Inhalable Particulate ($PM_{2.5}$)

State of the Environment Monitoring

Annual Report

2020-2021

Technical Report 2022-83

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Taranaki Regional Council

Taranaki Regional Council
Private Bag 713
Stratford

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Executive summary

Section 35 of the Resource Management Act (RMA) requires local authorities to undertake monitoring of the region's environment, including land, air, and fresh and marine water quality. This report describes the results of the Taranaki Regional Council's Inhalable Particulate programme from throughout the period 2020-2021. The programme is designed to assess the quality of the ambient air in the New Plymouth CBD through the continuous monitoring of $PM_{2.5}$ concentrations (particulate matter less than 2.5 microns across) at Central School. The Council decided to monitor for $PM_{2.5}$ in lieu of PM_{10}, to align with proposed amendments to the National Environmental Standards for Air Quality, which proposes that $PM_{2.5}$ is more meaningful for evaluating public health risk than the current PM_{10} standard.

The monitoring programme entailed the sampling of air using a Beta Attenuated Monitor (BAM) equipped with a $PM_{2.5}$ size selective inlet, sited at Central School, New Plymouth. Continuous sampling has been conducted from February 2016 – December 2021, when the equipment was decommissioned and replaced. This report is focussed on monitoring results obtained at the site between January 2020 and December 2021, and is supplementary to the Inhalable Particulate ($PM_{2.5}$) Monitoring Programme Report 2016-2020.

Results show that between 2016 and 2021, 96% of daily mean $PM_{2.5}$ concentrations fell into the Ministry for Environment's 'excellent' or 'good' air quality categories. There were no exceedances of the 2005 World Health Organisation's (WHO) daily mean threshold of 15 $\mu g/m^3$. However, the maximum individual daily mean recorded over the entire dataset, 18 $\mu g/m^3$, represents a single exceedance of WHO's updated and more stringent 2021 guidelines. An annual mean of 4 $\mu g/m^3$ was recorded for each of the six years of monitoring at the Central School site, which is below both the 2005 and 2021 WHO maximum annual mean guidelines.

Monitoring results from the 2020 and 2021 years lend weight to previous findings that emissions from domestic fires used for heating are a major contributor to concentrations of $PM_{2.5}$ levels during winter months. The elevated levels of $PM_{2.5}$ recorded during colder winter months result in a clear seasonality in the overall Central School dataset. Exploratory long-term trend analysis undertaken on the complete Central School $PM_{2.5}$ record shows no evidence that overall $PM_{2.5}$ concentrations in New Plymouth are either increasing or decreasing. It is however, recommended that the Council continues to carry out screening monitoring to determine the extent and severity of winter domestic heating pollution in the region's other urban centres.

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1 Introduction

1.1 General

This report summarises the results for the Inhalable Particulate ($PM_{2.5}$) State of Environment programme over the 2020-2021 calendar years. This is the second report on the Council's continuous $PM_{2.5}$ monitoring programme, which was initiated in 2016. With the decommission of the Central School E-BAM monitoring equipment in December 2021, this report summarises the results of the last two years of monitoring at this site, and completes the reporting of results from this particular E-BAM set-up. The present report is written as a supplement to the more major 2016-2020 report. The reader is referred to this earlier report for an in-depth introduction to the programme and more complete discussion of air quality in New Plymouth.

1.2 Background

In October 2004, the National Environmental Standards for Air Quality (NES-AQ) were released by the Ministry for the Environment (MfE). The NES is built up of 14 standards, which together aim to set a guaranteed minimum level of health protection for all New Zealanders. One aspect of air quality which is covered by the NES, and forms the focus of this report, is fine particulates, which can pose a health hazard when inhaled into the body.

