Northland Air Quality

State and trends 2015 – 2021

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Abbreviations/Glossary

Term	Meaning
AAQG	Ambient Air Quality Guidelines
Aerodynamic diameter	Particulate matters have irregular shape, and their behaviour in air is expressed in terms of the diameter of a spherical particle.
Aerosol	Mixture of very small solid or liquid particles that can remain suspended in air from few minutes to many months depending on particle size and weight.
Airshed	Also known as 'gazetted airshed'. Airshed is an 'air quality management area' (i.e., an area delineated by the regional council for the purposes of managing air quality).
Ambient air quality	General quality of the surrounding air, reflecting the cumulative effect of all activities, both anthropogenic and natural. This does not include air quality inside the buildings.
Anthropogenic	Generated by human activities
BAM	Beta Attenuation Monitor
BAU	Business as Usual
CO	Carbon Monoxide, an air pollutant.
Coarse particles	Particulate matter sized between 2.5 µm and 10 µm
EPI	Environmental Performance Indicator
Fine particles	Particles less than 2.5 µm in size
HAPINZ	Health and Air Pollution in New Zealand
IANZ	International Accreditation New Zealand
LAWA	Land Air Water Aotearoa. Platform to share environmental data and information in New Zealand
MfE	Ministry for the Environment
µm	Micrometre. One millionth of a metre
MoH	Ministry of Health
NAAQG	National Ambient Air Quality Guidelines
NESAQ	National Environmental Standard for Air Quality
NIWA	National Institute of Water & Atmospheric Research
NO_2	Nitrogen Dioxide, a harmful air pollutant
NZTA	The New Zealand Transport Authority
PCE	Parliamentary Commissioner for the Environment
PM	Particulate matter made up of various sizes.
PM_{10}	Particulate matter less than 10 µm in aerodynamic diameter.
$PM_{2.5}$	$PM_{2.5}$ is a subset of $PM_{10,}$ which is less than 2.5 µm in aerodynamic diameter. Also referred to as fine particulate.
RH	Relative Humidity
RMA	Resource Management Act
Sea salt	Particulate matter released to air through the action of wind and waves. Also called marine aerosol.
Windblown dust	Particulate matter released from unsealed roads, construction sites, land use activities etc
WHO	World Health Organisation
WSL	Watercare Services Limited

Executive Summary

Having clear and clean air is essential for human health and the environment. Northland enjoys high standard of air quality, thanks to the south-westerly wind, a relatively dispersed population, low vehicle density and few heavy industries. The quality of air we breathe is influenced by natural and human activities. The key issues affecting Northland's air quality are solid fuel burning for home heating, backyard burning, transport, industrial emission, agrichemical application and dust from vehicles travelling on unsealed road or earthworks.

People with respiratory and heart disease, diabetes, children, and pregnant women are more susceptible to the dangers of air pollutants. The World Health Organisation 2021 report estimates about seven million deaths annually are caused because of air pollution. Based on 2016 data, Health and Air Pollution New Zealand study suggested that human made air pollution causes around 98 premature deaths per year in Northland. The same report estimated the social cost from air pollution in Northland as $461 million each year.

Northland Regional Council (council) ensures that air quality in Northland region is maintained within the National Environmental Standards for Air Quality. To achieve the air quality standards, council adopted a new Proposed Regional Plan (incorporating provisions for air, water, and soil resources) in 2019. The plan contains rules around activities that cause air pollution. Council monitors compliance from discharge to air resource consents, investigates environmental incidents, and monitors the state of the region's air. The main objectives of air monitoring are to:

- Assess state of the air quality in Northland,
- Determine compliance with the National Environmental Standards for air quality and relevant guidelines,
- Assess effectiveness of air quality policies and plans,
- Determine trends in air quality, and
- Ensure public health is protected and amenity values maintained.

This report provides information on state and trends of PM_{10}, $PM_{2.5}$ and meteorological parameters monitoring conducted by the council at its two permanent monitoring stations located at Robert Street, Whangārei and Bream Bay College, Marsden Point airsheds between 2015 and 2021.

Both PM_{10} and $PM_{2.5}$ are continuously monitored using BAM (beta attenuation monitor). Along with PM_{10} and $PM_{2.5}$, council monitors meteorological parameters using Vaisala. Particulate matter monitoring and meteorological monitoring methods comply with respective standards. This report assesses particulate monitoring results against the National Environmental Standards for air quality (NESAQ) and World Health Organization (WHO) 2021 guidelines.

Between 2015 and 2021, PM_{10} concentrations at Whangārei and Marsden Point airsheds were compliant with the NESAQ. Similarly, $PM_{2.5}$ concentrations at Whangārei confirm compliance with the proposed NESAQ. However, an increase in PM_{10} and $PM_{2.5}$ concentrations was noticeable between December 2019 and January 2020, which is believed to be the effect of Australian bushfire. Seasonal variation showed a distinct seasonal peak for $PM_{2.5}$ concentrations with highest measurements in the months of June, July, and August. Similar but not as distinct peak was observed for PM_{10} at Whangārei in winter. However, PM_{10} concentrations at the Marsden Point were peaked during December, January, and February.

Statistical trend analysis of PM_{10} and $PM_{2.5}$ concentrations indicate a statistically significant reduction in particulate matter concentrations in Whangārei. However, PM_{10} trend analysis for Marsden Point did not show any sign of increase or decrease.

The effect of COVID-19 lockdowns in 2020 and 2021 on particulate matter concentration in Northland was investigated. PM_{10} concentrations at Whangārei, Marsden Point, and Kaitāia were significantly lower than business as usual (BAU) during level 4 restrictions. However, there was no reduction on PM_{10} concentrations at Marsden Point during 2021 lockdown.

Introduction

Ambient air quality is defined as the quality of surrounding air, reflecting the cumulative effect of human activities (industrial, commercial, domestic) and natural sources (MfE, 2009; NRC, 2022). Identifying these sources of emissions to air means that air quality management can be focused to manage air pollution more effectively.

Clean air is essential for the health of humans and the environment. Everyday each person inhales about 14,000 litres of air (LAWA, 2021). Breathing clean air is fundamental to our wellbeing, allowing us to live healthy and active lives. Many recreational, cultural, and economic activities are directly related to the clean air and the sky (MfE, 2022). Breathing polluted air can adversely affect human health, increasing rates of cardiovascular and respiratory related hospitalisation (Barnett et al., 2006). Health effects of air pollution and public concern regarding the quality of air we breathe has started to increase in the recent years as air pollution has become one of the leading environmental concerns in the world. In 2019, air pollution was identified as the fourth largest risk factor for early death globally, after high blood pressure, tobacco use and poor diet (Health Effects Institute, 2020). Recently, World Health Organization (WHO) estimated about seven million deaths annually from breathing polluted air (WHO, 2021).

Air quality in Northland

Northland's air quality is dominated by the region's exposure to the prevailing south-westerly winds, which quickly disperses air pollutants. This along with relatively dispersed population, low vehicle density and sparse heavy industry, means that Northland enjoys a high standard of natural air quality. However, based on the 2016 data, Kuschel et al. (2022) suggested that anthropogenic air pollution caused about 98 premature deaths per year in Northland alone. Kuschel et al. (2022) further estimated that the social cost from air pollution in Northland is approximately $461 million per year. Furthermore, Northland's air monitoring records suggested that on occasions pollutants approach or even exceed the National Environmental Standards for air quality (NESAQ). The NESAQ was established by the Ministry for the Environment (MfE) in 2004 to protect human health and the environment. These exceedances often occur under cool and calm conditions, during which air pollutants accumulate and increase to the levels that can be harmful to human health. Northland's air quality generally follows a seasonal trend, with better air quality observed during the summer months and worst air quality in winter. Exceptions are dust, which is more of an issue during summer due to lower rainfall and PM_{10} in coastal locations such as Marsden Point airshed, the majority of which is sea salt. The key issues affecting air quality in Northland are:

- Solid fuel burning for home heating and backyard burning,
- Agrichemical application,
- Transport and industrial emissions, and
- Dust from vehicles travelling on unsealed roads or other activities such as earthworks.

The Resource Management Act (RMA) 1991 requires council to manage air quality in Northland. There are five gazetted airsheds in Northland for air quality monitoring and management purposes. Northland's five air sheds are Kaitāia, Kerikeri, Whangārei, Marsden Point and Dargaville shown in Figure 1. Particulate matter (PM) is monitored at two permanent air monitoring stations, in Whangārei (PM_{10} and $PM_{2.5}$), and at Marsden Point (PM_{10}).

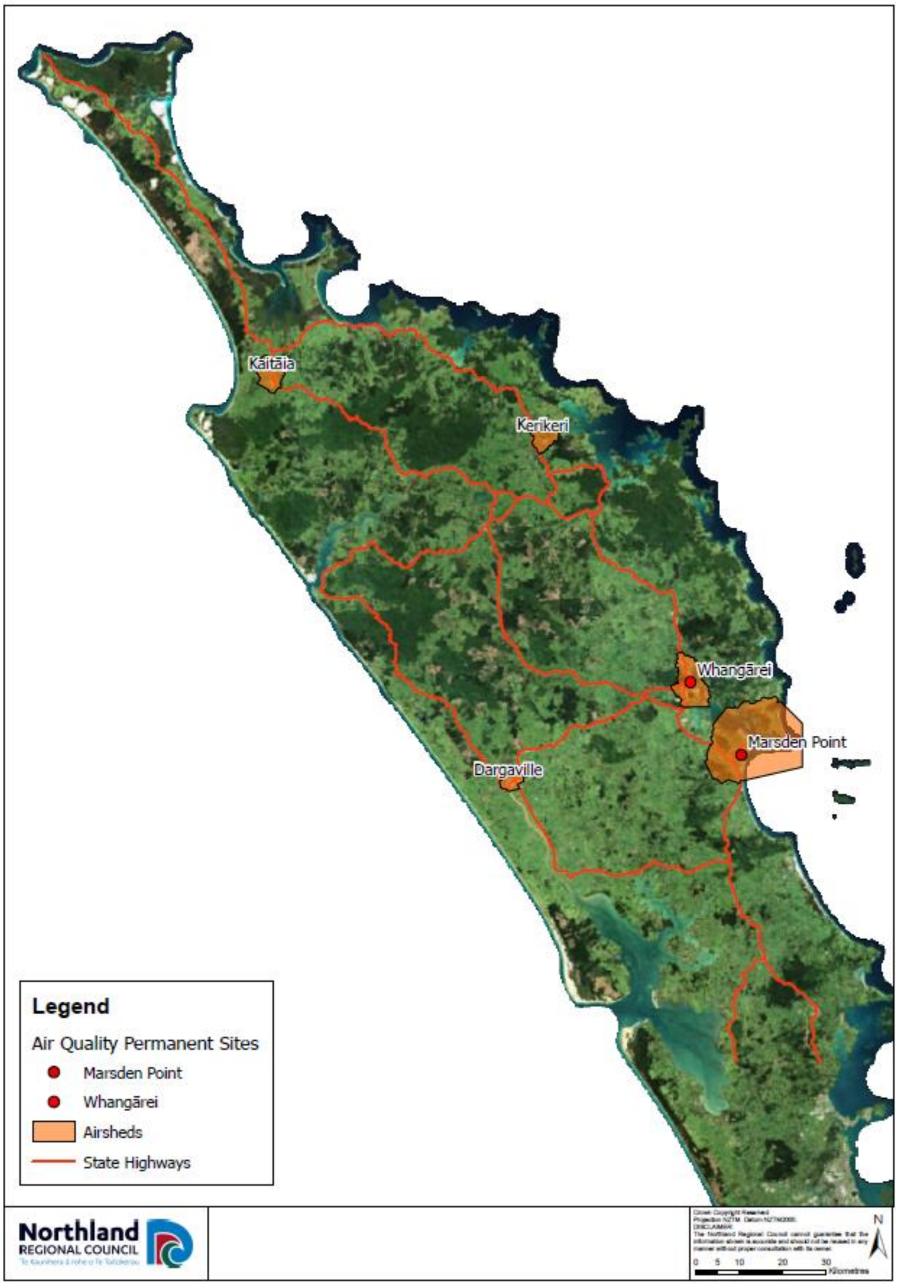


Figure 1: Map of Northland region showing gazetted airsheds and the Northland's two permanent air monitoring locations.

In addition, since 2015, the Northland Regional Council (council) is monitoring PM_{10} on an annual basis using a mobile monitor as an alternative to establishing permanent monitoring sites in unmonitored airsheds and towns in Northland. The council deployed the mobile monitor in Kaitāia, Kerikeri, and Dargaville airsheds, as well as the Kaikohe and Kawakawa townships. The results from the mobile monitor will be published in future reports.

Objectives

To sustain and improve the quality of our air resources, council's air quality monitoring objectives are:

- The sustainable management of air quality in Northland,
- Determine whether pollutant concentration in airsheds comply with the NESAQ and relevant guidelines,
- Assess the state of the air quality,
- Assess effectiveness of air quality policies and plans,
- Produce monitoring data for air quality research,
- Determine trends in air quality, and
- Ensure public health is protected and amenity values maintained.

This report presents results of particulate matter monitoring conducted by the council at its two permanent air monitoring sites located in Whangārei and Marsden Point airsheds between 2015 and 2021. The report assesses the results against the NESAQ and WHO 2021 guidelines. Impact of COVID-19 lockdowns on Northland's air quality is mentioned at the end of this report for which Kaitāia airshed is also included. Kaitāia airshed PM_{10} monitoring data was collected by Juken New Zealand and is not part of council's ambient monitoring. Data from Kaitāia airshed is included in this investigation to cover the regionwide effect of COVID-19 restrictions.

Particulate Matter (PM_{10} and $PM_{2.5}$)

Particulate matter is a collective term used to describe very small solid or liquid particles such as dust, fumes, smoke and mist or fog (Khanal, 2003; MfE & Stats NZ, 2021). Particulate matter with an aerodynamic diameter of less than 10 microns (µm) is referred as PM_{10}. $PM_{2.5}$ is a subset of PM_{10} and refers to particulate matter smaller than 2.5 microns. Research has shown that PM_{10} are small enough to be inhaled. However, finer particles $PM_{2.5}$ are a better indicator of health impacts across the population than PM_{10} (Khanal, 2003; PCE, 2015; MfE & Stat NZ, 2018; Zoran, 2020). PM_{10} and $PM_{2.5}$ originate from both natural sources (e.g., windblown dust, forest fires, sea salt), and anthropogenic sources (e.g., automobile exhaust, solid fuel burning) (NRC, 2015; Khanal, 2003).

When inhaled, particulate matter can be deposited in various parts of human respiratory system (Figure 2). Coarse particles (also called thoracic particulates) 2.5 to 10 micron in diameter, deposit mainly in the upper airways and $PM_{2.5}$ deposit the lower respiratory tract in small airways and alveoli (Zoran, 2020). Symptoms of exposure to the particulate matter at less severe level start from shortness of breath, coughing, chest pain etc. But at severe level this can lead to heart attack, stroke, and premature deaths (Khanal, 2003; Beer, 2010; MfE & Stats NZ, 2021; WHO, 2021; Boamponsem, 2022). Elderly people with existing respiratory disease such as asthma, chronic obstructive pulmonary disease, and bronchitis, those with cardiovascular disease, those with infections such as pneumonia and children are most susceptible to impacts of the particulate matter (Beer, 2010; MfE & Stats NZ, 2021; Boamponsem, 2022). Particulate matter exposure increases mortality, hospital admissions and emergency department visits (Kuschel, et al 2022).

