Pollutants and climatic conditions related to the formation of photochemical oxidants

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World Journal of Biology Pharmacy and Health Sciences, 2021, 05(02), 001–005

Publication history: Received on 22 January 2021; revised on 30 January 2021; accepted on 02 February 2021

Article DOI: https://doi.org/10.30574/wjbphs.2021.5.2.0009

Abstract

Solar radiation produces harmful compounds such as atmospheric oxidants and pharmaceutical intermediates through photochemical reactions. To clarify the variables related to the formation of photochemical oxidants, hourly data of air pollutants and climatic conditions in the Tokyo region of Japan from late May to early June 2020 were analyzed. Air pollutants, NO, NO$_2$, CO, SO$_2$, NMHCs and CH$_4$, were significantly lower in 2020 than those in 2019. It seems to indicate that Japan’s economic activity was suppressed by the COVID-19 emergency. Photochemical oxidants and NO were significantly higher during the day than at night. It shows the photochemical reaction is progressing during the day. Stepwise linear regression analysis revealed that relative humidity, ambient temperature, NO, CO, wind speed and NMHCs (non-methane hydrocarbons) were significant independent variables for photochemical oxidants formation.

Keywords: Photochemical oxidants; NO; CO; NMHCs; Relative humidity; Ambient temperature; Wind speed.

1. Introduction

Sunlight have positive and negative effects on the community environmental health. Solar radiation produces harmful compounds such as atmospheric oxidants [1] and pharmaceutical intermediates [2] through photochemical reactions [3], increasing environmental health burden. Since atmospheric oxidants are formed under the influence of sunlight by a complex photochemical reaction in the air containing nitrogen oxides and reactive hydrocarbons as precursors, climatic conditions play an important role in oxidants formation [4, 5, 6, 7].

This study reports the relationship between photochemical oxidants formation and air pollutants and climatic conditions in the Tokyo region of Japan, from late May to early June 2020.

2. Methods

2.1. Air pollutants levels

Hourly levels of air pollutants of the Tokyo National Environmental Observatory were obtained from the Japan Atmospheric Environmental Regional Observation System (soramame.taiki.go.jp). Air pollutants were as follows; photochemical oxidants, nitrogen monoxide (NO), nitrogen dioxide (NO$_2$), carbon monoxide (CO), sulfur dioxide (SO$_2$), non-methane hydrocarbons (NMHCs) and methane (CH$_4$).
2.2. Climatic conditions
The climatic conditions were from the values of the Tokyo Meteorological Observatory. The climatic value such as hourly ambient temperature, relative humidity, wind speed and global solar radiation was downloaded from the Japan Meteorological Agency.

(www.data.jma.go.jp/obd/stats/etrn/index.php?sess=6ef525a9cdef28cea634ce58ca736e68)

2.3. Statistical analysis
Results were expressed as means ± standard deviations (SD). Multiple linear regression analysis was performed to determine the relationship between photochemical oxidants formation and air pollutants and climatic conditions. \( p < 0.05 \) was considered as statistically significant.

3. Results and discussion
3.1. Air pollutant levels and climatic conditions
Table 1 shows air pollutant levels and climatic conditions from May 26 to June 8, 2020 compared to the same period previous year. NO, NO\(_2\), CO, SO\(_2\), NMHCs and CH\(_4\) were significantly lower in 2020 than those in 2019. Table 2 compares air pollutant levels and climatic conditions during the day with those at night. Photochemical oxidants and NO were significantly higher during the day than at night.

**Table 1** Air pollutant levels and climatic conditions from May 26 to June 8, 2020 compared to the same period previous year.