While relatively coarse particulate matter of 2.5-10 µm diameter may deposit in the nose, throat and upper airways, finer particulates of less than 2.5 µm ($PM_{2.5}$) can be inhaled deeper into the lungs, where air-blood exchange occurs. Ultrafine particles, of less than 0.1 µm diameter, are small enough to transfer into blood vessels and circulate around the body. While coarser particulates settle on the ground relatively quickly, fine and ultrafine particles can remain suspended in the air for extended periods of time. Short term episodes of exposure to PM pollution has been shown to correlate with increased adverse medical outcomes for heart, respiratory and circulation conditions (eg asthma, emphysema, heart attack, strokes); over the longer term, increased concentrations correlate with increased cancer rates and premature death rates as well as chronic respiratory illnesses.

While the current NES-AQ, set by MfE in 2004, is for fine particulate matter of 10 µm diameter (PM_{10}), it is anticipated that the next revision of the NES-AQ will focus on $PM_{2.5}$, given its higher potential for adverse health effects. As a result, in this report exposure to $PM_{2.5}$ has been assessed against the 2005 World Health Organisation guidelines, which are expected to be taken up in the revised NES-AQ. For the first time, exposure is also assessed against the more stringent $PM_{2.5}$ air quality guidelines that the World Health Organization recommended in September 2021.

Table 1 WHO guidelines for $PM_{2.5}$ monitoring

Averaging Period	Permissible Exceedances (per year)	2005 Threshold (µg/m^3)	2021 Threshold (µg/m^3)
24-hours	3	25	15
Annual	NA	10	5

2 Monitoring methodology

2.1 Site location

The Central School site, shown in Figure 1 through Figure 3, is centrally located, with the edge of the New Plymouth CBD and main traffic routes 100-200 m to the north, and residential area surrounding the site to the south, west, and east. The site is located at the 'crossroad' of the prevailing wind directions from the west and south-east, lying in the path of air flows that have either just passed over, or are about to impinge on, residential areas. The site is thus located in a sensitive area, which is exposed to possible $PM_{2.5}$ emissions arising from traffic, commercial, and residential sources.

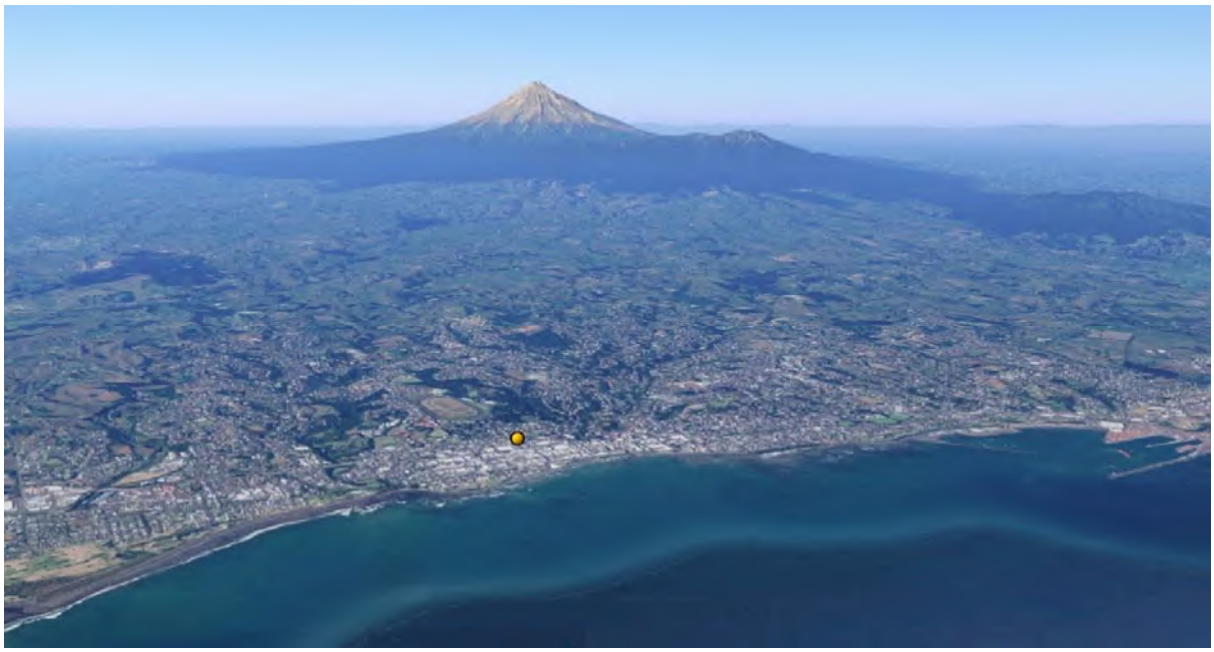

Figure 1 Overview of the regional setting of the Central School $PM_{2.5}$ monitoring site (yellow dot). The image is taken facing true South. (Background image: Google, 2020)

