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Air Quality Impact from Petroleum Refinery at Sapugaskanda, Sri Lanka

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Abstract: Sapugaskanda Oil Refinery, the largest in Sri Lanka, is situated in a mixed land-use area and necessitates an investigation into its potential impacts on ambient air quality in the surrounding region. This study aims to assess the concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and particulate matter ($PM_{2.5}$ and PM_{10}) near the Sapugaskanda Oil Refinery during normal operations and major shutdowns in 2018. It seeks to identify compliance issues with regulated limits and explore the effects of refinery activity on pollutant levels. Active monitoring results indicated no statistically significant differences in the concentrations of SO_2 (W=8, p=0.094), NO_2 (W=11, p=0.062), and O_3 (W=7.5, p=0.125) between normal operation and shutdown periods of the Sapugaskanda Oil Refinery for Wilcoxon Signed Rankings Test. $PM_{2.5}$ and PM_{10} concentrations were higher during shutdowns (W=1, p=0.031). However, weather conditions varied between monitoring periods and may have influenced particulate matter concentrations. Measured pollutant concentrations were below the ambient air quality standards set by the Sri Lankan Ministry of Environment. Passive monitoring revealed no statistically significant spatial or temporal variation in SO_2 and NO_2 concentrations. However, long-term monitoring could help identify pollution hotspots and inform appropriate action plans in areas where industrial and urban pollution coexist.
Keywords: Air pollution, Ambient air quality, Oil refinery emission, Active and passive sampling, Statistical analysis

1. Introduction

Air quality degradation has increased today due to increased pollutant emissions from vehicles, industries, domestic activities, and transboundary transportation of air pollutants [1]. Though the concept of industrial zoning has been put into practice worldwide as one of the main policy tools of economic growth with the primary objective of creating employment, excessive concentration of industries results in air pollution problems in the vicinity of the site [2,3]. Highly industrialized areas have the highest pollutant emission sources, like petroleum refineries and petrochemical plants [4,5]. Studies show that the major sources of pollutant emissions from human activities include fossil fuel combustion products used for industrial and domestic heating, transportation, and oil refining emissions [6]. Several studies done throughout the world, including Taiwan, the United States, Turkey, Oman, and China, showed that the petroleum refinery is a source of criteria pollutants [5,7, 8, 9, 10].

The emissions from an oil refinery can occur due to equipment leaks, combustion processes at high temperatures when fuels are burned to create electricity, etc. [11]. The dominant source emissions from the petroleum refining industry are process emissions, combustion emissions, fugitive emissions, storage & handling emissions, and auxiliary emissions [2]. The types of pollutants emitted from an oil refinery are SO_x, NO_x, particulate matter ($PM_{2.5}$ and PM_{10}), and hydrocarbons. When these pollutants are released into the atmosphere, they reacts with molecules in the atmosphere to form secondary pollutants.

For example, sulfurous and sulfuric acids are formed when SO_xreact with water vapor and

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return to the earth as a dry or wet deposition [12].

Volatile hydrocarbons are formed when NOx reacts with sunlight to form ozone (O_3) [13]. As oil refineries emit pollutants, health effects have become a concern, especially when emission sources are found closer to built-up areas with residences, institutes, stores, supermarkets, and other places where public activities are common [4].

Rapid industrialization and urbanization in developing countries result in higher energy consumption and waste generation [14]. To understand the background pollutant concentrations and to ensure they remain within regulated limits; generally, air quality monitoring studies are carried out by regulatory bodies [15]. As per air quality monitoring results, the ambient air pollution level in the Western Province is higher than in the other provinces in Sri Lanka [16]. Another study showed that ambient air pollution (which contains SO_2 and NO_x) was statistically significant with acute wheezing among children in Sri Lanka [17]. Sapugaskanda is one of such highly industrialized areas located within the Western Province of Sri Lanka [18]. A study carried out on the spatial variation of the pollutant levels in the Sapugaskanda area over the period from 1997 to 2004 indicates that the pollution levels concerning SO_2 and NO_2 are scattered in the Sapugaskanda area throughout the study period [19].