In Whangārei airshed, domestic wood burning contributes 45% and 54% to the annual emissions of PM_{10} and $PM_{2.5}$, respectively (PDP, 2021). However, contribution from domestic wood burning increases to 71% and 78% of PM_{10} and $PM_{2.5}$ respectively during winter months (PDP, 2021; Bluett et al., 2022). Transport is the second largest contributor of PM_{10} and $PM_{2.5}$ in Whangārei followed by industrial emissions and backyard burning. During other seasons, emissions from motor vehicles, crustal matter and marine aerosol were primary sources (Davy et al., 2014). Davy et al. (2014) also found a noticeable contribution of sea salt to PM_{10} collected from Water Street, Whangārei. Wilton et al. (2012) suggested that domestic wood burning, motor vehicles, industry, sea salt and backyard burning are the major sources of particulate matter in Marsden Point airshed. The council monitors PM_{10} in Marsden Point airshed and the monitoring results indicate that sea salt is the major contributor of PM_{10} during summer months.

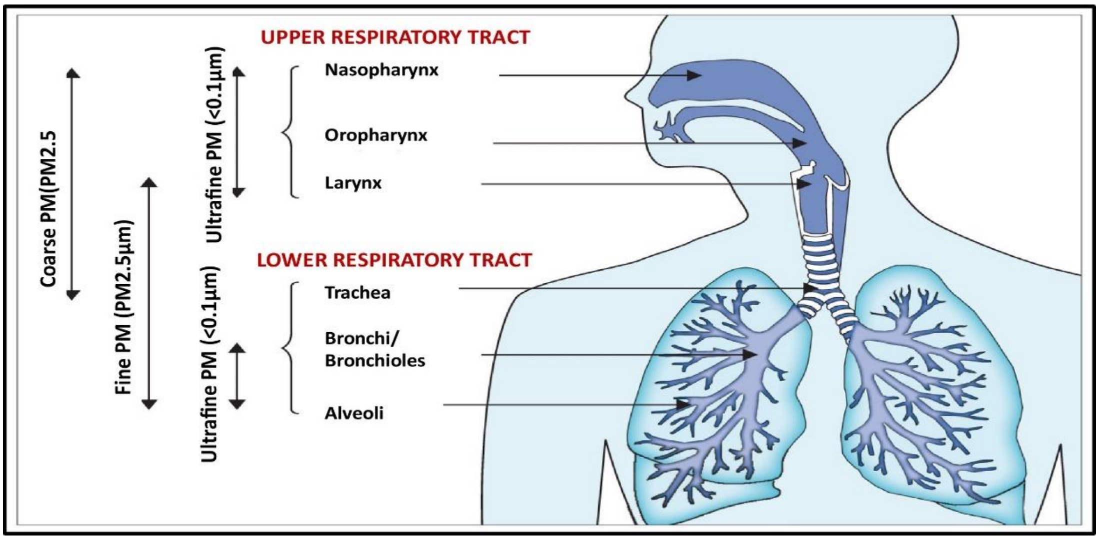


Figure 2: Deposition of particulate matter in different size fraction on the respiratory tract (Zoran, 2020).

Air Quality Assessment Criteria

The Ministry for the Environment (MfE) first published National Ambient Air Quality Guidelines (NAAQG) in 1994 and revised it in 2002 (MfE, 2002). Some of these guideline values were adopted as part of the NESAQ in 2004. The NESAQ specifies minimum requirements for ambient air quality parameters (PM_{10}, carbon monoxide, sulphur dioxide, nitrogen dioxide and ozone) to provide a nationally consistent level of protection for human health and the environment.

The air quality standard for PM_{10} is 50 micrograms per cubic metre (50 µg/m^3) of air averaged over a 24-hour period (midnight to midnight), with one exceedance allowed per 12 months period (MfE, 2004).

To provide guidance on when improvement should be required, the MfE has provided Environmental Performance Indicators (EPI) for air quality, as set out in Table 1. These indicators can act as both indicators of poor air quality and goals which policy can work towards achieving.

Table 1: Environmental Performance Indicator for air quality.

Category	Maximum measured value	Comments
Action	Exceeds the guideline value	Exceedances of the guideline are a cause for concern and warrant action, particularly if they occur on a regular basis.
Alert	Between 66% and 100% of the guideline value	This is a warning level, which can lead to exceedances if trends are not curbed.
Acceptable	Between 33% and 66% of the guideline value	This is a broad category, where maximum values might be of concern in some sensitive locations but are generally at a level that does not warrant urgent action.
Good	Between 10% and 33% of the guideline value	Peak measurements in this range are unlikely to affect air quality.
Excellent	Less than 10% of the guideline value	Of little concern: if maximum values are less than a 10th of the guideline, average values are likely to be much less.

Methodology

Monitoring Method

Both PM_{10} and $PM_{2.5}$ are monitored using Beta Attenuation Monitors (BAM). The Thermo model FH62 is used for PM_{10} and Thermo model 5014i for $PM_{2.5}$. The instrument continuously draws ambient air (16.7 litres per minute) into a 10 or 2.5-micron size selective inlet which separates particles with an aerodynamic diameter above and below 10 or 2.5 µm. The ambient PM is then drawn down onto a heated sample tube. The heated sampling tube is to reduce moisture in particulate matter and the relative humidity. Ambient PM_{10} or $PM_{2.5}$ from sampling tube gets deposited on a glass fibre filter tape, which is located between the detector and a beta source. Beta beam passes through filter tape and the deposited PM. As the mass of PM increases on the filter tape, the beta count is reduced. The relationship between the decrease in beta count and particulate mass is computed and a continuous "real time" concentration (µg/m^3) of particulate is measured. The measured concentration is then used to calculate the 24-hour averages, in accordance with the MfE's NESAQ guidelines. PM_{10} and $PM_{2.5}$ concentration is calculated to standard temperature (0^0 C) and pressure (1 atmosphere). BAM operates with a full-scale measurement range of 0 – 10,000 µg/m^3.

Watercare Services Limited (WSL) manages council's air quality instrument maintenance, calibrations, and data management. WSL uses Envitech Comserve for downloading data at 10-minute intervals, and Envista Air Resource Manager (ARM) as data management and reporting tool. All monitoring data is stored and processed in accordance with MfE Good Practice Guide (MfE, 2009b).

Averages (10-minute intervals) of PM_{10} and $PM_{2.5}$ are aggregated to hourly averages where there is at least 75% data capture. Daily averages are calculated every 24 hours at midnight for the preceding 24 hours (00:10 to 24:00 hours) and require at least 18 hours of data for each 24-hour period to be included in the dataset. PM_{10} and $PM_{2.5}$ values are rounded up to the nearest whole number for reporting proposes as per the MfE Good Practice Guide (2009b).

The council's monitoring methods, pollutants and instrument details are described in Table 2. Most of the graphs presented in this report are produced using Microsoft Excel and some using the Openair R package. Hilltop Hydro was used to produce monthly and daily averages of data.

Table 2: Methods for sampling and analysis of ambient air.

Pollutant	Standard	Details	Instrument
PM_{10}	AS/NZS 3580.9.11 - 2016	Determination of suspended particulate matter - PM_{10} beta attenuation monitors	BAM FH62
$PM_{2.5}$	AS/NZS 3580.9.12 – 2013	Determination of suspended particulate matter – $PM_{2.5}$ beta attenuation monitors	BAM 5014i
Meteorology	AS 3580.14 – 2014	Meteorology monitoring for ambient air quality monitoring applications	Vaisala
Siting	AS/NZS 3580.1.1 - 2016	Guide to siting air monitoring equipment	

Monitoring Site Locations

Whangārei airshed

Whangārei is the largest urban centre in Northland region. Whangārei airshed covers an area of about 62 km^2 (covering most of Whangārei city), which has a population of 54,300 as of census 2018 (PDP, 2021; StatsNZ, 2021). Whangārei has the highest density of wood burners in use in Northland (NIWA, 2020). Whangārei airshed also has highest traffic counts from the NZTA counters in Northland (NZTA, 2020). NIWA (2020) identified Whangārei and Kaitāia airsheds as high priority airsheds in Northland for development of a particulate matter monitoring program.

Council is operating a long-term ambient monitoring station in central Whangārei within a commercial area at 88 Robert Street (Figure 1). The site currently measures PM_{10}, $PM_{2.5}$, and meteorological data (e.g., wind speed, wind direction, relative humidity, temperature, rainfall, and solar radiation). Site metadata is presented in Appendix 1.

Marsden Point airshed

Marsden Point airshed is located approximately 40 km south of Whangārei and largely covers an industrial area with a small residential population in the coastal towns of Ruakākā and One Tree Point. Historically, the area is well known as New Zealand's only oil refinery. Northport and Carter Holt Harvey mill are located within this airshed.

Council has been operating ambient PM_{10} monitoring in Marsden Point airshed since late 2012. The air monitoring site is located at Peter Snell Road at Bream Bay College (Figure 1). Currently, the council monitors PM_{10} and meteorological data from this site. Site metadata is presented in Appendix 2.

Results and Discussion

Robert Street, Whangārei airshed

Meteorological monitoring

It is useful to collect meteorological data along with air pollutants as air quality and meteorological parameters are closely linked. Meteorological parameters such as temperature, wind speed, wind direction, and relative humidity play vital role in pollutant formation, transportation, dispersion, and chemical reactions between air pollutants (Habeebullah et al., 2014). Air pollutant concentrations show typical diurnal, weekly, seasonal, and annual cycles as a result of change in meteorological conditions and emission sources over the period.

Meteorological, PM_{10}, and $PM_{2.5}$ data from Robert Street monitoring station (Whangārei) are presented in this section.

Ambient temperature

Monthly ambient temperature records from Robert Street station (2015–2021) followed an expected seasonal pattern of temperature variation (Table 3;
Figure *3*). Temperature is higher in summer months (December, January, and February) and lower in winter months (June, July, and August). Error bars shown are standard errors of monthly averages. Annual average temperature ranged from 16.04 ^{0}C (± 3.39) to 16.84 ^{0}C (± 3.22). Annual average temperature increased each year from 2015 to 2021, except 2018. Overall temperature increase was 4.9 % between 2015 and 2021. Minimum temperature followed a similar pattern to the annual averages, increasing from 11.42 ^{0}C in 2015 to 12.41 ^{0}C in 2021 (Table 3). It is worth noting that minimum temperature has increased from 11.4 to 12.4 ^{0}C for a short period of time.

Table 3: Ambient temperature summary of statistics of monthly averages at Robert Street. (Note: Percentage change is change in mean from previous year).

	2015	2016	2017	2018	2019	2020	2021
Mean	16.04	16.55	16.57	16.50	16.61	16.63	16.84
Median	16.09	16.22	16.50	16.07	15.85	16.55	16.71
Std Deviation	3.39	3.48	3.37	3.76	3.44	3.14	3.22
Std Error	0.98	1.01	0.97	1.08	0.99	0.91	0.93
Maximum	20.96	21.95	21.32	22.37	21.84	21.87	21.40
Minimum	11.42	11.91	11.76	12.79	12.58	12.29	12.41
Change %	NA	3.11	0.17	-0.41	0.68	0.09	1.25

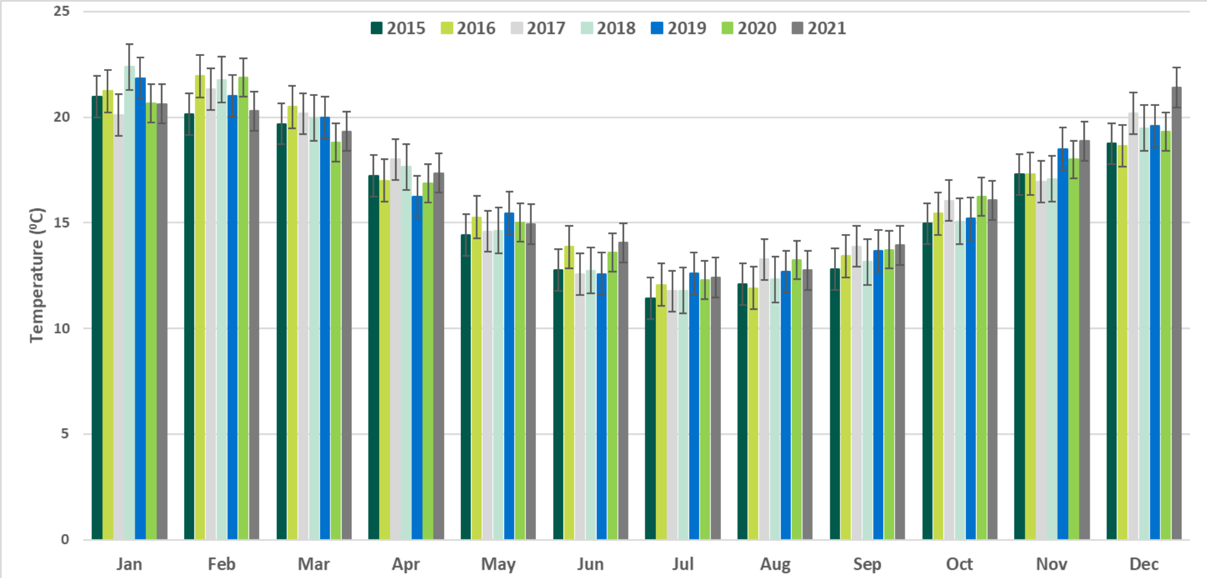


Figure 3: Monthly average ambient temperature at Robert Street, Whangārei.

Relative Humidity (RH)

Monthly relative humidity at Robert Street followed an expected seasonal pattern for each year (2015–2021; Figure 4), higher in winter months (June, July, and August) and lower in summer months (December, January, and February). Annual average RH ranged from 71.01% (± 4.6) to 72.04% (± 5.53), showing an increase of 1.45%. However, RH annual average did not show the similar pattern as ambient temperature. For example, the highest RH was recorded in 2018 (73.71%; Table 4), the same year that recorded the lowest ambient temperature (16.50 ^{0}C; Table 3).

Table 4: Relative humidity percent annual summary of statistics monthly averages at Robert Street, Whangārei. Note: High standard deviation and standard errors for 2020 are the result of missing data (only 60% data was available for 2020).