2.2 Monitoring equipment and method

A Met Instruments Inc. Model E-BAM measurement system (Figure 4) was used to automatically measure and record airborne $PM_{2.5}$ concentration levels at the Central School site between 2016 and 2021. While the beta attenuation method is one of four general recognised equivalent methods for $PM_{2.5}$ monitoring, the E-BAM system employed is not currently designated as a US EPA Federal Equivalent Method (FEM). It was, however, deemed to be the most appropriate instrument to use in this case, given that this monitoring programme represented a first test both of continuous monitoring at a permanent ambient air site, and of SEM $PM_{2.5}$ monitoring in the region. The E-BAM equipment at Central School was decommissioned in December 2021, and replaced with an upgraded BAM1022 system in July 2022. Further details on the E-BAM equipment and data collection can be found in the report Inhalable Particulate ($PM_{2.5}$) Monitoring Programme Report 2016-2020 (TRC, 2020).

Figure 2 Location of the Central School $PM_{2.5}$ monitoring site within New Plymouth

Figure 3 Location of the $PM_{2.5}$ monitoring site in the NE corner of Central School (yellow dot)

Figure 4 E-BAM set-up and installation at Central School, New Plymouth

2.3 Data processing and analysis

In accordance with the *MfE Good Practice Guide for Air Quality Monitoring and Data Management 2009*, data collected during the calibration and maintenance period was excluded to provide sufficient time within the data record for instrument stabilisation. Data screening was also undertaken, with data removed for periods where the E-BAM air-flow rate dropped by more than 5% from its usual steady state of 16.7 L/min. Spikes in $PM_{2.5}$ levels were also investigated, with data removed when the spike was found to be due to monitor malfunction, or other anomalous events – such as when it was found people were smoking directly underneath the monitoring equipment.

In line with *MfE 2009,* negative data values were left in the data record. This is particularly important given the generally low ambient concentrations of $PM_{2.5}$ measured, as there were a notable number of hourly measurements with $PM_{2.5}$ concentrations between 0 and -5 $\mu g/m^3$. These measurements are, within analytical uncertainty, indistinguishable from the lower detection limit of the E-BAM, so were retained in the overall data set as to avoid artificially increasing the average ambient concentration. The exception to this was between midnight and 01:00 each day, when the E-BAM automatically undertook a filter change and recalibration. Here, a large negative spike was consistently encountered in the record. The decision was made to omit the 24:00 to 01:00 hour from daily average calculations, resulting in 23-hour averages been calculated, rather than 24-hour.

All hourly averages in the main database apply to the preceding hour (e.g. the hourly measurement for 13:00 represents data collected between 12:00 and 12:59). However, for compatibility reasons, all measurements were stepped back one hour when imported into R software. Thus in all plots and statistics in this report, data assigned to e.g. 13:00 is for the time period 13:00 to 13:59. All measurements are recorded and reported in NZST.

All statistical analyses and plots produced in this report were undertaken and produced using the R statistical software (R Development Core Team. 2011), using the package 'openair' (Carslaw and Ropkins. 2012).

3 Results

3.1 Summary statistics

Daily $PM_{2.5}$ concentration means were calculated from hourly data for days where at least 18 hours of data was obtained (a 75% data acceptance threshold). A summary of results from the entire monitoring period, and for each year, is given in Table 2 and Figure 5, below. It is noted that while the 75% data threshold is met for every year of the monitoring programme, there may be some bias in the 2016 statistics, as the monitoring programme was only commenced at the end of February.

