest temperatures show an increasing trend in June, July, and August.

The temperatures were particularly high in 2010, 2013, and 2016. The monthly average of daily highest temperatures in August exceeded the heat wave alert level (33 ℃). For recent 10 years, the monthly average of the daily highest temperatures in July and August exceeded 30 ℃ in Daegu except in 2009 and 2014, indicating that the high temperature phenomenon occurred every year. This high temperature is a factor for increasing the ozone concentration. Photochemical smog is created when sunlight triggers numerous reactions and transformations of gases and aerosols. These reactions are intense and occur more often during high temperatures. When temperatures increase, ozone concentrations tend to increase as well (Aguado and Burt, 2001).

To examine the meteorological conditions that cause high ozone concentrations in summer, the frequency and ranking of high ozone concentrations during summer in Daegu for recent 10 years were considered and are listed in Table 2. The frequency of 0.06 ppm or higher 1-hour average ozone concentrations at each site was determined and the concentration rankings were divided into seven classes so that the target period for each class would be

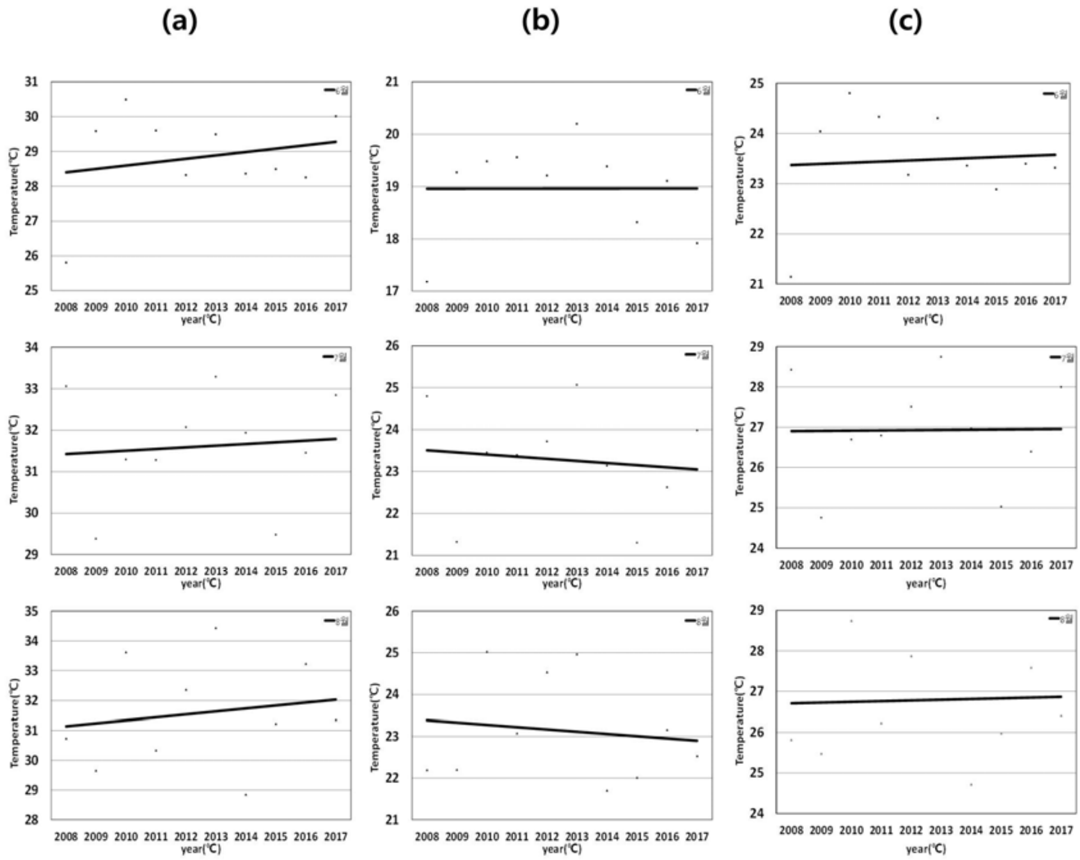

Fig. 5. Trend of monthly temperature changes in the summer season (June-August) of Daegu for the recent 10 years (2008-2017).