	2015	2016	2017	2018	2019	2020	2021
Mean	71.01	72.30	72.38	73.71	71.43	71.19	72.04
Median	72.05	73.10	73.05	73.80	71.35	71.60	73.10
Std Deviation	4.60	4.51	6.07	3.91	5.23	7.01	5.53
Std Error	1.33	1.30	1.75	1.13	1.51	2.65	1.60
Maximum	76.70	78.20	79.20	79.20	80.00	81.10	80.40
Minimum	64.00	64.20	59.70	68.10	64.30	62.30	61.90
Change %	NA	1.82	0.12	1.83	-3.10	-0.34	1.20

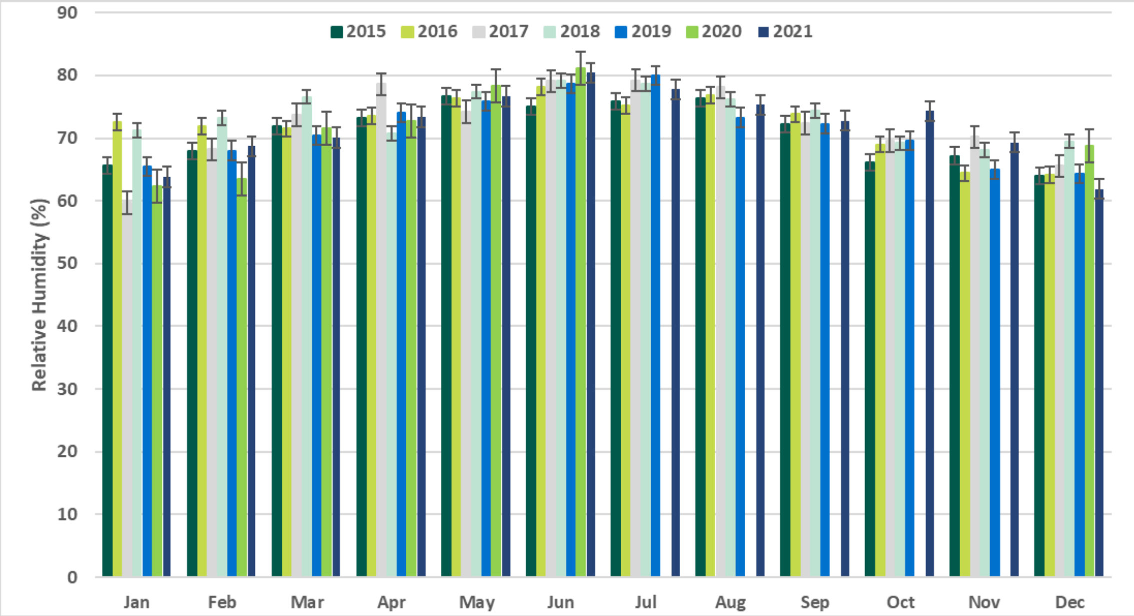


Figure 4: Monthly averages of relative humidity at Robert Street, Whangārei.

Wind speed and wind direction

Wind speed plays a vital role in accumulation or dispersal of air pollutants. Similarly, wind direction is useful in understanding which direction air pollutants are originating from at each monitoring station. Wind rose showing the relative frequency and speed of winds from different directions for 2015 to 2021 is shown in Figure 5. The wind speed and wind direction between 2015 and 2021 is consistent, showing that most of the wind was coming from north and northwest with high frequency of low to moderate wind speeds (Figure 5). South-westerly wind is also consistent over the years, and it is noticeable that high wind speed is from south-west compared to the north or northwest. The average wind speed shows consistency between years.

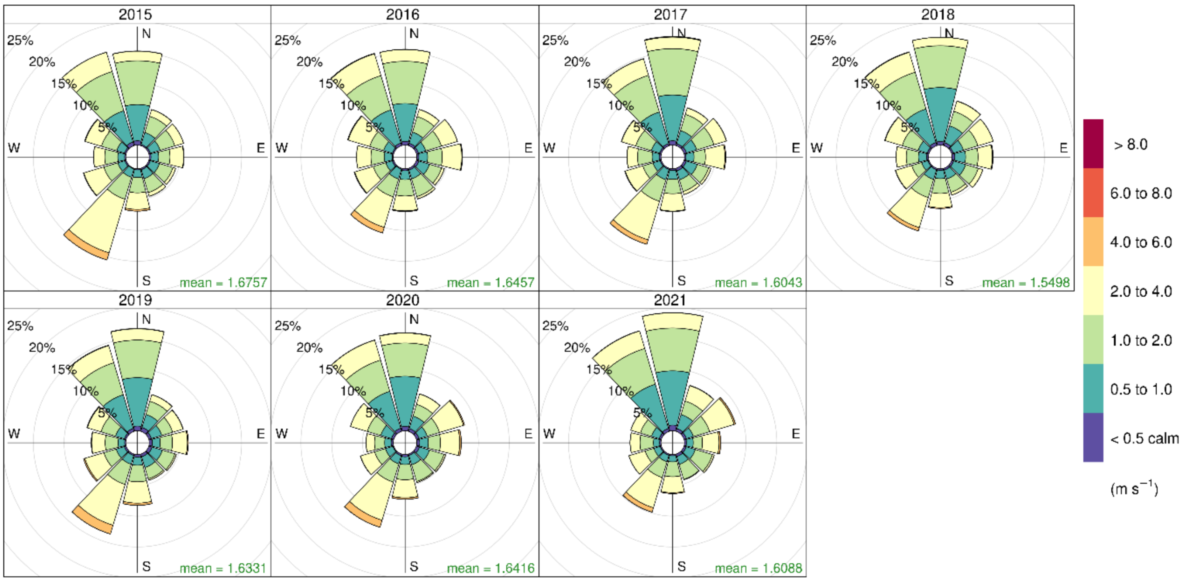


Figure 5: Wind rose showing wind direction and wind speed at Robert Street, Whangārei (2015 – 2021).

Particulate Matter (PM_{10})

Hourly PM_{10}

There is no hourly standard for PM_{10} in New Zealand, therefore, the council is using MfE suggested trigger level of 150 µg/m^3 for PM_{10} from dusty sources (MfE, 2016; Metcalfe & Wickham, 2019). The main purpose of hourly threshold of PM_{10} is to manage dusty environments on time and to avoid exceedance of longer time-averages (Metcalfe & Wickham, 2019). The hourly box plots of PM_{10} at Robert Street station during the monitoring period is presented in Figure 6 below. In box plots boxes represent 25th (the bottom of the box) and 75th (top of the box) percentile, central line through the box is the median, bars outside the box (whiskers) represent the 1.5x interquartile range, and x markers are the means, and circles are outliers (Boamponsem, 2022).

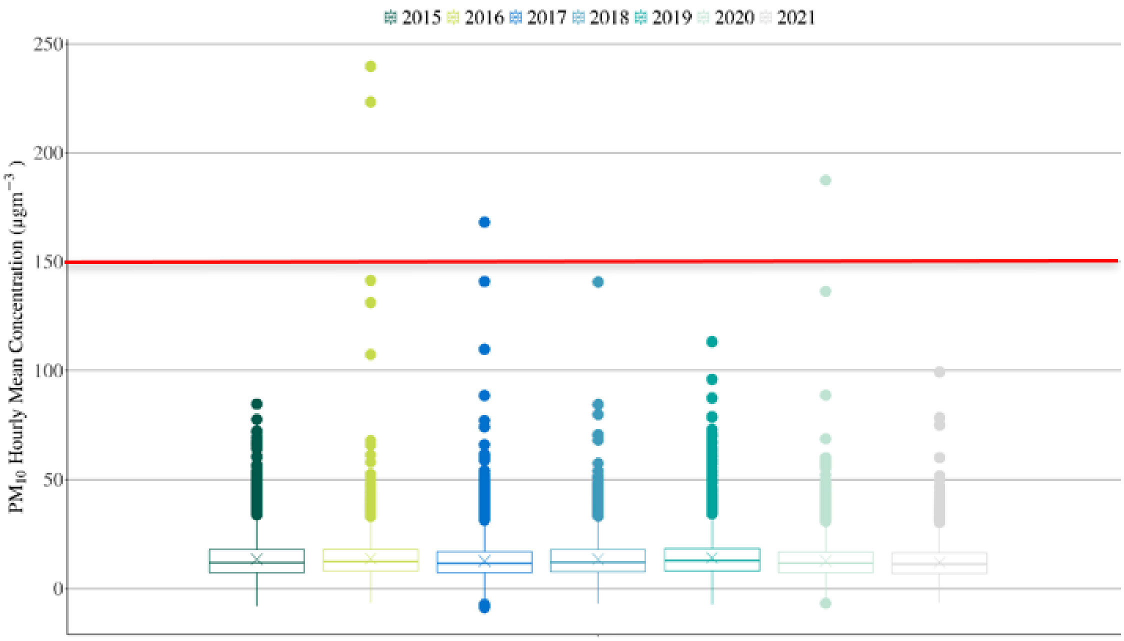


Figure 6: Box plots of hourly PM_{10} concentration at Robert Street, Whangārei 2015–2021.

The hourly averages of PM_{10} concentration are higher than MfE's trigger level on several occasions, but it is important to note that hourly spikes are normal and could be influenced by a short-lived source near the monitoring station (Figure 6).

Daily PM_{10}

A summary of daily PM_{10} concentrations measured at Robert Street between 2015 and 2021 is presented in Table 5. There was no exceedance of PM_{10} concentrations (50 µg/m^3 NESAQ) occurred during the reporting period.

PM_{10} concentration on 5 December 2019 (48 µg/m^3) was higher than the WHO guideline value of 45 µg/m^3 (WHO, 2021; Figure 7). Recent studies revealed that the high concentration of PM_{10} between December 2019 and January 2020 was a result of Australian bushfire (Nature, 2020; Arriagada et al., 2020; Dillane, 2020; Nature News, 2020). Furthermore, it was noted that PM_{10} concentrations are slightly higher during winter months than summer months, indicating source of PM_{10} in Whangārei is from domestic home heating during winter. Similar observation was noted by other councils in New Zealand e.g., Auckland Council (Boamponsem, 2022).

Table 5: Summary statistics of daily PM_{10} concentrations at Robert Street 2015–2021.

Statistics	2015	2016	2017	2018	2019	2020	2021
Annual mean	14	14	13	13	14	13	12
Maximum	35	31	29	33	48	29	24
Minimum	3	4	4	4	5	6	3
Median	13	13	12	13	13	12	11
Std deviation	5.24	4.92	4.39	4.80	5.21	4.12	3.83
99^{th} percentile	28.88	28.82	23.80	26.56	27.97	24.11	22.41
75^{th} percentile	16.70	16.31	15.06	16.20	17.22	14.88	14.23
25^{th} percentile	9.95	9.90	9.44	10.04	10.42	9.55	9.39
No. > 50 (µg/m^3)	0	0	0	0	0	0	0
Data capture %	98.90	99.45	96.99	99.18	100	100	96.16

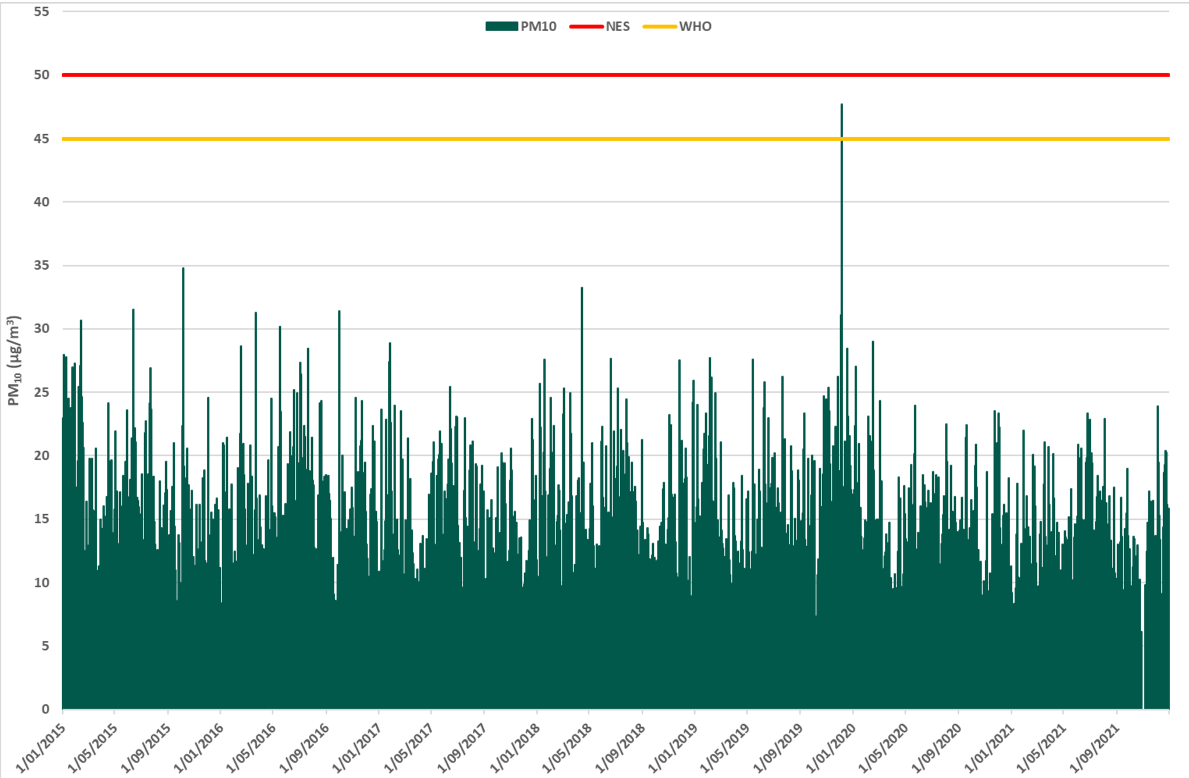


Figure 7: Daily PM_{10} concentration at Robert Street, Whangārei 2015–2021.

Diurnal and seasonal variations

Diurnal variation of PM_{10} has two peaks, one around the midday and a slightly higher peak in the evening. However, on a closer look difference between two peaks on weekends is not as visible as seen on weekdays (Figure 8). Overall diurnal peak shows PM_{10} concentrations start to increase just before midday and again around 1800 hours of the day. Wintertime peak stays for longer period in the evening every day of the week than other seasonal peaks. This is typical trend found in New Zealand towns where solid fuel burning for home heating is the primary source of particulate matter during winter months. Another reason for higher evening peak is due to more stable atmosphere in the evening than the afternoon. Secondary peak between 1100 and 1400 hours is mainly attributed to daytime human activities such as vehicle, industries, and backyard burning, among others. Similar observations were observed by Boamponsem (2022) and LAWA (2021). The difference in winter and summer diurnal variation is distinctively noticeable but this is not the case for spring and autumn months. The time variations during spring and autumn are similar to each other.

Monthly averages are useful to understand seasonal variation of PM_{10} concentrations. Monitoring results show slight increase in PM_{10} in June and July (Figure 8). This increase is likely caused by emissions from domestic home heating (Boamponsem, 2022). However, high PM_{10} concentration during summer months suggests non-domestic heating sources of PM_{10} and it is believed to be from natural sources such as sea salt and windblown dust (Davy et al., 2014). Robert Street monitoring station is located a few hundred meters from Whangārei town basin marina. PM_{10} concentration on weekends are lower than the weekdays (Figure 8). Workday concentrations are higher than weekend due to increased traffic and industrial emissions. But for some unknown reason highest PM_{10} concentrations are recorded on Wednesdays and Thursdays. Taranaki Regional Council (TRC) also reported highest PM concentrations (e.g., $PM_{2.5}$) on Thursday (TRC, 2020).