One of the major industries located in Sapugaskandais the Oil Refinery. This is the largest oil refinery in Sri Lanka. The refinery processes around 6000 tons of crude oil per day and produces many finished products, namely, petrol, diesel, kerosene, etc. The plant operates 24 hours continuously throughout the year except for the major shutdown periods which occurs once in two years when scheduled maintenance works are carried out. However, there are limited studies on how its operations specifically affect ambient air quality in the surrounding area. The potential fluctuations in pollutant levels, particularly during different operational phases such as normal functioning and major shutdown periods are not done in previous studies.Since the surrounding community is more concerned about environmental problems associated with ambient air quality, and their perception is of critical importance for the undisturbed operation of the industries in the area, this research focuses on investigating whether the operation of Petroleum Refinery at Sapugaskanda, Sri Lanka, significantly contributes to the ambient air quality of the surrounding area.

Furthermore, while the local community expresses concern regarding air pollution from the refinery, there is a lack of comprehensive data comparing the concentrations of key pollutants, such assulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and particulate matter ($PM_{2.5}$ and PM_{10}), during these distinct operational phases. This study addresses these gaps by conducting ambient air quality monitoring during both normal operation and major shutdown periods of the refinery, providing a clear understanding of how refinery activity impacts pollutant levels.

To fulfil the aim, first, the measurement of ambient air quality concerning SO_2, NO_2, CO, O_3, $PM_{2.5,}$ and PM_{10}around the petroleum refinery during the major shutdown of the refinery in March 2018 and during the normal operation of the refinery in October 2018 was done. Then, compliance with the regulated limits was identified, and the effect of refinery operation or shutdown on the concentrations of air pollutants was investigated.

2. Materials and Methods

2.1 Study Area Selection

The Sapugaskanda oil refinery (06^0 57′ 57″ N, 79^0 57′ 30″ E) is the single largest oil refinery located in the Western Province of Sri Lanka. The oil refinery processes around 6000 tons of crude oil per day. To understand the pollutant concentration around the refinery, active and passive sampling was carried out during the major shutdown period of the refinery in March 2018 and again in October 2018 when the refinery was in normal operation. Although the shutdown period in March 2018 was predetermined by the refinery's maintenance schedule, October 2018 was selected to represent typical normal operations. Although weather conditions differ between these months, the comparison was necessary to assess the refinery's impact on air quality during both phases while considering the seasonal variability as a limitation.

All active and passive sampling locations are shown in Figure 1. A categorization of locations was created based on potential exposure to the refinery to measure ambient concentration levels of air pollutants. Sampling locations were selected along the main roads and spread across the refinery in parallel with the wind direction.

Five locations (L1 to L5) were selected for the active sampling of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and particulate matter with a diameter less than 10 μm and 2.5

µm (PM_{10} and $PM_{2.5}$). L1 was 1.3 km from the refinery to 180^0 from the North, L2 was 0.75 km from the refinery to 30^0 from the North, L3 was 1.25 km from the refinery to 100^0 from the North, L4 was within the refinery premises and towards the North, and L5 was 0.2 km from the refinery to 115^0 from the North. The ambient exposure levels of SO_2& NO_2 using the passive air sampling technique were measured at twenty (20) locations (P1 to P20) and are shown in Figure 1.

The area selected was within the 10 km radius of the refinery and the selected passive sampling locations were along the main roads and spread across the refinery in parallel with the wind direction which was towards the north-east. Locations along the main roads were selected for ease of access, and the reason most residences are clustered along the main roads, so that any harmful pollutant concentration to the residents could be identified. Furthermore, the concentration of pollutants NO_2 and SO_2 in the ambient air was monitored at five locations (CS1 to CS5) as shown in Figure 1 for continuous passive sampling. CS1 was 0.7km away from the refinery to 30^0 from the North, CS2 was 0.2 km away from the refinery to 115^0 away from the north, CS3 was 0.6 km away from the refinery to 105^0 from the north, CS4 was 0km away from the refinery and is 0^0 away from the north and CS5 was 0.8km away from the refinery to 185^0 from the north.

2.2 Active Sampling

For active sampling, a wet chemical analysis was carried out. Air samples were collected on an eight (08) hour basis for the analysis of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), one (01) hour basis for ozone (O_3), and twenty-four (24) hour basis for particulate matter (PM_{10} and $PM_{2.5}$). Air samples were collected at a height of about 3 m from ground level, and sampling rates were 0.5 l/min for SO_2 and NO_2, 1.0 1/min for O_3, and 1.0 m^3/min for PM_{10} and 16 1/min for $PM_{2.5}$, respectively.