Table 2 $PM_{2.5}$ air quality summary statistics, based on daily means

Year	Days of Data	% Data Capture	Mean	Max	Median	25th percentile	75th percentile	95th percentile
2016	310	84.7	4	14	4	3	5	8
2017	344	94.2	4	13	4	3	5	7
2018	357	97.8	4	11	4	3	5	7
2019	365	100.0	4	13	4	3	5	8
2020	327	89.3	4	13	3	2	4	7
2021	330	90.4	4	18	4	3	5	7
Total	**2,033**	**92.7**	**4**	**18**	**4**	**3**	**5**	**8**

3.2 Comparison to WHO guidelines

Overall, data across the entire monitoring period shows that New Plymouth experiences low concentrations of $PM_{2.5}$, with the annual mean remaining steady at 4 µg/m^3 throughout the entire six years of monitoring. All annual means are below both the 2005 WHO guideline of 10 µg/m^3, as well as the more stringent revised 2021 guideline of 5 µg/m^3. In addition, there have been no exceedances of the 2005 WHO daily mean guideline of 25 µg/m^3 throughout the entire monitoring programme. A single exceedance of the revised 2021 WHO daily mean guideline (15 µg/m^3) was recorded, in February 2021. With three allowable exceedances of the daily mean guideline within a year, this single exceedance is not of major concern. Over the entire six years of monitoring, the 95th percentile of $PM_{2.5}$ concentrations lies around 44% of the maximum daily value that was recorded. This indicates that it is only a few days that have mean $PM_{2.5}$ levels significantly higher than the typical range, and indeed, mean concentrations exceeded 10 µg/m^3 on only 26 days over the near six years of monitoring.

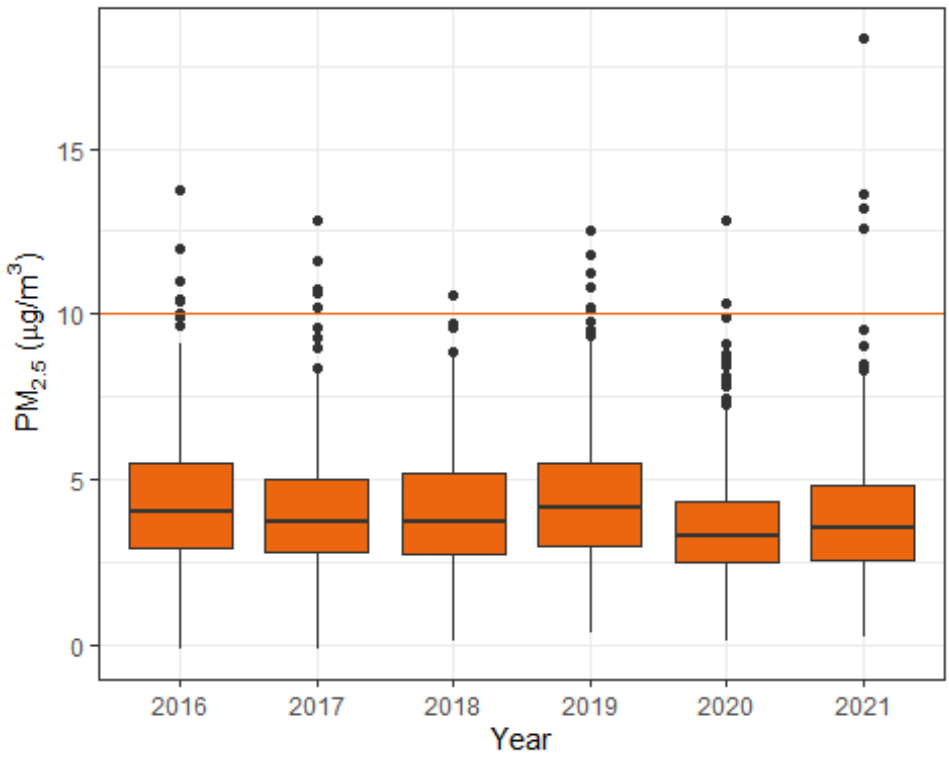

Figure 5 Boxplots of daily mean $PM_{2.5}$ concentrations from each year of the monitoring programme. The orange line depicts the 2005 WHO guideline for mean annual $PM_{2.5}$ levels. The guideline for daily average concentration advised by WHO in 2005 is 25 µg/m^3, well above the maximum recorded concentration, and outside the bounds of the plot