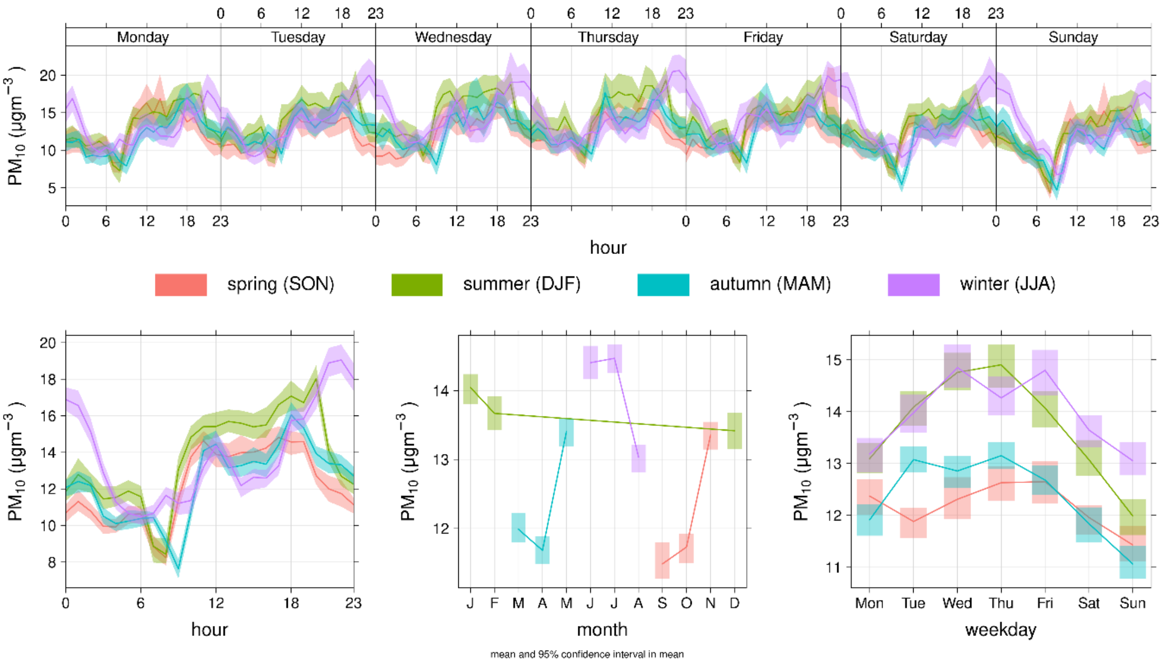


Figure 8: Diurnal variation in PM_{10} concentration at Robert Street station, Whangārei between 2015 and 2021. The four plots show the variation in PM_{10} concentration during different seasons by: hour and day of the week, hour of the day, month of the year and day of the week. 95% confidence intervals for the means are shown by the shaded areas.

PM_{10} Pollution roses

Meteorological conditions such as wind speed and wind direction influence the concentration of air pollutants (Habeebullah et al., 2014). Pollution roses are useful tools to show emission sources of pollutants and dependence of pollutants on wind speed and wind direction. As expected, PM_{10} concentrations are highest in winter, followed by summer, autumn, and lowest in spring (Figure 9). Highest PM_{10} concentrations at Robert Street station is mainly sourced from northwest and southwest. Southwest wind is dominant in spring and summer while winter and autumn concentrations are dominated from north to north-westerly wind.

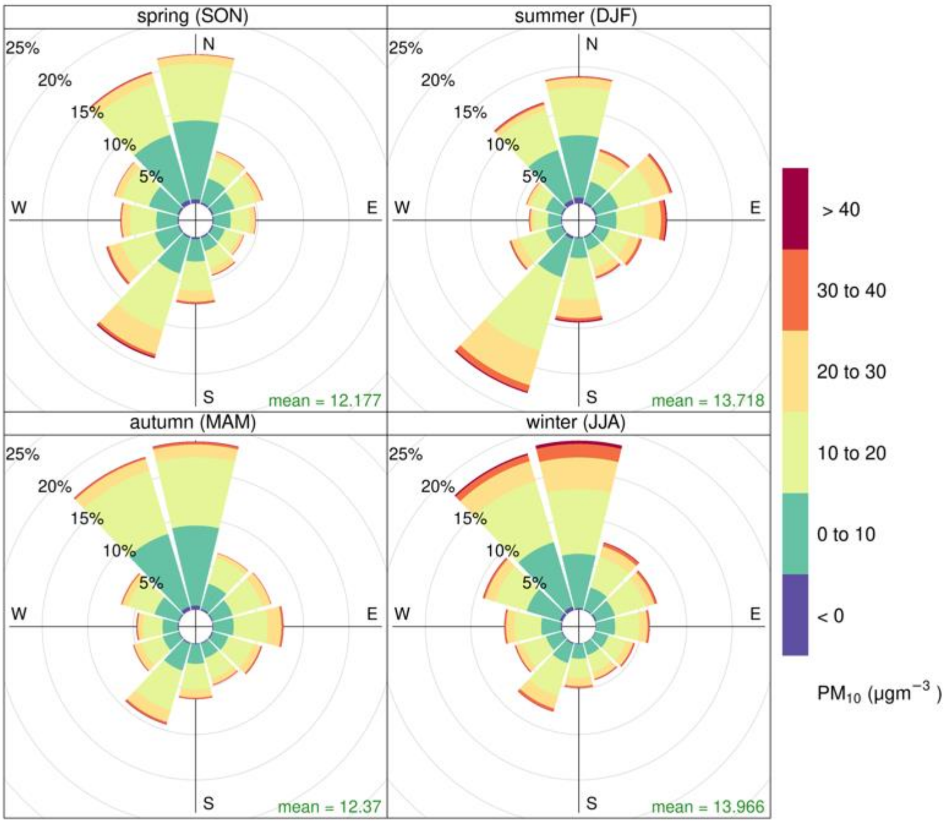


Figure 9: Seasonal PM_{10} pollution roses for Robert Street.

Particulate Matter ($PM_{2.5}$)

Council started monitoring $PM_{2.5}$ at its Robert Street monitoring station in Whangārei from August 2016. Summary statistics of daily $PM_{2.5}$ concentration between 2017 and 2021 is presented in Table 6. The averages shown in Table 6 demonstrate compliance with the 2020 NESAQ amendments proposed by the Ministry for the Environment. However, daily, and annual averages of $PM_{2.5}$ exceed the WHO guidelines value of 15 and 5 μg/m^3 respectively (WHO, 2021).

Table 6: Summary statistics of daily $PM_{2.5}$ concentrations at Robert Street 2017–2021.

Statistics	2017	2018	2019	2020	2021
Annual mean	6	6	7	8	5
Maximum	23	20	20	25	19
Minimum	2	1	1	2	1
Median	5	6	6	7	5
Std deviation	3.18	3.39	3.09	3.43	2.57
99th percentile	16.71	17.32	16.90	17.88	15.98
75th percentile	6.88	7.61	8.00	9.54	6.40
25th percentile	4.03	4.34	4.61	5.26	3.63
No. > 25 (μg/m^3)	0	0	0	0	0
Data capture %	96	98	95	92	99

Concentration of $PM_{2.5}$ increases during winter months, indicating that the majority of $PM_{2.5}$ in Whangārei is sourced from emissions from home heating (Figure 10). Emissions released from combustion mainly contain finer particles. Daily $PM_{2.5}$ concentrations exceeded WHO guidelines in winter months except for 2019. $PM_{2.5}$ concentrations started to increase towards the end of 2019 and stayed high until March 2020. The high $PM_{2.5}$ concentrations during this period was caused by the Australian bushfire (Nature, 2020; Arriagada et al., 2020; Dillane, 2020).

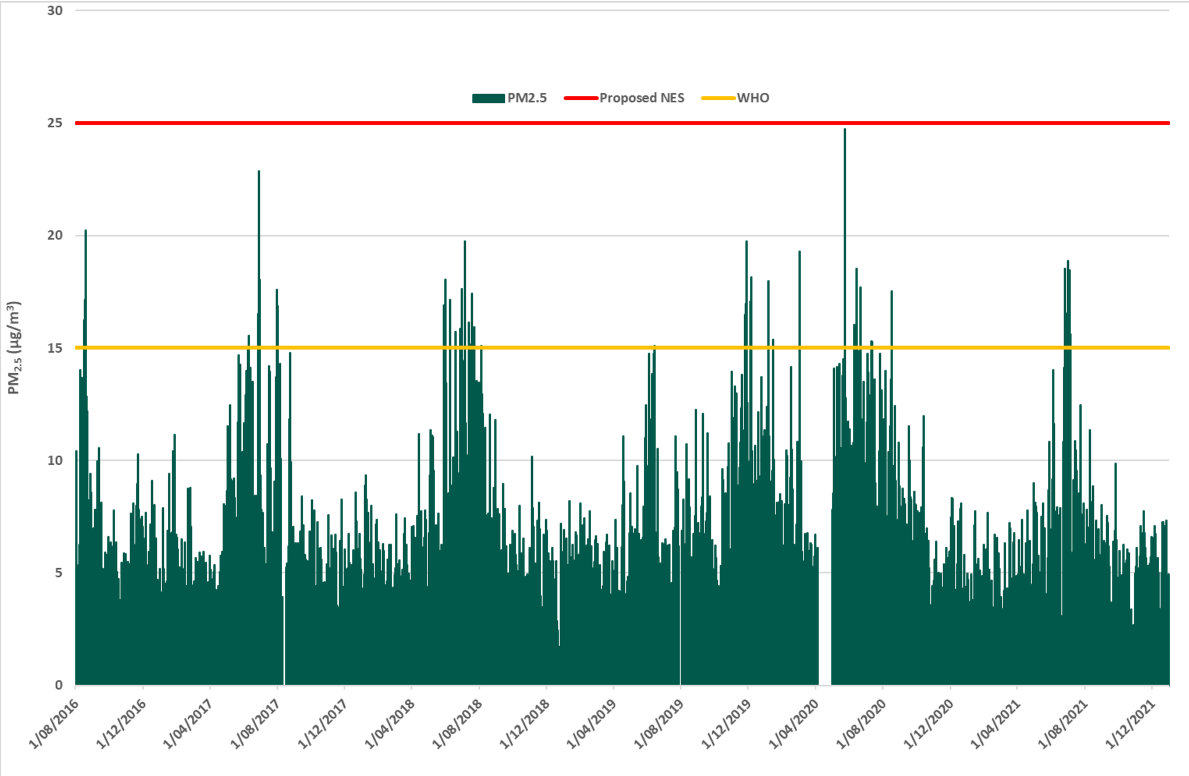


Figure 10: Daily $PM_{2.5}$ concentration at Robert Street, Whangārei 2017–2021.

The highest daily $PM_{2.5}$ concentration was recorded on 23 May 2020 (25 µg/m^3; Figure 10). On this day wind was flowing from all directions at different time of the day. The temperature, and wind speed both were recorded lower than expected for this time of the year. It was one of the coldest days of the year with daily mean temperature of 11 °C and wind speed of 1 m/s (Figure 11). Low temperature and wind speed are perfect conditions for air pollutants to accumulate and increase the overall concentration (Caldwell, 2019; MfE & Stats NZ, 2021). Hourly $PM_{2.5}$ concentration on this day showed higher afternoon peak and a small peak in the morning. Even though hourly $PM_{2.5}$ averages peaked on several occasions, annual averages were below the proposed NESAQ value of 10 µg/m^3 (MfE, 2020) (Figure 12).

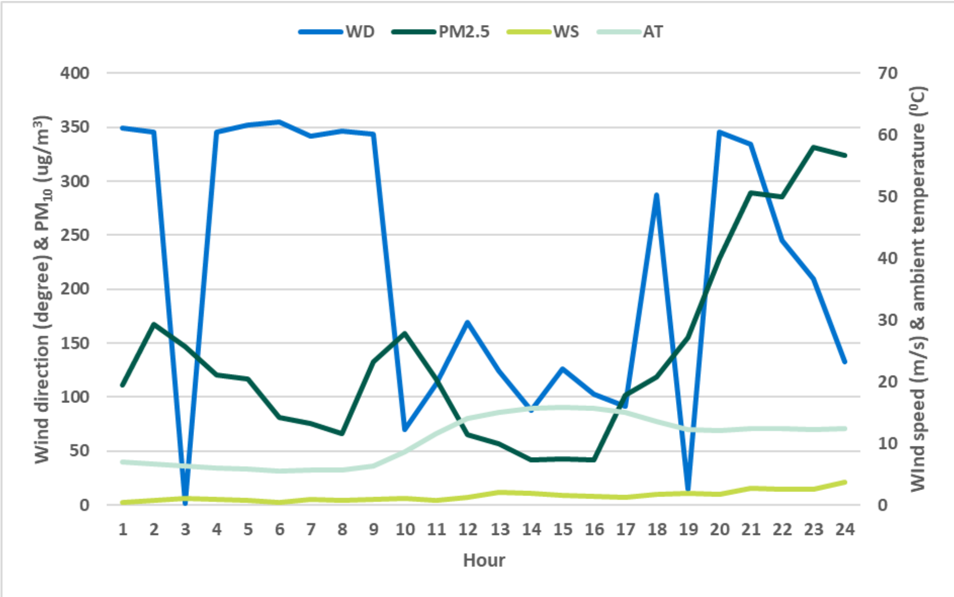


Figure 11: Hourly $PM_{2.5}$ and meteorological parameters on 23 May 2020, the day highest $PM_{2.5}$ concentration was recorded between 2015 and 2021.

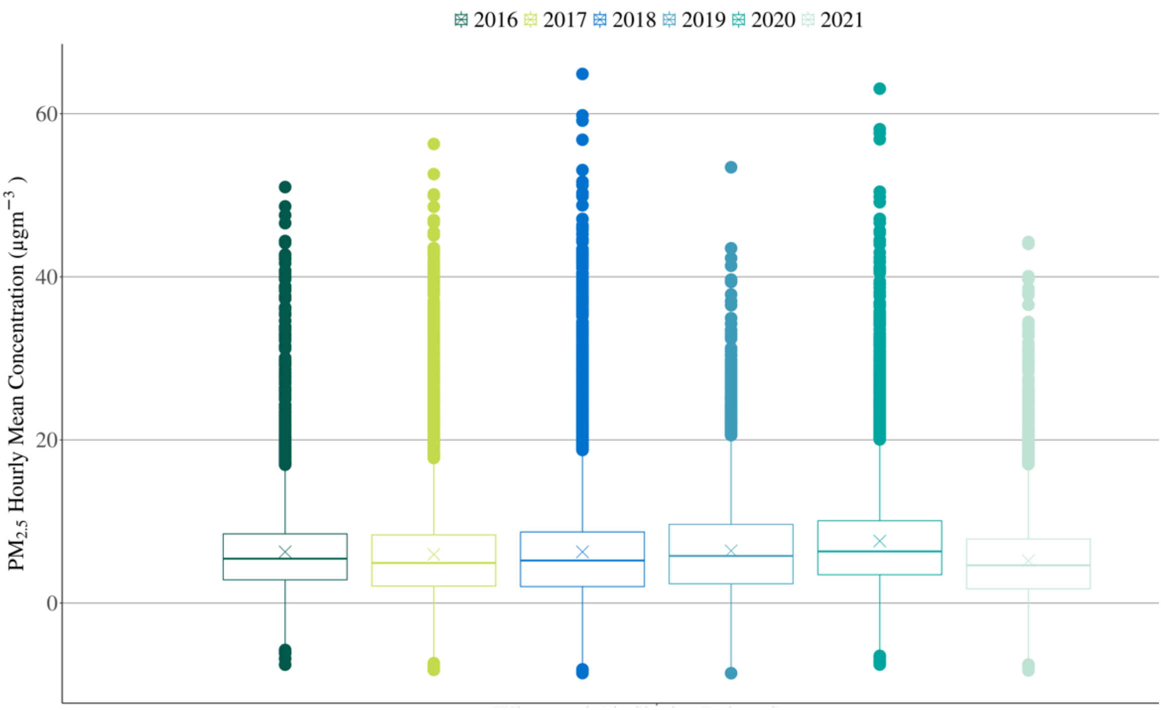


Figure 12: Box plots of hourly $PM_{2.5}$ concentration at Robert Street, Whangārei 2016–2021.