2.3 Passive Sampling

For passive sampling, all samplers were installed at a height of about 3 m from the ground level. The duration of the sampling was two weeks for both the plant shutdown period and the plant operation period. For passive sampling continuously, sampling was done for three consecutive months starting from June to August 2018 (7th June to 21stJune, 22nd June to 3rd July, 4th July to 17th July, 18th July to 31st July, 1st Aug to 14th Aug, and 15th Aug to 28th Aug 2018).

2.4 Analytical Methods

NO_2 analysis was carried out by active/ passive air sampling with the Saltzman method using the UV spectrophotometer. The Ogawa-type sampler was used for passive analysis and glass impinges with a personal air sampler for active measurements. SO_2 analysis was carried out by active/ passive air sampling with the Pararosaniline colorimetric method using the UV spectrophotometer. Again, the Ogawa-type sampler was used for passive analysis and glass impinges with a personal air sampler for active measurements. O_3 was measured by the NBKI UV spectrophotometric method by ASTM D5156-02, 2008, and $PM_{2.5}$ and PM_{10} were measured by high-volume sampling and the gravimetric analysis method per ASTM D4096 – 82, 2017.

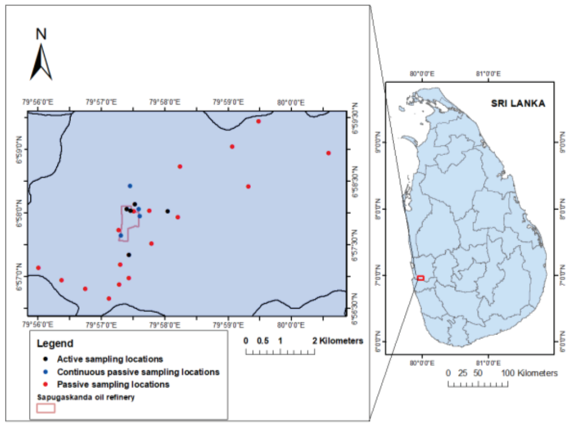


Figure 1 - Selected Sampling Locations around the Sapugaskanda Oil Refinery

Then the monitored data was statistically analyzed and checked with the acceptance levels indicated in the national ambient air quality standards stipulated by the Ministry of Environment Sri Lanka. Sri Lanka has standards for ambient air quality as published in Gazette notification No. 1562/22 dated 15/08/2008. These standards are expressed as Permissible Ambient Air Quality Standards with the classes of Air Pollutants. The specified pollutants are PM_{10}, $PM_{2.5}$, NO_2, SO_2, O_3, and CO.

2.5 Statistical Analysis of Air Quality

The sample data were analyzed using paired samples t-test, one-way ANOVA and Wilcoxon signed ranked test to find out the significant levels of each parameter under consideration. The test hypothesis for comparison is as follows.

H_0: The two groups are equal.

H_1: The two groups are not equal.

A comparison between passive sampling results for SO_2 and NO_2 was performed using the paired sample t-test. The method can be applied here because the sample size is reasonably larger. A test statistic t value is calculated using the sample data and is compared to a critical t value: $t_{crit.}$ The rejection criteria are:

If t >t_{crit}then the null hypothesis that the two-sample means are equal can be rejected.

If t <t_{crit}then the null hypothesis that the two-sample means are equal cannot be rejected.

The comparison of active sampling results for SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ was carried out using Wilcoxon signed ranked test. The method was selected since the sample size is small. The Wilcoxon signed rank test utilizes the sum of the ranks 'W' calculated against the W_{crit} obtained from the tables. The rejection criteria are:

If W >W_{crit}, then the null hypothesis that the two-sample means are equal can be rejected.

If W <W_{crit}then the null hypothesis that the two-sample means are equal cannot be rejected.

The temporal and spatial variation of exposure levels of NO_2 and SO_2 using a passive monitoring method was carried out in five selected locations in two-week intervals from June – 2018 to August – 2018. The test hypothesis is as follows.