|                      | Year  | n   | Mean  | SD    | \( P\)-value \# |
|----------------------|-------|-----|-------|-------|-----------------|
| Photochemical Oxidants (ppm) | 2020  | 330 | 0.0392 | 0.0170 | 0.901           |
|                      | 2019  | 329 | 0.0394 | 0.0190 |                 |
| NO (ppm)            | 2020  | 323 | 0.0007 | 0.0005 | 0.000           |
|                      | 2019  | 328 | 0.0016 | 0.0009 |                 |
| NO\(_2\) (ppm)      | 2020  | 323 | 0.0119 | 0.0067 | 0.000           |
|                      | 2019  | 328 | 0.0155 | 0.0079 |                 |
| CO (ppm)            | 2020  | 331 | 0.2514 | 0.0810 | 0.048           |
|                      | 2019  | 329 | 0.2657 | 0.1027 |                 |
| SO\(_2\) (ppm)      | 2020  | 327 | 0.0006 | 0.0007 | 0.000           |
|                      | 2019  | 329 | 0.0016 | 0.0014 |                 |
| NMHCs (ppmC)        | 2020  | 329 | 0.1440 | 0.0383 | 0.001           |
|                      | 2019  | 328 | 0.1548 | 0.0481 |                 |
| CH\(_4\) (ppmC)     | 2020  | 329 | 2.0009 | 0.0413 | 0.000           |
|                      | 2019  | 328 | 1.9624 | 0.0548 |                 |
| Ambient Temperature (°C) | 2020  | 336 | 22.4  | 3.1   | 0.547           |
|                      | 2019  | 336 | 22.5  | 3.2   |                 |
| Relative Humidity (%) | 2020  | 336 | 76.5  | 15.7  | 0.007           |
|                      | 2019  | 336 | 73.1  | 17.1  |                 |
| Wind Speed (m/s)    | 2020  | 336 | 0.58  | 0.42  | 0.011           |
|                      | 2019  | 336 | 0.67  | 0.49  |                 |
| Global Solar Radiation (MJ/m\(^2\)) | 2020  | 238 | 1.0580 | 1.0597 | 0.678           |
|                      | 2019  | 238 | 1.0183 | 1.0239 |                 |

\#Statistical analysis of mean values between "2020" and "2019"
Table 2 Air pollutant levels and climatic conditions during the day (4:00 AM-8:00 PM) and at night (8:00 PM-4:00 AM)

| Section                      | n   | Mean  | SD   | P-value* |
|------------------------------|-----|-------|------|----------|
| Photochemical Oxidants (ppm) |     |       |      |          |
| Day                          | 206 | 0.0427| 0.0180| 0.000    |
| Night                        | 124 | 0.0335| 0.0135|          |
| NO (ppm)                     |     |       |      |          |
| Day                          | 199 | 0.0010| 0.0006| 0.000    |
| Night                        | 124 | 0.0003| 0.0010|          |
| NO₂ (ppm)                    |     |       |      |          |
| Day                          | 199 | 0.0121| 0.0058| 0.517    |
| Night                        | 124 | 0.0116| 0.0079|          |
| CO (ppm)                     |     |       |      |          |
| Day                          | 207 | 0.2546| 0.0798| 0.350    |
| Night                        | 124 | 0.2480| 0.0830|          |
| SO₂ (ppm)                    |     |       |      |          |
| Day                          | 203 | 0.0006| 0.0007| 0.170    |
| Night                        | 124 | 0.0005| 0.0007|          |
| NMHCs (ppmC)                 |     |       |      |          |
| Day                          | 205 | 0.1467| 0.0399| 0.096    |
| Night                        | 124 | 0.1394| 0.0352|          |
| CH₄ (ppmC)                   |     |       |      |          |
| Day                          | 205 | 2.0020| 0.0394| 0.569    |
| Night                        | 124 | 1.9993| 0.0443|          |
| Ambient Temperature (°C)     |     |       |      |          |
| Day                          | 209 | 23.4  | 3.0  | 0.000    |
| Night                        | 127 | 20.8  | 2.3  |          |
| Relative Humidity (%)        |     |       |      |          |
| Day                          | 209 | 71.4  | 16.4 | 0.000    |
| Night                        | 127 | 85.0  | 9.8  |          |
| Wind Speed (m/s)             |     |       |      |          |
| Day                          | 209 | 0.65  | 0.42 | 0.000    |
| Night                        | 127 | 0.46  | 0.38 |          |
| Global Solar Radiation (MJ/m²)|    |   |      |          |
| Day                          | 209 | 1.2048| 1.0497| 0.000    |
| Night                        | 127 | 0.0000| 0.0000|          |