The MfE ambient air quality guidelines (MfE 2002) propose that regional air quality can be categorized based on a comparison with the ambient guidelines. These categories are set out in Table 3, using the 2005 WHO daily mean threshold of 25 µg/m^3 as a reference. The results show that the over the six years of monitoring, the air in New Plymouth can be considered to have been 'excellent' or 'good' 96% of the time, and at least 'acceptable' on all bar one day. Results are relatively constant across the six years of monitoring. Further details on the air quality categories recorded for each year are given in Table 3 and Figure 6.

Table 3 Number of days falling into environmental performance indicator category each year of monitoring

Year	Excellent (>2.5)	Good (2.5–8.3)	Acceptable (8.3-16.6)	Alert (16.6-25)	Action (>25)
2016	58	234	18	0	0
2017	70	264	10	0	0
2018	74	274	9	0	0
2019	54	294	17	0	0
2020	85	233	9	0	0
2021	81	238	10	1	0
Total	422 (20.8%)	1537 (75.6%)	73 (3.6%)	1	0

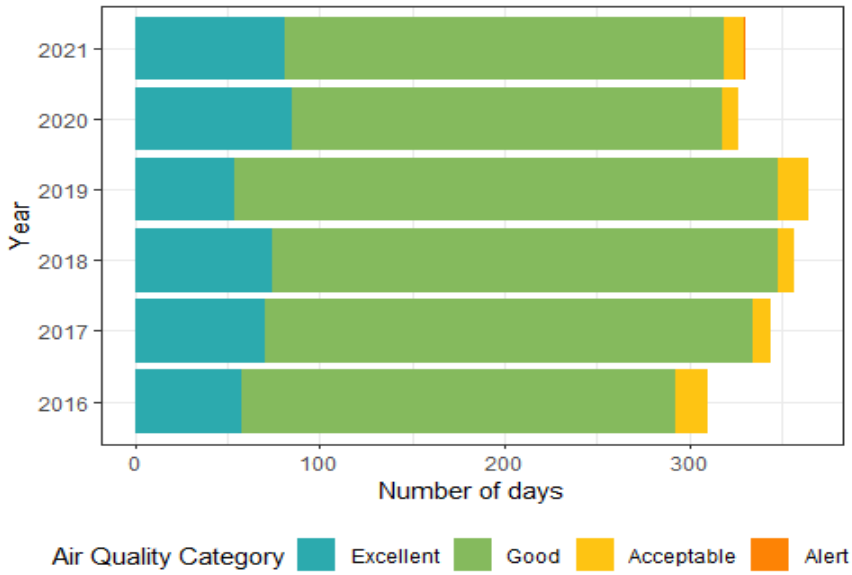

Figure 6 Number of days per calendar year with $PM_{2.5}$ concentrations in each air quality category

3.3 Temporal Patterns

Throughout 2020 and 2021, observed diurnal variations in $PM_{2.5}$ concentrations continued to show similar patterns to the previous four years (Figure 7). In particular, a strong seasonality is observed, with winter $PM_{2.5}$ concentrations displaying a different diurnal pattern to the other three seasons. In particular, dual peaks in $PM_{2.5}$ concentrations are observed in the mornings and evenings during winter months (June – August). These are consistent with the influence of wood fires being used for home heating throughout winter, with a large peak in evenings while a smaller morning peak could be due to some households relighting burners during the cool morning hours.

