Fluctuation of Nighttime Ground Level Ozone Due to Artificial Light

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Abstract Ultraviolet (UV) radiation creates ground-level ozone (O_3) during the day and is subsequently eliminated by nitrogen oxides at night. However, excessive artificial light use, those results in light pollution, may interfere with the chemistry of ground-level O_3 at night by supplying enough energy to start that creation. Therefore, this study aims to identify the effect of artificial light on nighttime ground-level ozone production. Minute average O_3 and NO_2 concentrations with light illumination were measured in two study sites at the USM School of Civil Engineering and its Main Campus. Results of this study suggested that in low-light illumination conditions, no conversions between NO_2 to O_3 were governed due to low-light energy that was unable to break NO_2 bonds. Thus, there are no changes in O_3 concentration trends in the School of Civil Engineering. However, in high-light illumination conditions such as in USM Main Campus, O_3 fluctuated negatively with NO_2 concentrations, and potential conversions were governed.

Keywords: nighttime chemistry, ozone production, anthropogenic light

1. Introduction

Artificial light pollution and nighttime ground-level ozone are two distinct environmental issues that can have interconnected effects and influences. Nighttime ground-level ozone (O_3) has emerged as a significant concern in air pollution research due to its unique characteristics and potential health and environmental impacts. O_3 during daytime was focused compared to nighttime conditions (Awang et al., 2015; Shith et al., 2020; Stolz et al., 2020). Meanwhile, artificial light pollution can indirectly contribute to the formation and accumulation of ground-level ozone through photochemical reactions. Artificial lighting sources emit light in various wavelengths, including blue and ultraviolet (UV) light. These wavelengths can react with certain air pollutants, such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs), triggering photochemical reactions that lead to the production of ground-level ozone (Shith et al., 2020).

Other studies have also extensively investigated fluctuations in O_3 concentration at night (Awang & Ramli, 2017; Shith et al., 2020; Wang et al., 2022(a); Wang et al., 2022(b)). Awang and Ramli (2017) reported an interrelation between daytime and nighttime O_3 concentrations in Malaysia. Specifically, the enhanced nighttime depletion chemical removal in O_3 concentrations influences the O_3 concentrations for the following day. Shith et al. (2020) detected low nighttime—NO titration during a haze event, indicating that O_3 from anthropogenic sources can stay in ambient air. Meanwhile, Wang et al. 2022(a) focus on understanding the diurnal pattern of O_3 and its interactions with nighttime nitrate radical (NO_3) and nitrous acid (HONO) in the atmosphere. However, Stark et al. (2011) revealed that this nighttime phenomenon is related to increasing the number of photons in the atmosphere and directly enhancing O_3 photochemical reactions. Therefore, this study aims to identify the effect of artificial light on nighttime ground-level ozone production.

2. Materials and Method

2.1. Study Area

This study took place in two locations of Universiti Sains Malaysia, Penang, the Main Campus and the School of Civil Engineering (Table 1.). The location of the Main Campus of Universiti Sains Malaysia, Penang, is near major transportation routes, including highways and roads, which can result in significant vehicular traffic. Increased transportation activities, including private vehicles, public transportation, and logistics, can lead to emissions of pollutants such as nitrogen oxides (NO_x), volatile organic compounds (VOCs), which are known as main O_3 precursors, and particulate matter (PM). Meanwhile, the School of Civil Engineering is located inside the Engineering Campus, which exposed Nibong Tebal, Penang, to vehicular emissions.

Table 1. Details of the selected study areas

No.	Location	Coordinate

1	Main Campus	5°21'22.5"N 100°18'28.8"E
2	School of Civil Engineering	5°08'48.9"N 100°29'33.5"E

2.2. Measurement and Instruments

The concentration levels of O_3 and NO_2 were monitored at two selected locations using the portable handheld Aeroqual S500 (Aeroqual Limited) monitors and six sensors' heads NO_2 (range 0–1 ppm) and O_3 (range 0–10 ppm). The relatively compact and lightweight Aeroqual S500 monitors were battery-powered at the selected TIs, interchanging the semiconductor and electrochemical sensor, permitting continuous monitoring of the range of selected gases at low mixing ratios (Lin et al., 2017). The instrument was placed nearest the artificial light located. Meanwhile, light Illumination in the selected locations was observed using HI97500 Portable lux meter (range:0.001-199.9 Klux). Figures 1 and 2 show the placement of the instrument with possible gas emissions emitted to the instrument.

Figure 1. The lobby of the School of Civil Engineering

Figure 2. Roadside at Main Campus

2.3. Nighttime Data Collection

Continuous data of selected variables are analysed according to the selected locations in this study. The average O_3 concentration and NO concentration visualise the condition of the O_3 reading and symbolise NO titration. No imputation methods were used in this study, and any missing values discovered during data collection were omitted from the analysis. Time Series fluctuation was conducted to identify the fluctuation of ozone during the nighttime O_3 concentration with existing artificial light. The monitoring duration was recorded per minute averaging data.

3. Result and Discussion

3.1. Nighttime O_3 and NO Concentration

Figure 3 illustrates the variation of O_3 and NO_2 concentrations and light illumination in the School of Civil Engineering (left) and USM Main Campus (right) during nighttime. For the monitoring in the School of Civil Engineering, freshly new emissions (from a car) were supplied, while no new emissions were supplied during the monitoring in USM Main Campus. The School of Civil Engineering result suggested that O_3 concentration is minimal during nighttime, while NO_2 concentration ranges from around 18 ppb to 10 ppb before the new emission; the NO_2 concentration increased significantly as new emissions were released with maximum concentration recorded at 60 ppb. The light illumination at the School of Civil Engineering during the monitoring period is constantly recorded at 28 lux, significantly lower than at USM Main Campus, which is recorded at 64 lux. Conversely, O_3 and NO_2 concentrations in this study area were significantly higher even when no new emissions were supplied.