H_0: The group means are equal.

H_1: The group means are not equal/ significantly different.

The variations were statistically analyzed with one-way ANOVA where a test statistic F is calculated and is compared to a critical F value, F_{crit}. The rejection criteria are:

If F >F_{crit}, H_0 can be rejected,

If F <$F_{crit,}$ H_0 cannot be rejected.

The analysis was performed with the Microsoft Excel Data Analysis Toolkit and the Real Statistic Toolkit for Excel.

3. Results and Discussion

3.1 Air Quality Monitoring by Active Sampling

Figure 2 shows box plots of SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ concentrations at five selected locations during the refinery shutdown (March 2018) and operation periods (October 2018) using the active sampling method. The ranges of the results, which are upper and lower quartiles, and median levels are depicted in boxplots.

The ambient air quality standards for active sampling stipulated by the Ministry of Environment, Sri Lanka, for SO_2,is 120 µg/m^3, NO_2 is 150 µg/m^3, O_3 is 200 µg/m^3, PM_{10} is 100 µg/m^3, and $PM_{2.5}$ is 50 µg/m^3.Consequently, the measured levels of ambient air quality for SO_2, NO_2, O_3, $PM_{2.5}$, and PM_{10} during the shutdown period of the refinery and the normal operating period of the refinery are lower than the ambient air quality standards stipulated by the Ministry of Environment of Sri Lanka.Figure2 shows that the measured concentration levels in the two cases differ. The average levels of SO_2 range from 18.8 µg/m^3 during the refinery shutdown period to 19.20 µg/m^3 during the refinery operation period. No significant differences were observed in the SO_2 concentration levels in both scenarios.

Average concentration levels of NO_2 vary from 34.80 µg/m^3 during the refinery shutdown period to 55.40 µg/m^3 during the refinery operation period while indicating a higher concentration of NO_2 during the refinery operation period. Again, the mean values of O_3 were 11.40 µg/m^3 during the refinery shutdown period and 11.80 µg/m^3 during the refinery operation period. Nonetheless, PM_{10} and $PM_{2.5}$ during the refinery shutdown period are higher than the concentration levels during the refinery operation periods.

The concentration of PM_{10} during the refinery shutdown period in March was 47.40 µg/m^3, compared to 26.80 µg/m^3 during normal operations in October. The concentration of $PM_{2.5}$ during the shutdown period was 26.20 µg/m^3, whereas it was 14.80 µg/m^3 during normal operations. The higher concentrations of particulate matter during the shutdown period can likely be attributed to intensive maintenance activities, such as equipment servicing and material handling, which are known to generate dust and increase particulate emissions [20]. Furthermore, weather conditions also play a significant role here. The shutdown occurred in March 2018, a drought period with minimal rainfall (5.4 mm during the test period), which allowed particulate matter to remain airborne for longer durations.

In contrast, the normal operation period in October 2018 had a high rainfall (43.6 mm during the test period), which likely contributed to lower particulate matter concentrations by washing particulates out of the atmosphere [21]. The combined effects of maintenance activities and the seasonal difference in rainfall likely explain the observed higher concentrations of $PM_{2.5}$ and PM_{10} during the shutdown period.

A study [22] on influencing factors of atmospheric particulate matter in Beijing, found that meteorological factors have a strong correlation with the variation of particulate matter concentration. Although wind patterns and other meteorological variables can affect pollutant dispersion, the trends observed in this study provide important insights into the refinery's influence on local air quality. Future research should incorporate detailed meteorological data, including wind direction and speed, to provide a more comprehensive understanding of these effects.