Diurnal and seasonal variations of $PM_{2.5}$

Similar to PM_{10}, there are two diurnal variation peaks for $PM_{2.5}$ but the timing of the peaks is different, and peaks are more distinct (Figure 13). Contrary to midday peak for PM_{10}, morning and evening peaks are recorded for $PM_{2.5}$ and interestingly lowest concentration is observed when PM_{10}

had a midday peak. A smaller morning peak could be due to households lighting wood burners during cool morning hours and emission from the morning traffic. The large smooth evening peak is due to emission from traffic and wood burning (TRC, 2020). The seasonal pattern of $PM_{2.5}$ is consistent, with winter peaks being the highest among all seasons, unlike PM_{10}.

Monthly averages are useful to check seasonal variation of pollutant concentrations (Figure 13). Unlike PM_{10} monthly averages, $PM_{2.5}$ monthly average concentrations significantly increase during May to August, which confirms outcome of the emission inventory for Whangārei airshed 2021. The inventory suggested that largest contributor to $PM_{2.5}$ in winter is emissions from domestic heating with transport being the second highest contributor (78% and 14%, respectively) (PDP, 2021). Monitoring data showed that $PM_{2.5}$ concentrations on weekend are lower than weekdays, similar trend as PM_{10} concentrations. Higher concentration on weekdays is due to increased traffic and industrial emissions.

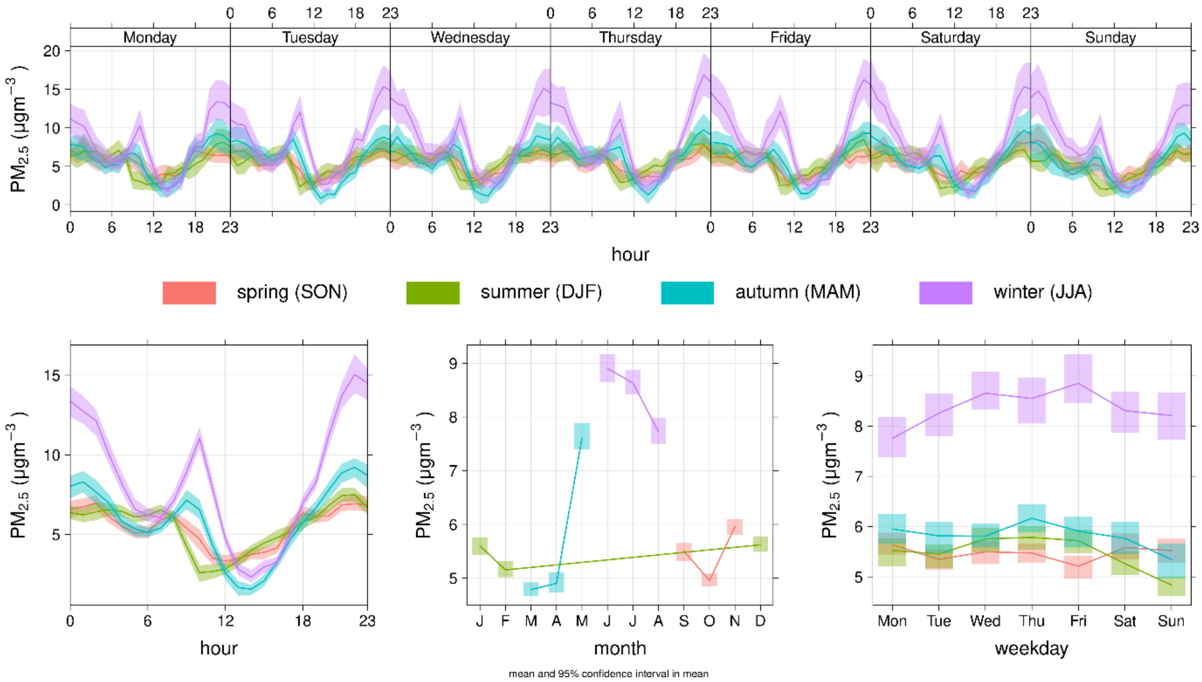


Figure 13: Diurnal variation in $PM_{2.5}$ concentration at Robert Street station, Whangārei between August 2016 and December 2021. The four plots show the variation in $PM_{2.5}$ concentration during different seasons by: hour and day of the week, hour of the day, month of the year and day of the week. 95% confidence intervals for the means are shown by the shaded areas.

$PM_{2.5}$ Pollution roses

The average $PM_{2.5}$ concentrations are similar in summer and spring (
Figure *14*). The highest $PM_{2.5}$ concentration at Robert Street monitoring station is mainly sourced from north and northwest wind during autumn, winter, and spring. However, southwest wind is dominant in summertime

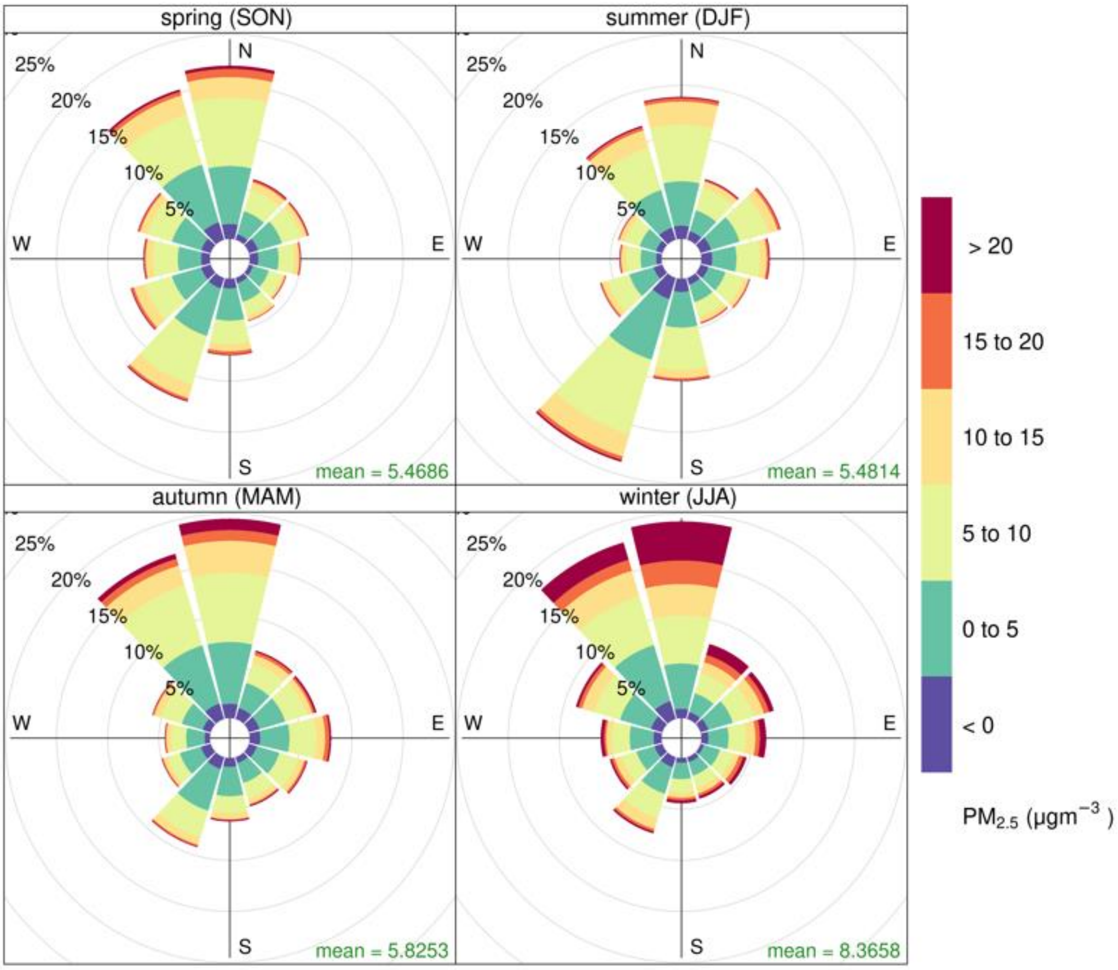


Figure 14: Seasonal $PM_{2.5}$ pollution roses for, Robert Street.

Marsden Point

Meteorological monitoring

Meteorological, and $PM_{10,}$ data from Bream Bay College monitoring station (Marsden Point) are presented in this section. Meteorological monitoring at this site started in mid-2016.

Ambient temperature

Monthly ambient temperature from Bream Bay College, Marsden Point (2017–2021) followed an expected seasonal pattern of temperature variation (Figure 15). Temperature is higher in summer and lower in winter. Annual average temperature ranged from 15.98 ± 3.24 ^{0}C in 2017 and 16.28 ± 3.00 ^{0}C in 2021. Highest monthly average temperature was recorded in 2020 (16.44 ± 2.90 ^{0}C). Overall annual average temperature increase during this period was 1.88%. Unlike Whangārei, minimum temperature at the Bream Bay College site increased every year from 11.13 ^{0}C in 2017 to 12.23 ^{0}C in 2021, which was a notable increase in five years.

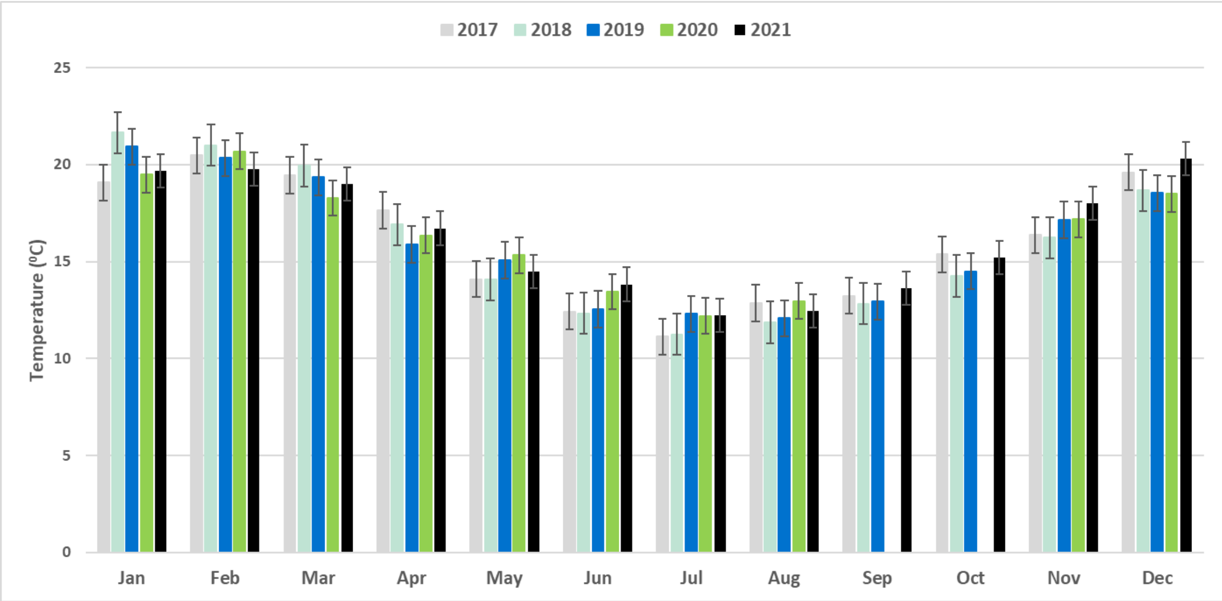


Figure 15: Monthly average ambient temperature at Bream Bay College, Marsden Point.

Table 7: Ambient temperature summary of statistics of monthly averages at Bream Bay College. (Note: Percentage change is change in mean from previous year).

	2017	2018	2019	2020	2021
Mean	15.98	15.92	15.97	16.44	16.28
Median	15.87	15.25	15.48	16.77	15.97
Std Deviation	3.24	3.70	3.24	2.90	3.00
Std Error	0.93	1.07	0.94	0.92	0.87
Maximum	20.48	21.66	20.93	20.69	20.30
Minimum	11.13	11.25	12.08	12.20	12.23
Change %	NA	-0.36	0.31	2.95	-0.98

Relative Humidity (RH)

The monthly average relative humidity at Bream Bay College, Marsden Point (2017–2021; Figure 16) followed an expected seasonal pattern with higher humidity in winter (June, July, August) and lower humidity in summer (December, January, February). Error bars shown are standard errors of monthly averages. Annual average RH ranged from 73.73% ± 4.77 to 75.06% ± 2.94, showing an increase of 1.84% in five years. Similar to Whangārei the ambient temperature and RH showed an inverse relationship to each other. Annual summary of statistics for RH at the Bream Bay College showed high standard deviation in 2020 due to missing data (Table 8).

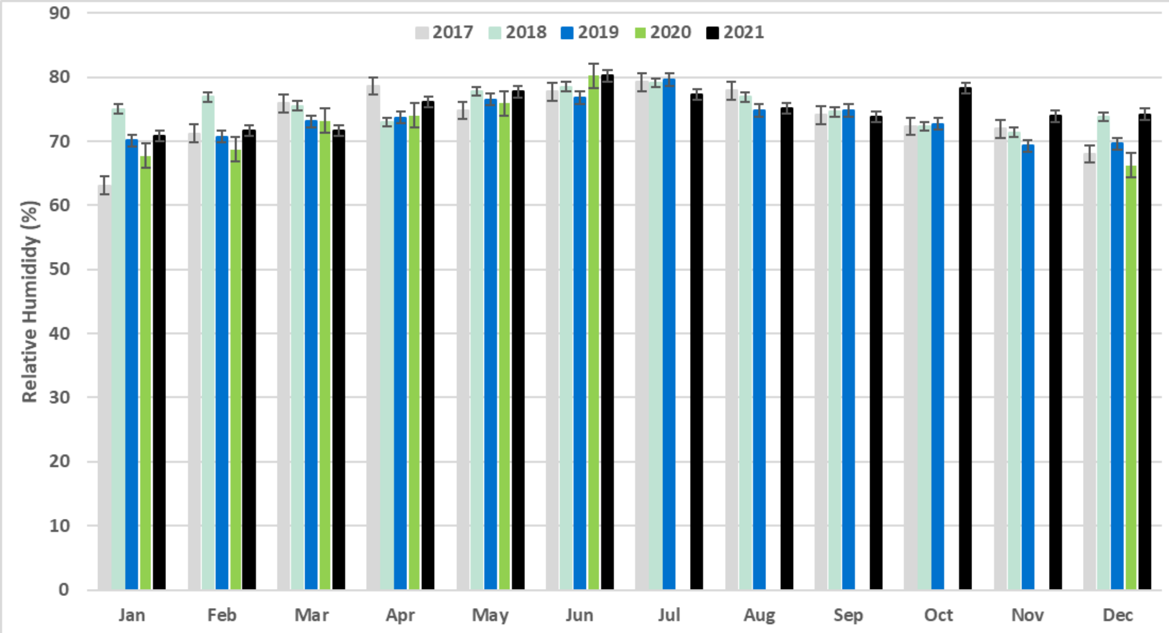


Figure 16: Monthly average relative humidity at Bream Bay College, Marsden Point.