Table. 2. Appearance frequency and concentration ranking of high concentrations of ozone (2008-2017)

Concentration ranking	Total number of times with 0.06ppm or higher concentrations/days	Target 920 days
1	86 or higher	43
2	59 to less than 86	99
3	38 to less than 59	98
4	22 to less than 38	96
5	8 to less than 22	103
6	1 to less than 8	107
7	0	374

approximately 100 days, as shown in Table 2.

The target period for grade 1 was set to 43 days to identify the high-concentration situation. Fig. 6 shows O_3 and NO_2 concentrations with respect to time divided into seven classes, and the temperature, wind speed, and solar radiation of the days in each of the

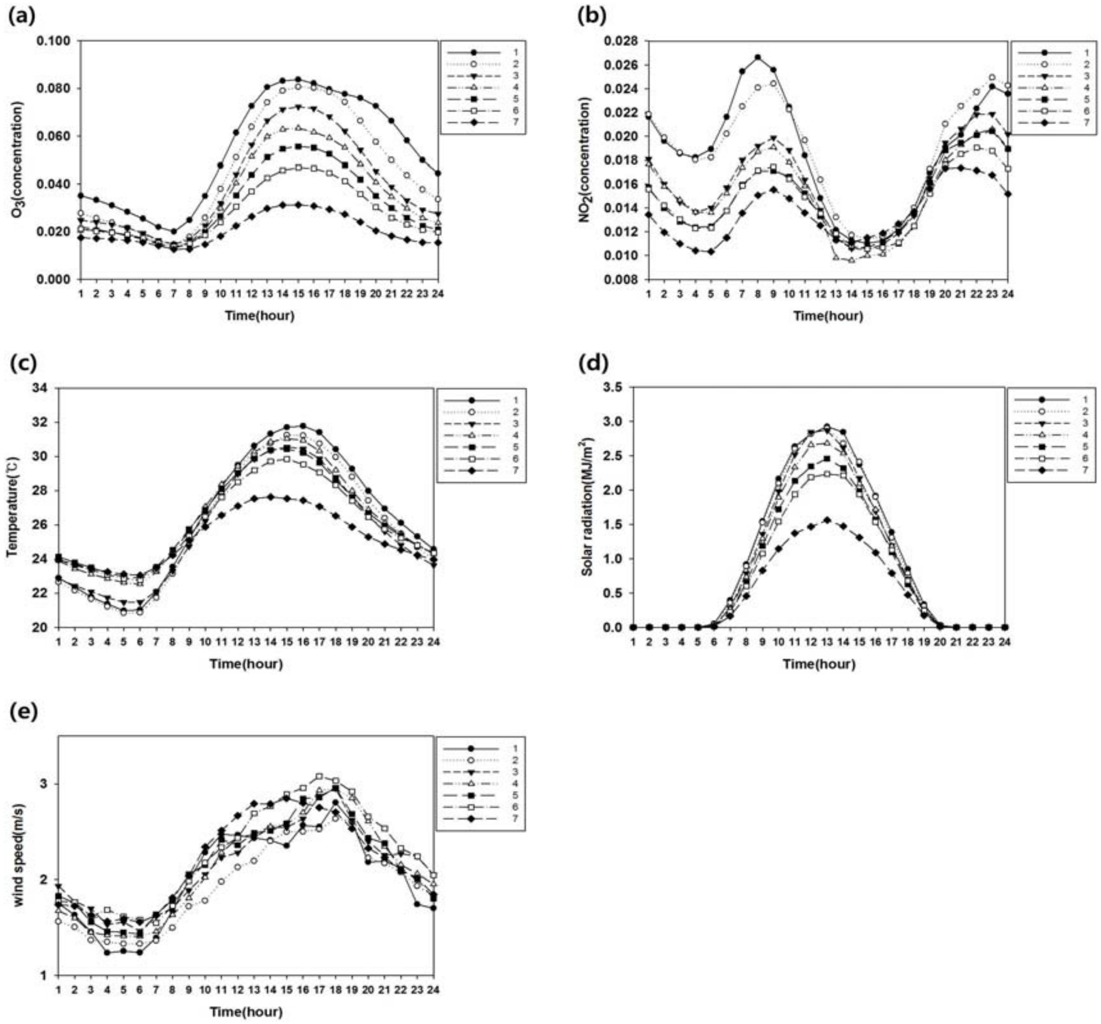

Fig. 6. Time variation by Class of Ozone Concentration(a) and time variation by Class of Nitrogen dioxide(b), time variations of meteorological factors affecting it ((c)∼(e)).

classes. The higher the class, the later the highest ozone concentration appears. The time when the highest concentration appeared was 15:00 for classes one to seven.