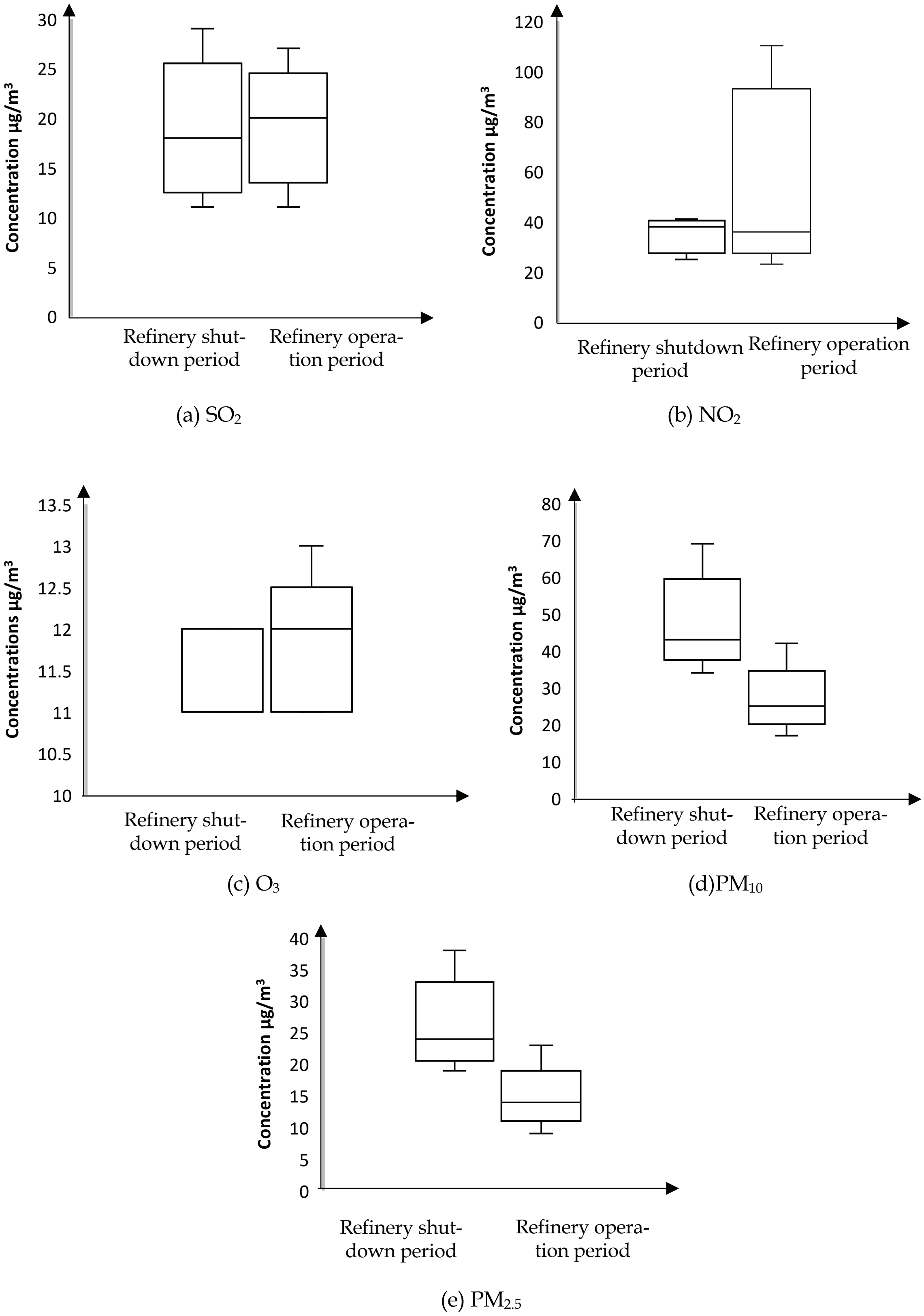


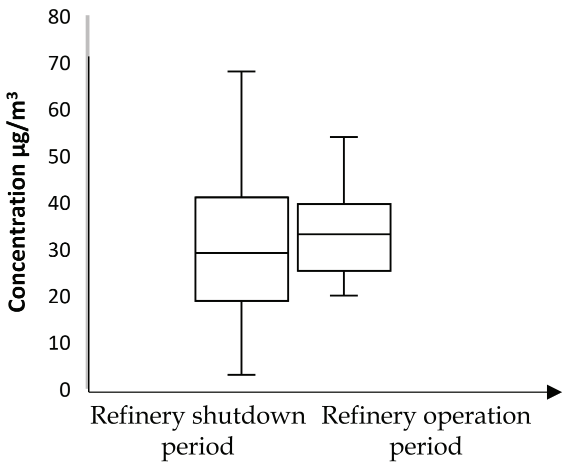
Figure 2-Measured concentrations of air pollutants during refinery shutdown and normal refinery operation periods using active sampling method at five selected stations: *(a) SO_2, (b) NO_2, (c) O_3, (d) PM_{10}, (e) $PM_{2.5}$*