Table 8: Relative humidity percent annual summary of statistics of monthly averages at Bream Bay College.

	2017	2018	2019	2020	2021
Mean	73.73	75.40	73.48	72.27	75.06
Median	74.45	75.25	73.40	73.20	74.65
Std Deviation	4.77	2.49	3.21	5.01	2.94
Std Error	1.38	0.72	0.93	1.89	0.85
Maximum	79.20	79.10	79.60	80.20	80.20
Minimum	63.10	71.40	69.30	66.20	70.80
Change %	NA	2.30	-2.51	-1.67	3.85

Wind speed and wind direction

Annual wind rose showing the relative frequency and wind speed from 2016 to 2021 is shown in Figure 17. The wind direction between 2016 and 2019 is dominated by westerly and south westerly with high frequency of low to moderate wind speeds. During this period westerly wind was found to be dominant. Wind rose for 2020 and 2021 also shows south westerly wind dominant and with a noticeable frequency of wind direction and wind speed from east to northeast than previous years (2016–2019). Wind speed ranged between 1.79 m/s in 2021 and 2.03 m/s in 2016. Wind speed at the Whangārei monitoring station was more consistent during the period than the Marsden Point.

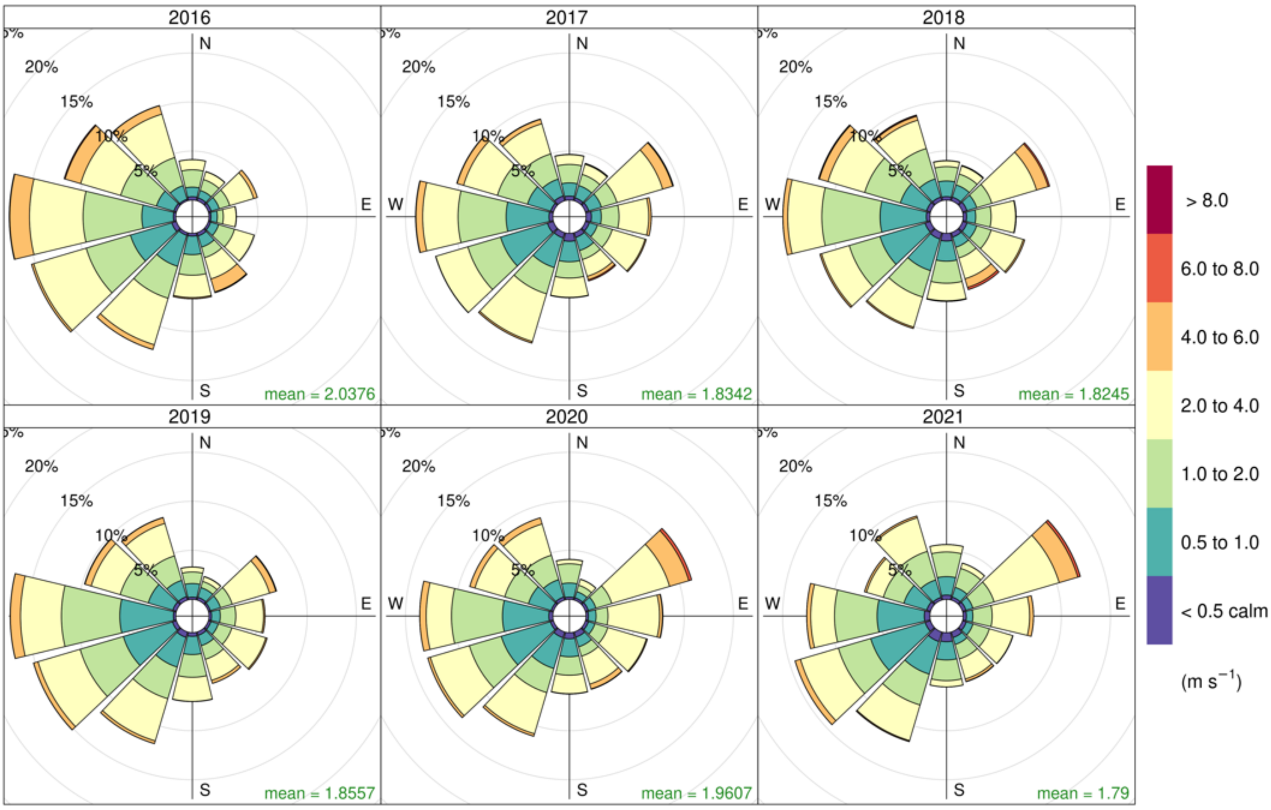


Figure 17: Wind rose showing wind direction and wind speed at Bream Bay College, Marsden Point (2016–2021).

PM_{10}

Hourly PM_{10}

Even though hourly averages of PM_{10} at the Bream Bay College were higher than the MfE's trigger level from time to time, the PM_{10} concentrations at this site confirm compliance with the NESAQ during the monitoring period. The hourly box plots of PM_{10} at Bream Bay College monitoring station from 2015 to 2021 is presented in Figure 18.

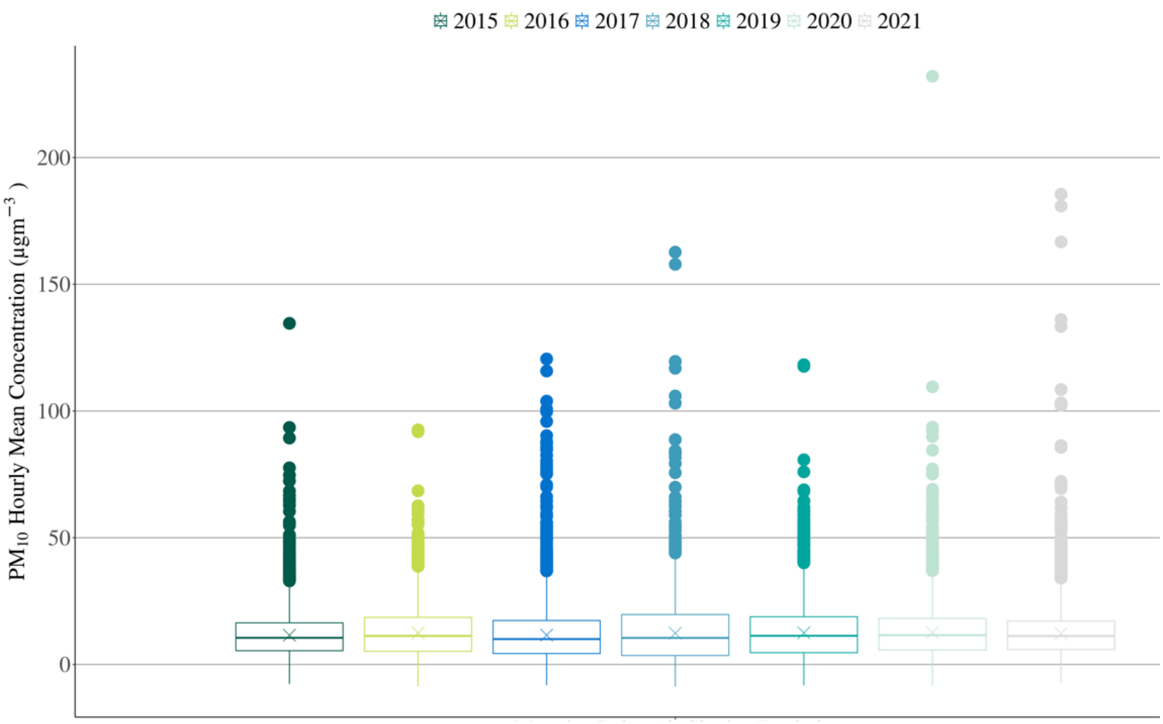


Figure 18: Box plots of hourly PM_{10} concentration at Bream Bay College, Marsden Point 2015–2021.

Daily PM_{10}

A summary of daily PM_{10} concentrations measured at Bream Bay College between 2015 and 2021 are presented in Table 9. A daily maximum concentration close to the NESAQ (50 µg/m^3) was recorded on 29 January 2021 with no apparent reason. On this day wind direction was from south to southwest, temperature and wind speed were as expected for the time of the year. Hourly PM_{10} concentration started to increase from 0800 hours and remained high until 1600 hours with a slight dip between 1300 and 1400 hours. Hourly meteorological parameters and PM_{10} concentration for 29 January 2021 is given in Figure 19. Wind direction suggests that source of PM_{10} (windblown dust or vegetation burning) originated at south to southwest of the monitoring site.

The highest PM_{10} concentration at Robert Street during the period was recorded on 5 December 2019 contributed by the Australian bushfire. On this day the Bream Bay College site recorded 35 µg/m^3, which was highest daily average for 2019.

Table 9: Summary of statistics of daily PM_{10} concentrations at Bream Bay College 2015–2021.

Statistics	2015	2016	2017	2018	2019	2020	2021
Annual mean	12	13	12	13	12	13	12
Maximum	29	28	38	42	38	31	50
Minimum	4	4	4	2	2	4	4
Median	11	12	11	11	11	12	11
Std deviation	4.66	4.42	4.90	5.50	4.94	4.86	5.41
99th percentile	26.93	25.35	27.11	28.34	27.47	27.42	34.81
75th percentile	14.12	15.47	14.45	16.02	14.96	15.40	14.29
25th percentile	8.41	9.50	8.18	8.78	8.60	9.37	9.02
No. > 50 (µg/m^3)	0	0	0	0	0	0	0
Data capture %	99.45	95.61	99.45	100	96.98	99.18	96.43

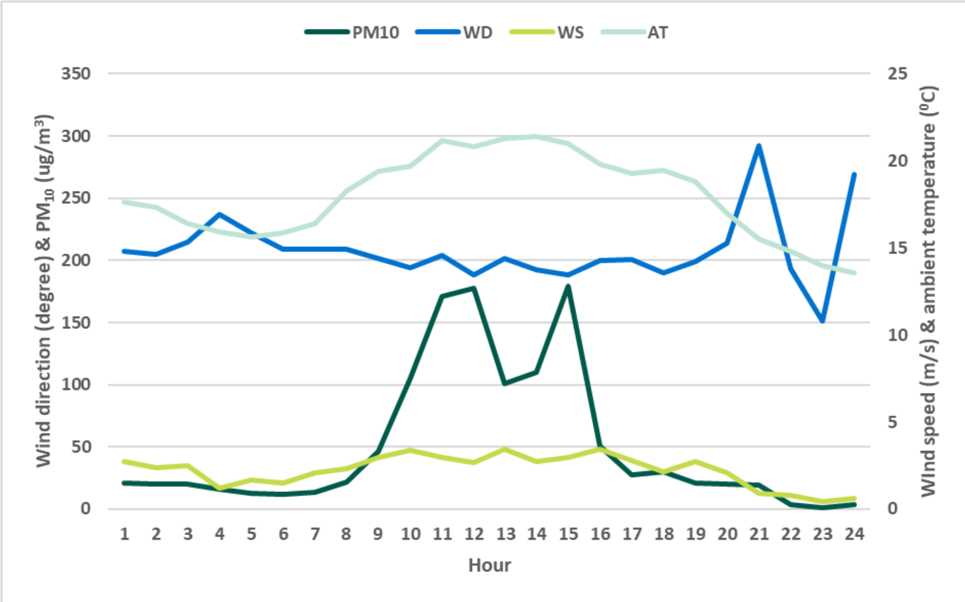


Figure 19: Hourly PM_{10} and meteorological parameters on 29 January 2021, the day PM_{10} concentration was recorded highest between 2015 and 2021.

Daily PM_{10} concentrations during the period (2015–2021) complied with the NESAQ (Figure 20). However, on one occasion PM_{10} concentration exceeds the WHO guideline of 50 µg/m^3 (WHO, 2021).

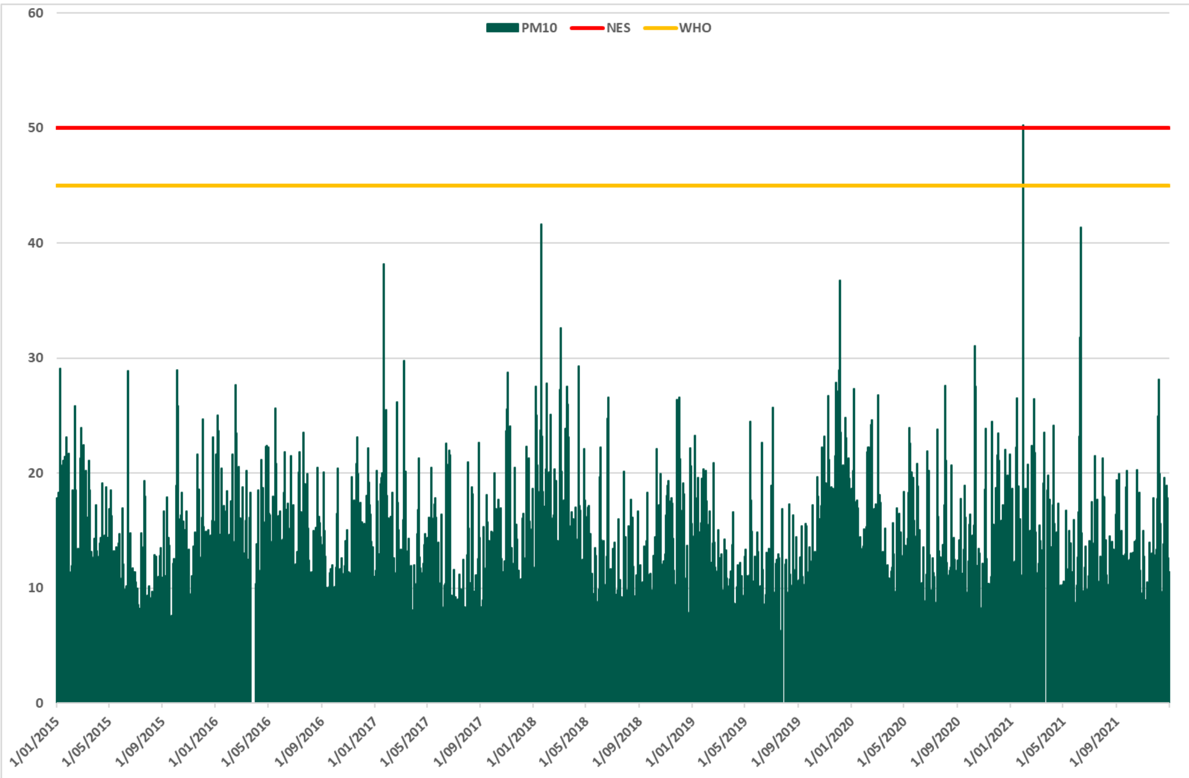


Figure 20: Daily PM_{10} concentrations at Bream Bay College 2015–2021.