Studies by Elbayoumi et al. (2014) and Warmiski et al. (2018) elucidate that the chemistry of nighttime ozone differs from that of daytime ozone, with (R1) to (R4) being the most common reactions. However, the primary precursor of O_3, NO_x, continues to have the most impact on nighttime O_3 changes. According to Awang et al. (2015), reactions between NO and O_3 concentrations, also known as the NO titration process/reaction, control nighttime O_3 chemistry (R1). The high NO concentrations produced by automotive and industrial emissions stimulate (R1), causing O_3 to be destroyed in the atmosphere. Furthermore, at night (R2), the combination between O_3 and NO_2 can deplete nocturnal O_3 concentrations by converting O_3 to nitrate (NO_3), which then interacts with NO_2 to generate dinitrogen pentoxide (N_2O_5) (R3). The N_2O_5 concentration combines with water in the ambient air to generate nitric acid, which is then eliminated from the atmosphere as acid rain or precipitation (Seinfeld & Pandis, 2016).

$$NO + O_3 \rightarrow NO_2 + O_2 \quad (R1)$$

$$NO_2 + O_3 \rightarrow NO_3 + O_2 \quad (R2)$$

$$NO_3 + NO_2 + M \leftrightarrow N_2O_5 + M \quad (R3)$$

$$N_2O_5 + H_2O \rightarrow 2HNO_3 \quad (R4)$$

$$NO_3 + \text{light} (\lambda < 590 \text{ nm}) \rightarrow NO_2 + O \quad (R7)$$

Meanwhile, further research has shown that this nightly cleansing action is not as effective as expected because NO_3 is being destroyed by the light reflected in the sky by outdoor lighting on the ground (Stark et al., 2011). In the presence of anthropogenic lights, NO_3 is destroyed, and O_3 concentrations increase through possible chemical reactions occurring at night, as in reactions (R1) and (R2). Reaction (R1) can occur during daytime; however, NO_3 is quickly photolysed by daylight (R3), and NO_3 and N_2O_5 are heavily suppressed during the day.

The results observed in the School of Civil Engineering suggested that in low light illumination conditions, NO_2 will remain as NO_2 even if there are freshly emitted concentrations due to the low light energy available. Thus, it reflected the finding as the O_3 concentration was consistently at minimal concentrations at the monitoring site. Meanwhile, results show interesting trends in USM Main Campus as the light illumination in the monitoring area is relatively higher than in the School of Civil Engineering. The result illustrated that there are opposite trends shown by O_3 concentrations and NO_2 concentrations throughout the study period. This trend might suggest a conversion of NO_2 concentration into O_3 concentrations due to high illumination conditions in the area due to the fluctuation trends shown by O_3 concentrations.

4. Conclusion

This study aims to identify the effect of two distinct environmental issues: artificial light's influence on nighttime ground-level ozone production. Previous studies elucidated that there might be chances that artificial light with a specific wavelength and right intensity is potentially initiating nighttime O_3 formations. If these were possible, the issues regarding O_3 pollution would possess more threats from current concerns as their formation is not limited to daytime only but also can form during nighttime. Results of this study suggested that in low-light illumination conditions, no conversions between NO_2 to O_3 were governed due to low-light energy that was unable to break NO_2 bonds. Thus, there are no changes in O_3 concentration trends in the School of Civil Engineering. However, in high-light illumination conditions such as USM Main Campus, O_3 fluctuated with NO_2 concentrations negatively, suggesting potential conversions were governed.

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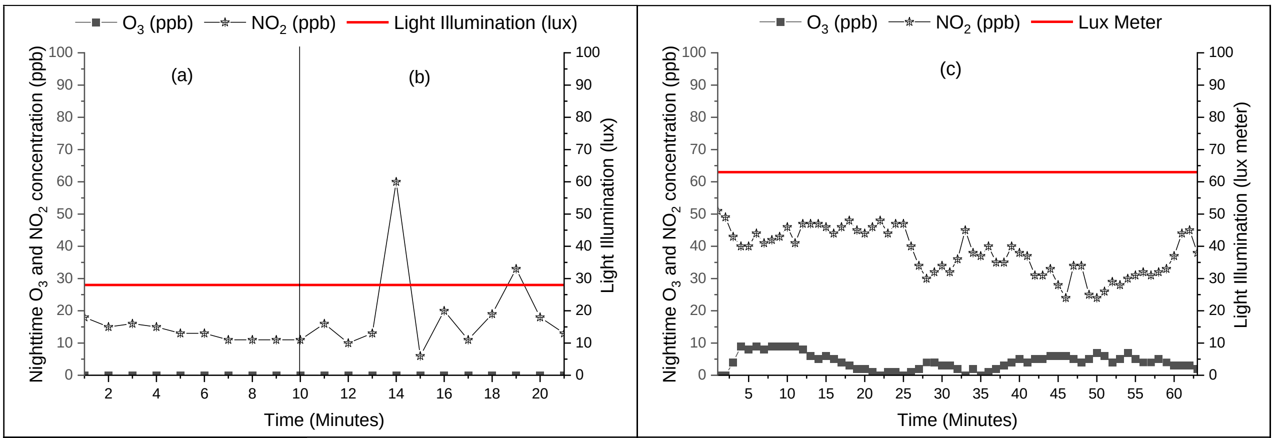

(a) Gas not emitted	(b) Gas emitted	(c) Gas not emitted

Figure 3. Variation of O_3 and NO_2 concentration and light illumination in the School of Civil Engineering (left) and USM Main Campus (right)

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