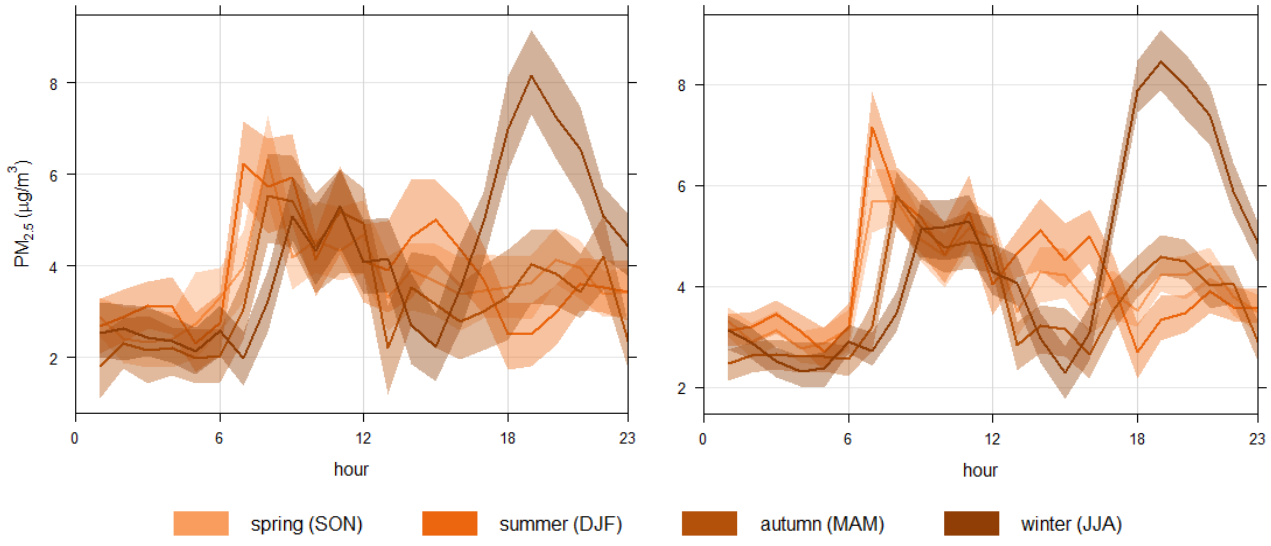

Figure 7 Comparison of the diurnal variation in $PM_{2.5}$ concentration during different seasons, for 2020 and 2021 (left), and for the full 2016-2021 monitoring period (right). 95% confidence intervals for the means are shown by the shaded areas

4 Trend Analysis

Mean daily $PM_{2.5}$ concentrations throughout the entire monitoring period are shown in Figure 8. Long term trend analysis was carried out on the Central School measurement records using a non-parametric Theil-Sen approach. Long term trends are more easily identified in longer continuous data sets than that currently recorded at this site, or when a known change of regulations or conditions has occurred in the region. However, an exploratory analysis is none-the-less undertaken in this case.

The Theil-Sen trend estimate, undertaken on de-seasonalised monthly-mean data, is shown in Figure 9. Data is analysed between March 2016 and December 2021. Given the breadth of the 95% confidence interval, which encompasses 0, it is indeterminate whether $PM_{2.5}$ levels are increasing, decreasing, or remaining steady.