3.2 Statistical Analysis of Air Quality Monitoring by Active Sampling

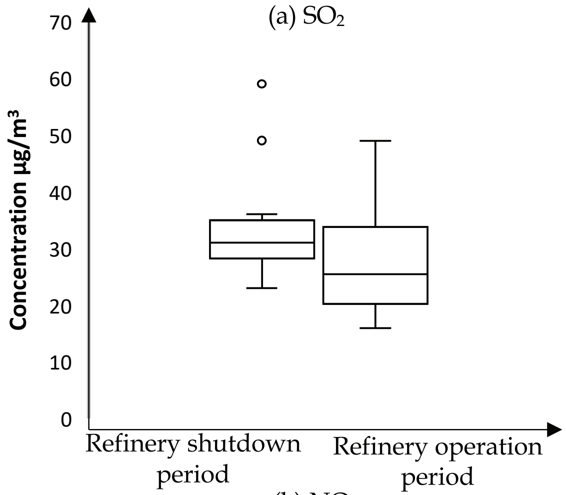
Active monitoring results indicated that SO_2, NO_2, and O_3 concentrations during the normal operation of the refinery are not statistically significantly different from those during the refinery shutdown period (Wilcoxon Signed Ranks Test; For SO_2, W=8, p = 0.094, NO_2, W=11, p = 0.062, O_3, W=7.5, p = 0.125). PM_{10} and $PM_{2.5}$ indicated that ambient concentrations during refinery shutdown are statistically significantly higher than during the normal operation period of the refinery(Wilcoxon Signed Ranks Test; W=1, p = 0.031).

3.3 Air Quality Monitoring by Passive Sampling

Figure 3 shows boxplots of SO_2 and NO_2 concentrations at the twenty selected locations during refinery shutdown (March) and operation periods (October) using passive sampling method.



(a) SO_2



(b) NO_2

Figure 3 - Measured concentrations of air pollutants during refinery shutdown and refinery normal operation periods using the passive sampling method at twenty selected stations: (a) SO_2 and (b) NO_2

The ambient air quality standards for passive sampling stipulated by the Ministry of Environment of Sri Lanka for $SO_2$is 80 µg/m^3 and NO_2 is 100 µg/m^3.Therefore, the air quality levels monitored are less than the air quality standards of the environment stipulated by the Ministry of Environment.

According to Figure 3, the average SO_2 levels vary from 31.55 µg/m^3 during the refinery shutdown period to 33.55 µg/m^3 during the refinery operation period. Average concentration levels of NO_2 vary from 33.65 µg/m^3 during the refinery shutdown period to 27.55 µg/m^3 during the refinery operation period. The SO_2 and NO_2 tests with the active sampling method further assured the result obtained by the passive sampling method.

3.4 Statistical Comparison of Air Quality during on and off Operation of the Refinery

To find out if there exist any significant differences in the results obtained during the on-and-off operation of the refinery, the paired-sample t-test and Wilcoxon signed ranks test were carried out for the results obtained from passive sampling.

The passive monitoring results of SO_2 indicate that there are no statistically significant differences between the shutdown period of the refinery and the normal operation period; paired-samples t-test t (19) = 0.5107, p = 0.61545. Similarly, the ambient concentration of NO2 indicates no statistically significant difference for the refinery shutdown period and normal operation period; paired-samples t-test t (19) = 1.85939, p = 0.07853. These results suggest that the operation of the petroleum refinery does not have an effect on the ambient concentrations of SO_2 and NO_2 within the area under investigation.

3.5 Continuous Monitoring by Passive Sampling During Plant Operation

To see if there exist any statistically significant spatial or temporal variations in the SO_2 and NO_2 concentration results obtained by continuous monitoring by passive sampling during the plant operation, a one-way ANOVA test was carried out.