The NO_2 concentration was found to be higher at morning and night. In the morning hours, the concentration was high between 8:00 and 9:00. The concentration gradually increased at 18:00, the time at which people usually left office, and reached the highest value around 23:00 to 24:00. The daily highest temperature appeared to be between 14:00 and 16:00. It appeared later on days with a higher class of ozone concentration. The highest temperature of class seven, where the 1-hour average ozone concentration was lower than 0.06 ppm, was lower by at least 5℃, the solar radiation was less than half, and the NO_2 concentration was the lowest, compared to those of the classes with a higher temperature.

In short, the meteorological conditions observed for a high class of ozone concentration was weak wind during late night to morning and high NO_2 concentration prior to the morning rush hour. During this condition, a very high ozone concentration is formed during the daytime on a day with a high solar radiation and high temperature. If the wind is weak, the solar radiation and temperature on the following day are high, and a strong urban heat island is likely to appear. The intensity of urban heat island is generally stronger in the night compared to during the day on a clear day with weak wind speed until early morning (Landsberg, 1980; Kim et al., 2013; Pak et al., 2013). As pointed out by Takahashi et al. (2009), the air pollution level in downtown is high because the wind blows from the suburbs to the downtown areas due to the urban heat island phenomenon and becomes stagnant, resulting in high air pollution level in these areas. Their study revealed the NO_2 concentration during the early morning hours and the ozone concentration during the day between 1976 and 2008 in Tokyo, Japan, and pointed out that the cause of this high NO_2 concentration was urban heat island.

3.3. Correlation between ozone concentration and temperature

Figs 7 to 9 show the correlation between ozone concentration and temperature during summer. Fig. 7 shows the Taejeon site data that has the least missing data for the target period. When the relationship between the 1-hour average ozone concentration and temperature in summer for recent 10 years was analyzed, the slope was determined to be 0.0022 and the value of R was 0.4168. Fig. 8 shows the relationship between ozone concentration and temperature during this period except for the time when the cloud cover is higher than 0.8. The value of R was 0.4446, which increased compared to the value prior to exclusion, and the slope increased to 0.0024, indicating a higher correlation. Fig. 9 shows the result

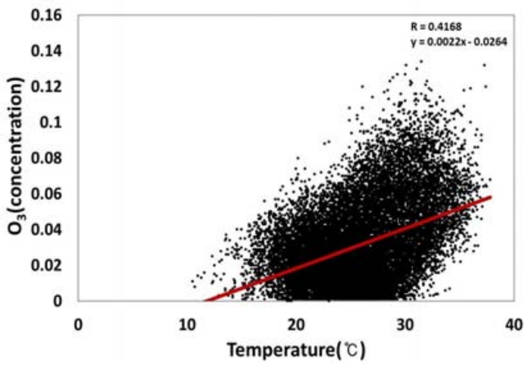

Fig. 7. Relationship between the Average Ozone Concent -ration and Temperatures in Summer (June-August) for recent 10 years.

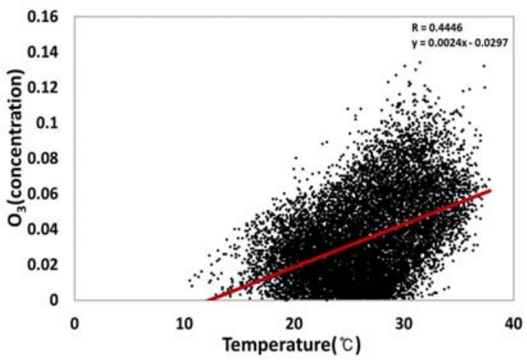

Fig. 8. Same as Fig. 6 except for in cases of cloud covers were 0.7 or less.