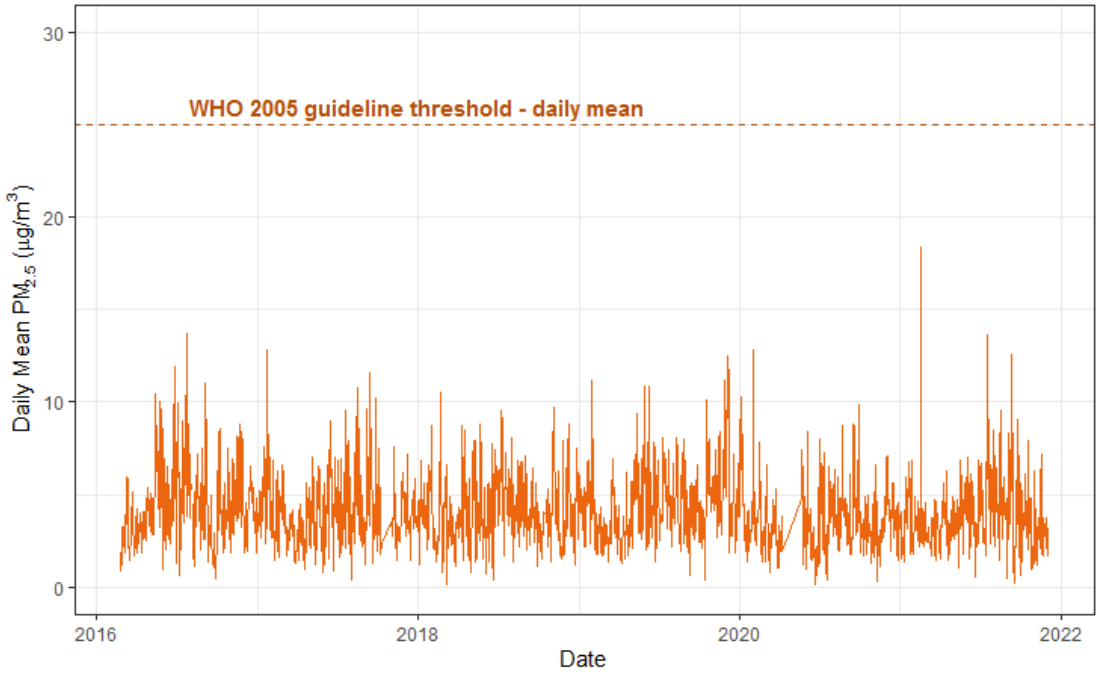

Figure 8 Daily average time series of $PM_{2.5}$ for the monitoring period.

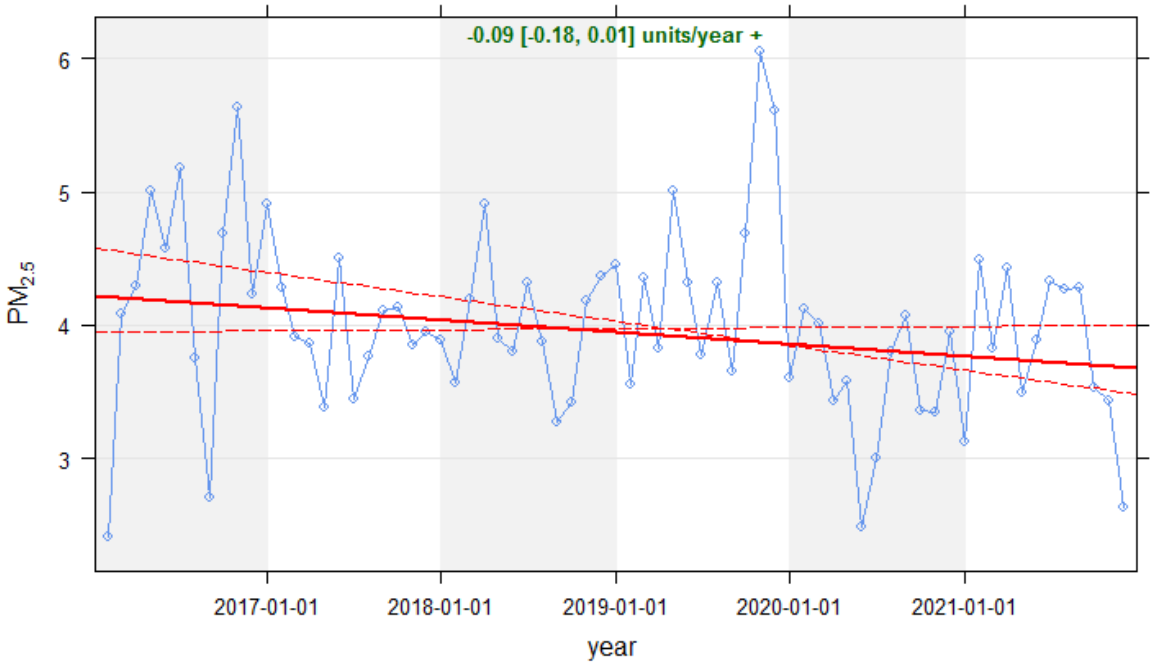

Figure 9 De-seasonalised monthly mean $PM_{2.5}$ concentrations and Theil-Sen trend line for data from the Central School site between March 2016 and December 2021. Dashed red lines represent the trend lines containing the 95% confidence interval

5 Discussion

Overall, the results of continuous $PM_{2.5}$ monitoring at Central School over the 2020 and 2021 calendar years reinforce the findings of monitoring between 2016 and 2020. The reader is referred to the 2016-2020 report (TRC 2020) for a detailed discussion of inhalable particulate air quality in New Plymouth, including meteorological correlations and possible anthropogenic drivers of pollution.