The exposure levels of NO_2 and SO_2 measured using the passive sampling method over three months at five selected locations are shown in Figure4 and Figure5. The test periods are 7th June–21stJune, 22nd June–3rd July, 4th July–17th July, 18th July–31st July, 1st August–14th August, and 15th August–28th August and are represented by T1, T2, T3, T4, T5 and T6, respectively. The period of exposure of the samples was two weeks and the refinery was in normal operation during this period. The mean values of measured concentrations of SO_2 in five selected locations in the study area are 25.8±10.7, 29.2±8.8, 24.6±10.3, 23.2±6.8, 23.0±7.6 and 22.4±5.1 μg/m^3. The measured values are well below the maximum allowed levels prescribed in the national air quality regulation, which is 80 μg/m^3. No statistically significant spatial variation of concentrations of SO_2 was detected (One-way ANOVA F (4,25) = 1.28, p = 0.30). The temporal variation of concentrations of SO_2 was also not statistically significant (One-way ANOVA F (5,24) = 0.44, p <0.81).

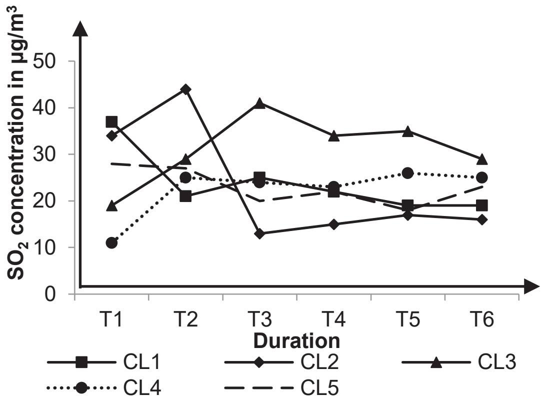


Figure 4 –Temporal Variation of Two-Week Average Exposure Level of SO_2 (μg/m^3) at Five Passive Monitoring Locations Measured over Three Months

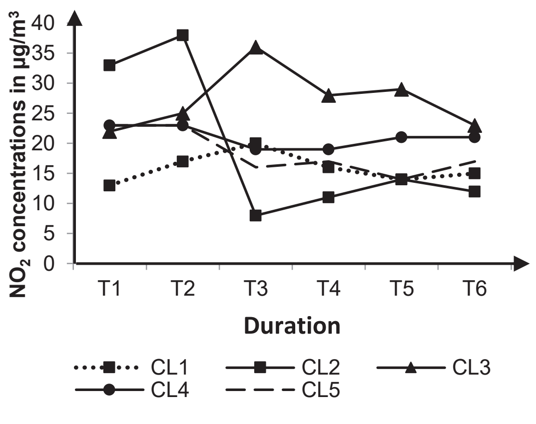


Figure 5 - Temporal Variation of Two-Week Average Exposure Level of NO_2 (μg/m^3) at Five Selected Locations Measured over Three Months using Passive Sampling Method

4. Conclusions

This study investigated the impact of the Sapugaskanda Oil Refinery on ambient air quality using monitoring data collected during both refinery shutdown and normal operation periods. The results indicate that the ambient concentrations of SO_2, NO_2, and O_3 were below the maximum permissible levels set by the Ministry of Environment, Sri Lanka. Additionally, there were no statistically significant differences in the concentrations of these pollutants between the refinery shutdown and operation periods, suggesting that these pollutants do not primarily originate from the refinery.

In contrast, particulate matter ($PM_{2.5}$ and PM_{10}) concentrations were significantly higher during the refinery shutdown period, likely due to increased maintenance activities. However, it is important to note that other contributing factors, such as the dry weather conditions during the shutdown period, may have also influenced these elevated concentrations. This highlights the need for further investigation to accurately attribute the sources of particulate matter emissions.

One limitation of this study is the potential influence of meteorological variations, such as wind direction, rainfall, and temperature, which were not fully accounted for. These factors can significantly affect pollutant dispersion and concentration levels. Additionally, the relatively short monitoring period may not capture long-term trends or seasonal variations in pollutant behaviour. A notable limitation of this study is the lack of comparative data from similar studies conducted at oil refineries in other Asian countries. Therefore, further research is recommended to comprehensively assess the temporal and spatial variability of pollutant concentrations, with a particular focus on meteorological influences. A more detailed study, incorporating long-term monitoring and advanced modelling techniques, is required to confirm the sources and reasons behind the observed particulate matter emissions.

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