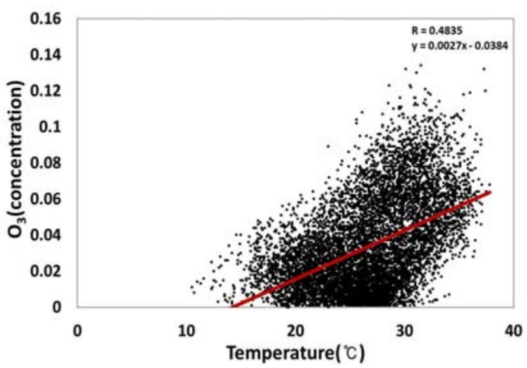

Fig. 9. Same as Fig. 6 except for in cases of cloud covers of 0.7 or less, wind speeds of 3m/s or less and daily solar radiation amount of 15MJ or higher.

for days satisfying the conditions of cloud cover of 0.7 or lower, wind speed of 3 m/s or lower, and daily solar radiation amount of 15 MJ or higher. It shows that a positive linear relationship exists.

These results confirm that high ozone concentrations appear on high-temperature days with no cloud, weak wind, and high solar radiation. It can be estimated that if heat wave appears when a strong upper level anticyclone has developed during summer, as in 2018, the meteorological condition for a very high ozone concentration is formed.

4. Conclusions

The relationship between urban high temperatures and ozone concentration in Daegu, South Korea was examined. The conclusions of the study are as follows:

Firstly, the ozone concentration of Daegu showed a sharp increasing trend since 2012 despite the improved NO_2 concentration. The increasing rate of ozone concentration was especially high in the downtown area.

Secondly, the excess frequency of environmental standard for 1-hour average ozone concentration was highest during May and June, but significantly high concentrations primarily appeared in August.

Thirdly, the conditions for high ozone concentration were particularly high NO_2 concentration that occurred prior to the morning rush hour, high solar radiation during the day, high temperature, and weak wind speed. It was estimated that the NO_2 concentration in the downtown area stayed high even before the morning rush hour because on a day when a strong urban heat island appeared at night, the wind blew from the suburbs to the downtown area and became stagnant.

Therefore, the strengthening of urban heat island is an important factor that just deteriorates the thermal environment of the city, but also worsens its air quality during summer. A limitation of this study is that the converging air current due to urban heat island could not be verified through data analysis because not many meteorological observation systems were available to verify this from the suburbs to the downtown area in Daegu. In the future, we will conduct follow-up research to verify this through special observations.

Acknowledgements

This research was supported by R&D project of DEGEC(No.2191-1-90-94-04)

References

Aguado, E., Burt, J., 2001, Understanding Weather and Climate, Pretice-Hall, Inc., New jersey, 406-408.

Hujibe, H. A., 2012, Urban climate change and abnormal weather, Asakura Press, Tokyo, 49-63.

Jeon, B. I., 2018, Characteristics of NO and NO_2 at roadside and urban residential locations in busan, J. Environ. Sci. Int., 27, 587-595.

Kim, H. D., Kim, J. B., Kim, H. Y., Bae, H. K., 2014, Introduction to Global Environment, Keimyung University Press, 162-163.

Kwon, O. Y., Jung, J. H., 2018, Global carbon budget study using global carbon cycle model, J. Environ. Sci. Int., 27, 1169-1178.

Lee, H. Y., 1980, Urban Climatology, Dae-Kwang Press(Seoul), 99-143.

Mizukoshi, S. M., Yamashita, S. S., 1993, Introduction of climatology, Kokin Press, Tokyo, 98-101.

Nishioka, H. J., Harazawa, H. O., 1998, Global warming and Japan, Kokin Press, Tokyo, 236-237.

Park, H. S., Song, S. K., Han, S. B., Cho, S. B., 2018, Spatio-temporal characteristics of the frequency of weather types and analysis of the related air quality in Korean urban areas over a the last decade (2007-2016), J. Environ. Sci. Int., 27, 1129-1140.

Park, M. H., Lee, J. S., Ahn, W. S., Kim, H. D., Oh, S. N., 2013, A Study on the thermal characteristics of midsummer in Daegu metropolitan area, J. Env. Sci., 22(6), 667-677.

Takahashi, K., Mikami, T., Takahashi, H., 2009, Influence of the urban island phenomenon in tokyo on land and

sea breezes, The 7th International Conference on Urban climate, Tokyo, 161-162.
Yoshino, M. T., 2010, Abnormal Weather under Global Warming Era, Seizando Press, Tokyo, 30-35.

• Professor. Hae-Dong Kim
Department of Global Environment, Keimyung University
khd@kmu.ac.kr
• Graduate student. Eun-Ji An
Department of Global Environment, Keimyung University
0601eunji@daum.net