Diurnal and seasonal variations

Temporal variations in seasonal PM_{10} concentrations at Bream Bay College, Marsden Point is shown in Figure 21. There is only one diurnal peak for $PM_{10,}$ around midday. The diurnal pattern shows that PM_{10} concentrations are not influenced by wood burners as noticed in Whangārei. High concentrations during midday are attributed by the day-to-day human activities, traffic, industrial emissions, and most importantly natural sources such as sea salt and windblown dust. The only similarity between Whangārei and Marsden Point airshed is that the highest concentrations were recorded on Thursdays. Thursday appeared to have highest concentrations of particulate matter in Northland. The cause of high concentrations (peak) on Thursday's needs to be investigated.

Monthly averages appear to range between 10 and 15 µg/m^3 with highest in January and lowest in September. Figure 21 shows a completely different seasonal variation at Bream Bay, Marsden Point from Robert Street, Whangārei. High PM_{10} concentrations during summer suggests non-domestic heating sources of PM_{10}, which is believed to be natural sources such as sea salt and windblown dust (Davy et.al., 2014).

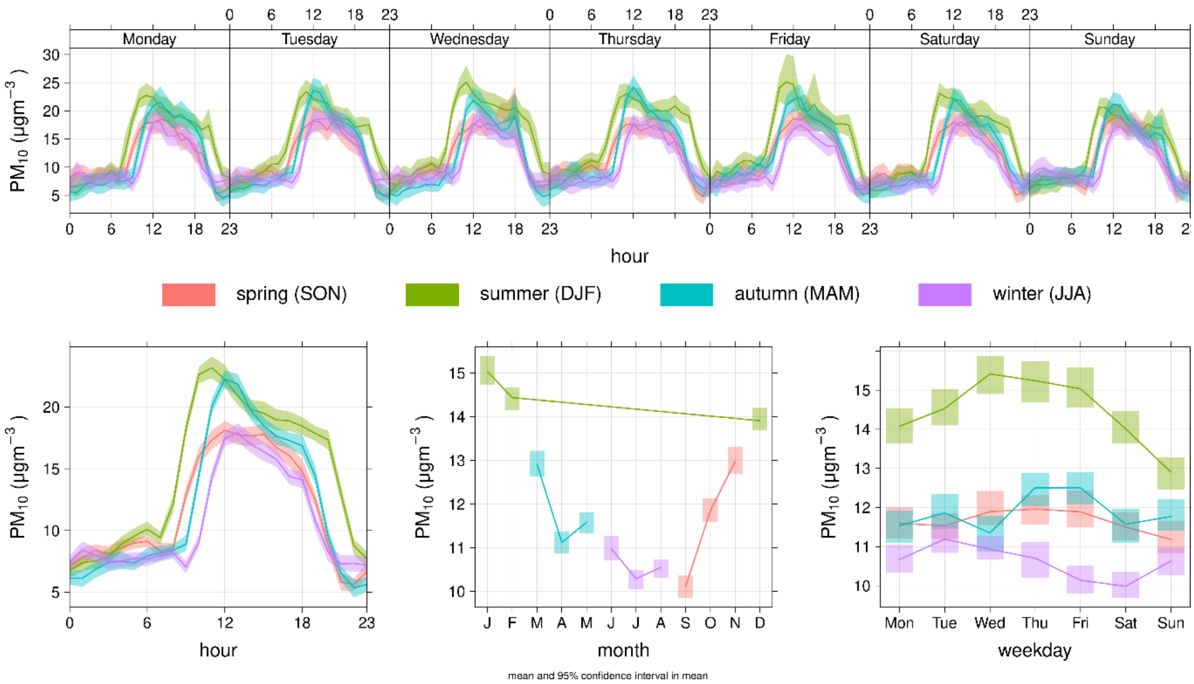


Figure 21:PM_{10} time variation plot for Bream Bay College, Marsden Point 2015 – 2021.

PM_{10} Pollution roses

Average PM_{10} concentrations from highest to lowest, in order of summer, spring, autumn, and winter are presented using pollutions roses (Figure 22). This order is the opposite of what was observed in Robert Street for PM_{10}. Highest PM_{10} concentration at Bream Bay College monitoring site are mainly sourced from southwest and from east during summer and spring, winter and autumn is mainly from western front.

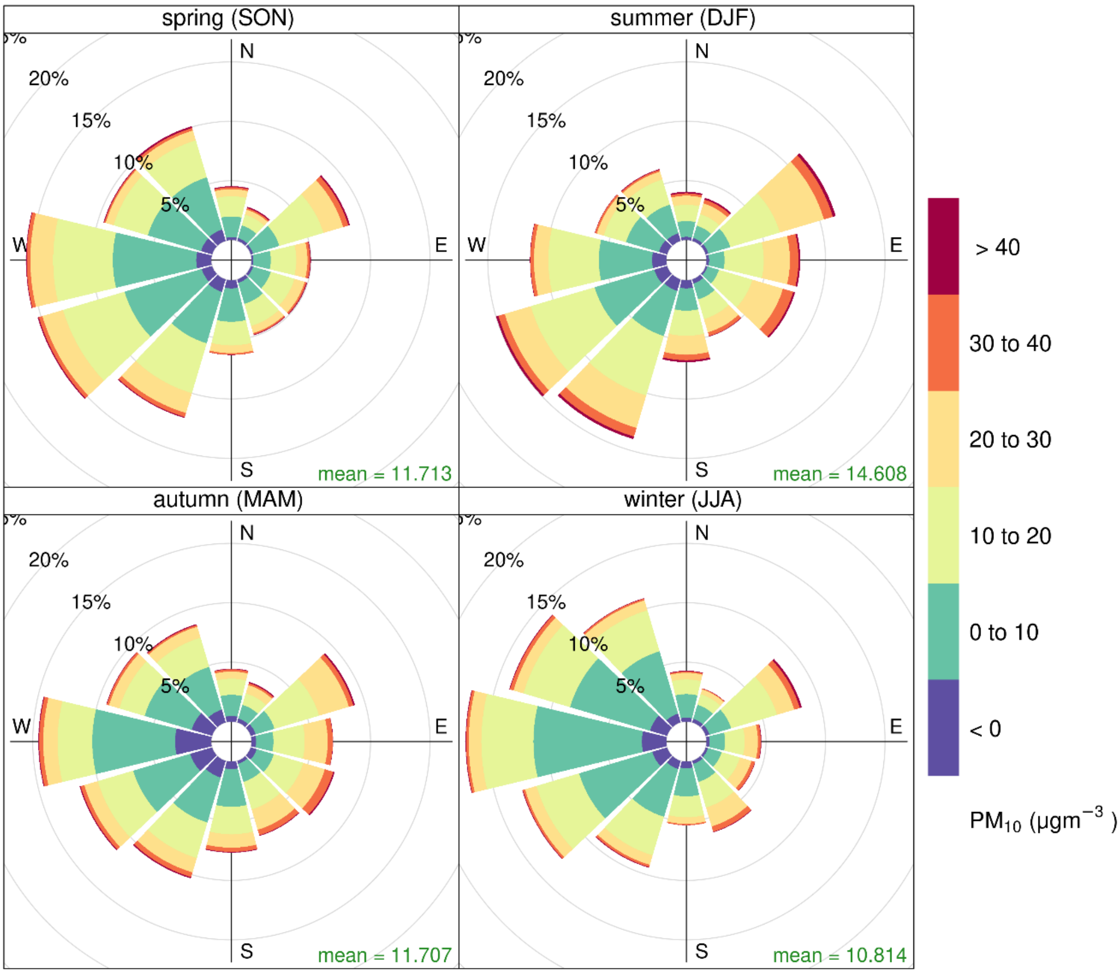


Figure 22: Seasonal PM_{10} pollution roses for Bream Bay College.

Long term trends

Trend analysis helps us to better understand the pattern of data collected over a period. Trend analysis was applied using an OpenAir R package de-seasonalised Theil-Sen technique, with the 95% confidence interval. Theil-Sen technique is commonly used by councils in New Zealand for air quality trend analysis (Caldwell, 2019; Talbot & Crimmins, 2020). De-seasonalised Theil-Sen trend analysis of PM (PM_{10} or $PM_{2.5}$) concentrations helps to understand whether the yearly variation in PM concentration is because of change in other parameters, such as wind speed, temperature, a localised pollutant source or if there is a real change in pollutant concentration pattern over the time.

Continuous PM_{10} monitoring at Robert Street, Whangārei started in 2006. Therefore, PM_{10} trends at Robert Street is divided into three separate time periods, two long term trends, the first for the whole monitoring period (May 2006 to August 2022), the second ten years (2012–2021) and then a short-term trend (2016–2021). PM_{10} monitoring at Bream Bay station started from late 2012. Monitoring data from late 2012 until the end of August 2022 is used for trend analysis for this site. For $PM_{2.5}$, at Robert Street only six years of data was available for trend analysis (August 2016 to August 2022). It is preferable to have ten years data for trend analysis. However, six full years of data is reasonable for trend analysis and have been used in MfE's recent report "Our Air 2021" (MfE & Stats NZ, 2021).

PM_{10} at Robert Street

The de-seasonalised trend for PM_{10} at Robert Street, Whangārei showed 0.18 µg/m^3 per year reduction in PM_{10} concentration from May 2006–August 2022 (P = <0.001), with a variability range between -0.24 to -0.11 (Figure 23). The ten-year trend from 2012 to 2021 shows an even greater improvement in PM_{10} concentration with 0.25 µg/m^3 year on year reduction (P = <0. 001). The short-term trend analysis for the period (2016–2021) also showed reduction in PM_{10} concentration (0.23 µg/m^3) but the reduction was weak significant (P = <0.05) compared to the long-term trends.

Reduction in PM_{10} concentration for Whangārei airshed over the monitoring period was expected, as no new major PM_{10} emission sources have been consented in this period, and three major consented industries, Ballance Fertiliser, TDC Sawmill and Cart Holt Harvey have ceased their operation in Whangārei. Other reasons could be the change to the backyard burning rule in 2008 for Whangārei airshed, increased use of electricity for home heating (heat pump and electric heater) and improved wood burners.

A comparison of the 2006 (Wilton, 2007), and 2018 (PDP, 2021) emission inventories suggested a reduction in total winter day PM_{10} emission in Whangārei airshed by approximately 27% (from 1.2 tonnes per day to 0.9 tonnes per day). PDP (2021) suggested large reduction (about 66%) of PM_{10} emissions in Whangārei airshed from industries. Emission from home heating and backyard burning were decreased by 14% and 78% respectively between 2006 and 2018 (PDP, 2021). However, PM_{10} emission from transport was found to be 44% higher in 2018 compared to 2006.

$PM_{2.5}$ at Robert Street

Six years of $PM_{2.5}$ monitoring data (August 2016 to August 2022) showed a decrease of 0.16 µg/m^3 per year, with -0.28 and -0.05 variability (Figure 24). The reason for the reduction in $PM_{2.5}$ concentration at Robert Street, Whangārei is same as the reason discussed earlier for PM_{10}.

PM_{10} at Bream Bay College

PM_{10} trend at Bream Bay College, Marsden Point did not show any sign of reduction or increase (Figure 25). PM_{10} concentrations at this site peak during summer months, which is largely contributed by natural sources, such as sea salt and windblown dust. There is no emission inventory available for the Marsden Point airshed.

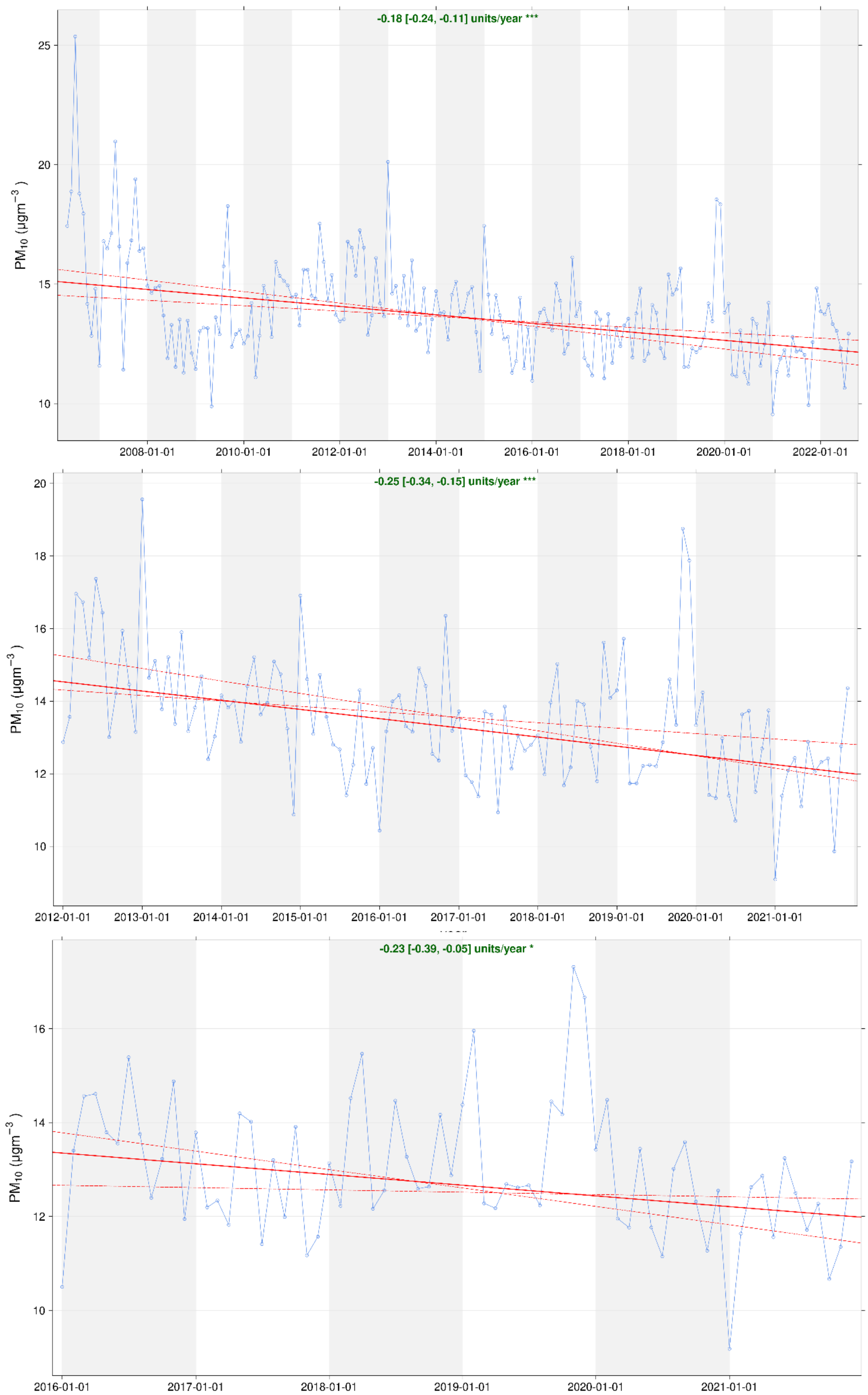


Figure 23: Trends for PM_{10} at Robert Street, Whangārei. Solid red line show year on year reduction in PM_{10}, upper and lower variability shown by hatched lines.