*Statistical analysis of mean values between "Day" and "Night"*

3.2. Multiple linear regression analysis

Air pollutants and climatic conditions, which are potential variables for the formation of photochemical oxidants, were entered as independent variables for multiple regression analysis. The analysis results are shown in Table 3. Stepwise linear regression analysis revealed that relative humidity, ambient temperature, NO, CO, wind speed, and NMHCs are significant independent variables. The Durbin–Watson statistic of 0.732 from the residual analysis was out of the preferred range of 1.5–2.5, suggesting presence of autocorrelation [8].

Table 3 Stepwise multiple linear regression analysis of variables related to the formation of photochemical oxidants.

|                        | Estimated regression coefficient B | 95% confidence interval | Partial regression coefficient β | Cumulative R² | P-value |
|------------------------|----------------------------------|-------------------------|-------------------------------|--------------|--------|
| **Intercept**          | 0.034                            | 0.013 - 0.054           | -                              | -            | 0.001  |
| **Relative Humidity**  | -0.001                           | -0.001 - 0.000          | -0.524                        | 0.560        | 0.000  |
| **Ambient Temperature**| 0.001                            | 0.001 - 0.002           | 0.266                         | 0.630        | 0.000  |
| **NO**                 | -5.439                           | -6.769 - 4.108          | -0.309                        | 0.690        | 0.000  |
| **CO**                 | 0.032                            | 0.013 - 0.051           | 0.146                         | 0.711        | 0.001  |
| **Wind Speed**         | 0.005                            | 0.001 - 0.009           | 0.127                         | 0.718        | 0.010  |
| **NMHCs**              | 0.048                            | 0.009 - 0.087           | 0.106                         | 0.725        | 0.015  |
4. Discussion

Photochemical oxidants, 98% of which is ozone [9]. Ozone and other photochemical oxidants (such as peroxyacyl nitrates and aldehydes) can form as a result of solar oxidation of precursor pollutants (nitrogen oxides and reactive hydrocarbons, etc.) released into the atmosphere and have adverse effects on health and environmental quality [10], [11, 12]. The quantities of the several formed photochemical oxidants are mainly dependent on intensity and duration of daily sunshine, temperature, oxidant concentrations at the beginning of a build-up period, and on emission rates and concentrations of primary pollutants [13]. Therefore, climatic conditions play an important role in the formation of oxidants. Present study investigated the relationship between photochemical oxidants formation and air pollutants and climatic conditions in Tokyo, Japan, from late May to early June 2020. The levels of air pollutants such as NO, NO\(_2\), CO, SO\(_2\), NMHC and CH\(_4\) in 2020 were significantly lower than those in 2019. It seems to indicate that Japan’s economic activity was suppressed by the COVID-19 emergency. Quarterly estimates of GDP from April to June 2020, Japan, was declining significantly [14]. Photochemical oxidants and NO were significantly higher during the day than at night. It shows the photochemical reaction is progressing during the day. Stepwise linear regression analysis revealed that relative humidity, ambient temperature, NO, CO, wind speed, and NMHCs are significant independent variables. Partial regression coefficients that allow comparison of effect sizes between independent variables indicate that relative humidity has a strong inhibitory effect on photochemical oxidants formation. High humidity causes ozone decomposition [15, 16, 17]. Other independent variables have been shown in previous studies [4, 5, 6, 7]. However the Durbin–Watson statistic of 0.732 from the residual analysis is outside the preferred range of 1.5–2.5 [8], suggesting presence of autocorrelation that causes an overestimation of the likelihood of a change.

5. Conclusion

Hourly data of air pollutants and climatic conditions in the Tokyo region of Japan from late May to early June 2020 were analyzed to clarify the variables related to the formation of photochemical oxidants. Stepwise linear regression analysis revealed that relative humidity, ambient temperature, NO, CO, wind speed, and NMHCs are significant independent variables.

Compliance with ethical standards

Acknowledgments

The author appreciates the help of colleagues in the laboratory.

Disclosure of conflict of interest

There is no conflict of interest in this work.

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