Results of monitoring to date show that $PM_{2.5}$ concentrations are consistently very low at the New Plymouth site, with an annual mean of 4 $\mu g/m^3$ recorded throughout the entire monitoring period, well below the guideline of 10 $\mu g/m^3$ set by WHO in 2005. Throughout the 2016-2021 monitoring period, 96% of days were categorised as having 'Excellent' or 'Good' $PM_{2.5}$ levels, with all but one day of the remaining 4% falling into the 'Acceptable' category. There were no exceedances of WHO's 2005 daily mean guideline of 25 $\mu g/m^3$, and only one exceedance of the recently revised 2021 WHO guideline of 15 $\mu g/m^3$.

A strong seasonal variation is observed in $PM_{2.5}$ levels due to domestic heating in the colder months. In the 2016-2020 report, this increase in $PM_{2.5}$ concentrations was shown to be correlated with cold calm evenings when the dispersal of pollutants from home heating is reduced by stable atmospheric conditions. It was suggested in this report that the effect of domestic heating emissions was likely to be greater in other localised areas in the region. Such vulnerable areas include non-coastal sites and sheltered valleys. Here, air drainage from the surrounding higher land may lead to stronger temperature inversions and an increased level of trapped $PM_{2.5}$ emissions near ground level.

Given the potential elevation of $PM_{2.5}$ concentrations in vulnerable areas, it is recommended that the Council continues to carry out screening monitoring to determine the extent and severity of winter domestic heating pollution in the region's urban centres.

6 Future Monitoring at Central School

This report completes the analysis of the full data set obtained with the decommissioned Met-One systems E-BAM monitoring set-up at Central School. Following the decommission of the E-BAM monitoring equipment in December 2021, the Central School site has been upgraded with the installation of a Met-One BAM1022 system completed in July 2022 (Figure 10). The BAM1022 uses a Federal Equivalent Method, improving the robustness and thus reporting uses of the data obtained at this site. Monitoring with the BAM1022 commenced on 2nd July 2022. Initial data will be compared to that obtained with the E-BAM set up, ensuring the compatibility of the two datasets to enable a continuous and ongoing record of $PM_{2.5}$ at the Central School site.

Once repaired, it is hoped that the Met-One E-BAM equipment will be used as a mobile ambient air quality monitoring set up, enabling $PM_{2.5}$ screening surveys to be undertaken at different locations around the region.

Figure 10 The new BAM1022 monitoring set-up at Central School. July 2022

7 Recommendations

1. THAT it be noted that Taranaki Regional Council has now carried out continuous gathering of $PM_{2.5}$ data in New Plymouth's CBD for a period of almost 6 years, spanning February 2016 – December 2021.
2. THAT it be noted that the E-BAM equipment used in monitoring at Central School to date is now decommissioned, and replaced with an upgraded Met One BAM1022 monitor, with data collection resuming on 2nd July 2022.
3. THAT it be noted that $PM_{2.5}$ monitoring of ambient air in New Plymouth has shown low mean $PM_{2.5}$ concentrations, with no exceedances of the 2005 WHO recommended thresholds, and only one exceedance of the more stringent 2021 WHO recommended thresholds.
4. THAT it be noted that sea spray is a major contributor of $PM_{2.5}$ in the Taranaki region year-round, with domestic heating also being a significant contributor during winter months.
5. THAT the Taranaki Regional Council continues to carry out regional screening $PM_{2.5}$ monitoring to determine the extent and severity of winter domestic heating pollution in the region's urban centres.

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