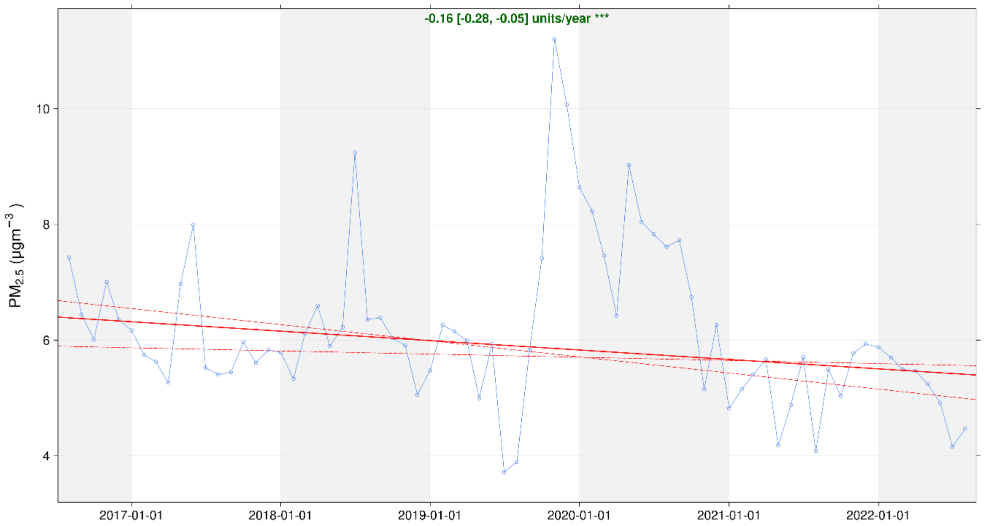


Figure 24: Trends for $PM_{2.5}$ at Robert Street, Whangārei.

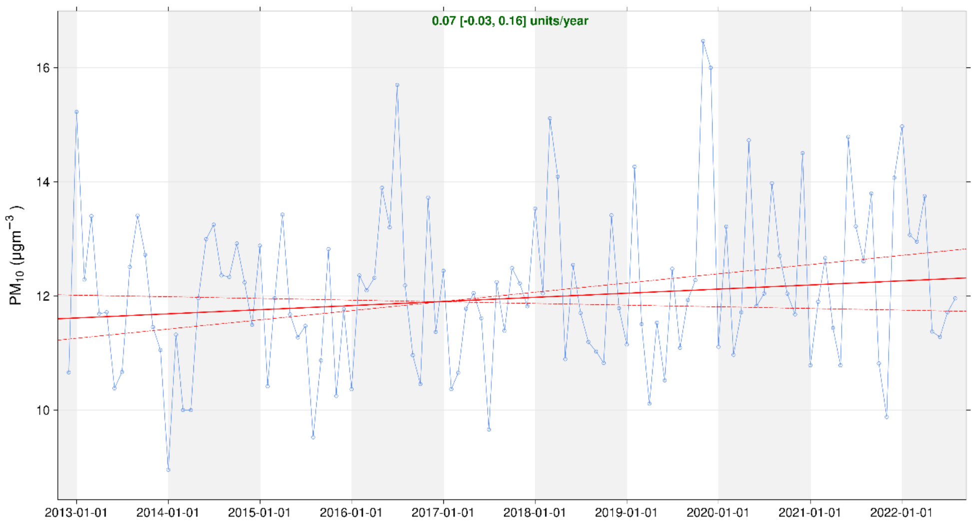


Figure 25: Trends for PM_{10} at Bream Bay College, Marsden Point.

Impact of COVID-19 restrictions on Particulate Matter (PM)

COVID-19 pandemic started in late 2019. The virus rapidly spread all over the word within a short period due to its highly contagious nature. As there was no cure or treatment available for the virus at the beginning, almost all the countries imposed partial to complete lockdowns on public movement. These lockdowns stopped or slowed down the spread of COVID-19. Restrictions on domestic and international travel, industrial operation, closure of educational facilities and working from home abruptly lowered emissions, resulting in significant reduction in air pollutant concentrations (Zoran, et al., 2020; Talbot, et al., 2021; Longley, 2020; Mitchell, 2021), and improved air quality. Higher reductions were noticed in traffic related air pollutants such as oxides of nitrogen, carbon monoxide and particulate matter. Auckland and Wellington monitoring sites recorded 80 – 90% reduction in nitrogen dioxide (NO_2) concentrations from the normal levels in week 3 of level 4 lockdown in New Zealand (Longley, 2020).

The first positive COVID-19 case in New Zealand was detected in late February 2020 (MoH, 2022). Within a month from the first case detected, New Zealand government imposed a restrictive lockdown to stop the spread of the COVID-19. Lockdown restrictions were categorised into four levels (Level 4 most to Level 1 least restrictive). A summary of restrictions applied during COVID-19 lockdown in New Zealand are presented in Appendix 3.

This report simply compares business as usual (BAU) and the observed air quality data during the different levels of COVID-19 restrictions, to check whether there was any difference in pollutant concentrations because of COVID-19 restrictions. BAU values were obtained by averaging the data for the same day of the year between 2015 and 2019 for each restriction level. For example, 26 March 2020 was the first day of level 4 lockdown, therefore, values for 26 March, between 2015 and 2019 were averaged to obtain a BAU. A simple t-test using MS Excel was used to compare difference between BAU and the observed values.

Meteorological data such as wind speed, wind direction, temperature and humidity were also considered for this investigation. However, there was no noticeable change in meteorological data during COVID-19 restrictions from BAU. Hence, this report only focuses on PM concentrations.

COVID-19 restriction in 2020

Monitoring data from Robert Street, Whangārei, Bream Bay College, Marsden Point and North Road, Kaitaia were used, for analysis. The data for Kaitāia was collected by Juken New Zealand, as part of their compliance monitoring. Robert Street $PM_{2.5}$ data was not included in 2020 restriction since the council did not have full data for the lockdown period due to instrument malfunction.

PM_{10} concentrations at Whangārei, Marsden Point and Kaitāia were significantly lower than business as usual (BAU) during level 4 restrictions (Table 10; Figure 26). The BAU and observed values in Table 10 are the averages of daily concentrations during the respective restriction levels. Significant decrease was expected as it was a complete lockdown and traffic was significantly reduced (Appendix *3*). During level 3, PM_{10} concentrations increased in Whangārei and Marsden Point but small decrease was seen in Kaitāia. Marsden Point PM_{10} concentration increase in level 3 was high and showed a weak significance. Kaitāia was the only site that showed decreased PM_{10} during all restriction levels. Whangārei showed noticeable decrease in level 3 and 4 restrictions.

Table 10: PM_{10} concentrations (µg/m³) for Whangārei, Marsden Point and Kaitāia airsheds showing impact of 2020 COVID-19 restrictions on PM_{10} concentrations.

Level	Airshed	BAU	Observed	Change %	P-value	Significance
Level 4	Whangārei	12	9	-25.0	0.0001	Yes
	Marsden Point	12	10	-16.6	0.002	Yes
	Kaitāia	17	13	-30.7	0.0001	Yes
Level 3	Whangārei	13	14	+7.7	0.50	No
	Marsden Point	12	14	+16.7	0.04	Weak
	Kaitāia	19	18	-5.3	0.18	No
Level 2	Whangārei	14	13	-7.1	0.5	No
	Marsden Point	11	14	+25	0.03	Weak
	Kaitāia	18	16	-11.1	0.10	No
Level 1	Whangārei	15	14	-6.7	0.15	No
	Marsden Point	11	11	0	0.77	No
	Kaitāia	18	14	-22.2	0.02	Weak

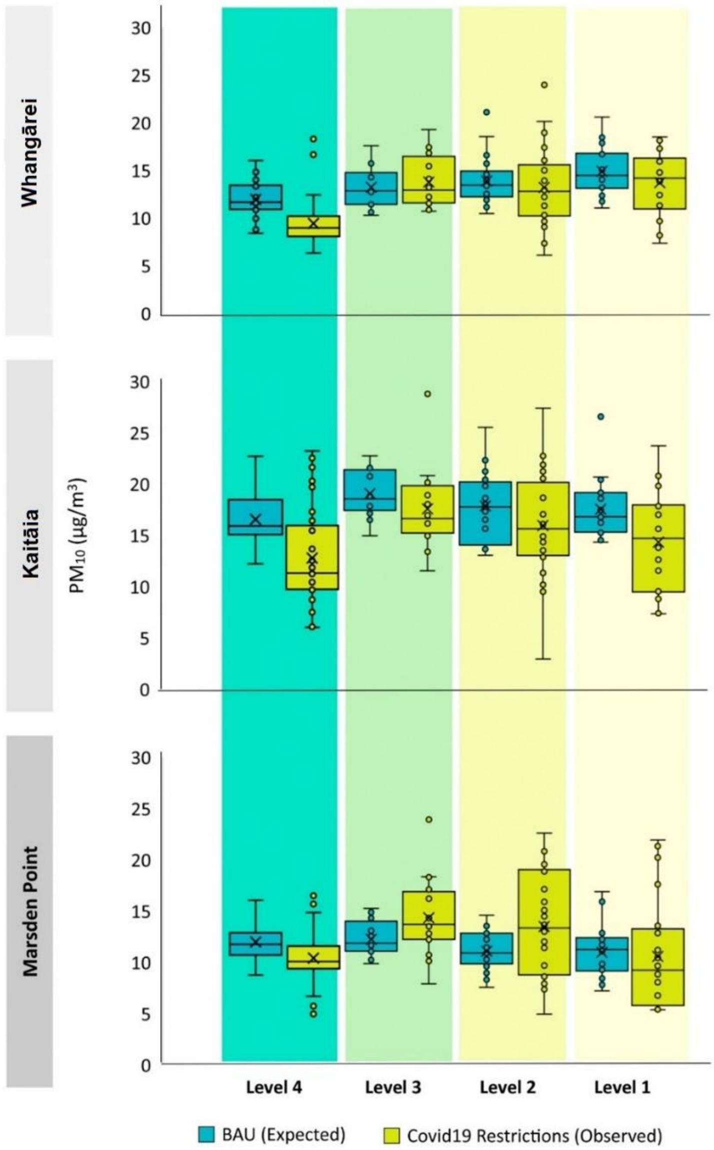


Figure 26: PM_{10} concentrations box plots for Whangārei, Marsden Point and Kaitāia airsheds during 2020 COVID-19 restrictions.

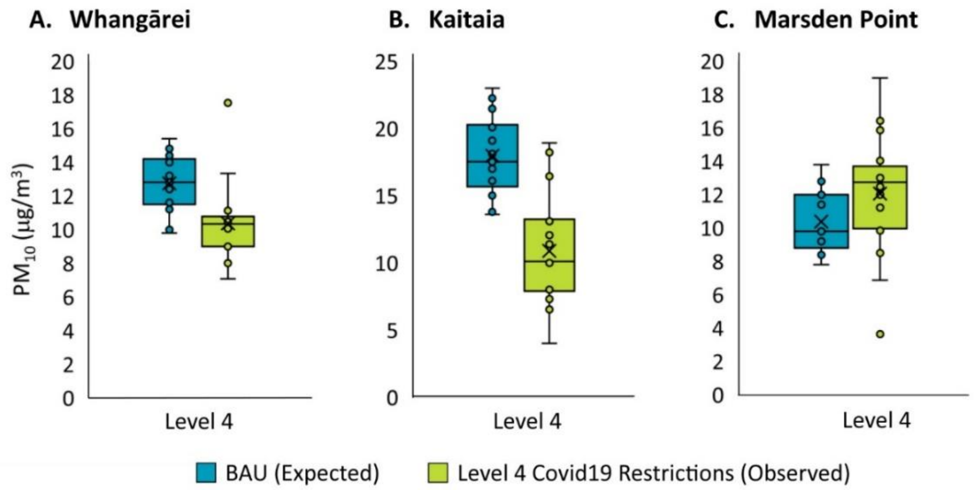
COVID-19 restriction in 2021

New Zealand was imposed to level 4 (L4) restrictions for 17 days between 18 August and 3 September 2021 to stop the spread of COVID-19 delta variant. Prior to this, there was a level 1 restriction and after the 17 days, COVID-19 restriction was changed to level 3 for only three days and then to level 2. PM_{10} and $PM_{2.5}$ monitoring data during L4 period and the BAU from Whangārei (PM_{10} and $PM_{2.5}$), Marsden Point (PM_{10}), and Kaitāia (PM_{10}) airsheds are presented in Table 11 and Figure 27.

Table 11: PM_{10} concentrations (µg/m³) for Whangārei, Marsden Point and Kaitāia airsheds showing impact of 2021 COVID-19 restrictions on PM_{10} and $PM_{2.5}$ concentrations.

Airshed	BAU	Observed	Change %	P-value	Significance
Whangārei PM_{10}	13	10	-23.1	0.002	Yes
Whangārei $PM_{2.5}$	7	5	-28.6	0.0003	Yes
Marsden Point	10	12	+20.0	0.15	No
Kaitāia	18	11	-50.0	0.00003	Yes

PM_{10}



$PM_{2.5}$

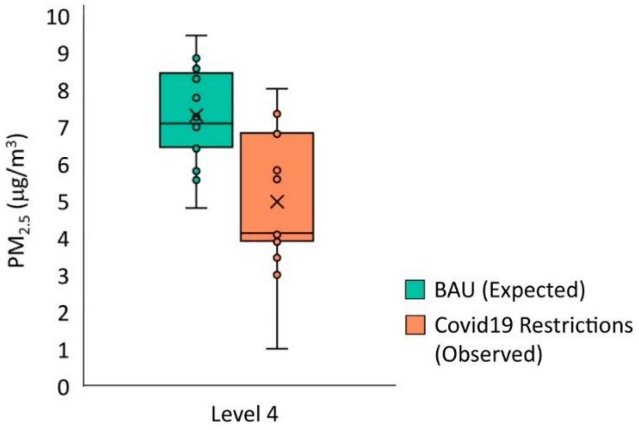


Figure 27: PM_{10} and $PM_{2.5}$ concentrations box plots for Whangārei, Marsden Point and Kaitāia airsheds during 2021 COVID-19 restrictions.

Significant reduction was noted in PM_{10} and $PM_{2.5}$ concentrations at Whangārei, and PM_{10} concentrations at Kaitāia (Table 11; Figure 27). However, PM_{10} concentrations increased by 20% at Marsden Point (Table 11). However, the increase was not statistically significant (P = 0.15). Highest reduction in PM_{10} was recorded at Kaitāia (50%). Kaitāia monitor was in industrial area and complete lockdown significantly reduced the emission from industries and surrounding businesses. Reduction in $PM_{2.5}$ was higher than PM_{10}, 28.6% and 23.1% respectively in the Whangārei airshed.

The days on which wind direction was dominant from east and southeast, PM_{10} concentrations were higher, especially at Marsden Point and in some extent at Whangārei. Sea salt may have increased PM_{10} concentrations at both sites as both monitors are located close to the coast (less than a kilometre). Wind roses during the different restriction levels are presented in Appendix 4.

Conclusions

Northland Regional Council is responsible for managing air quality in the region. Council monitors PM_{10} and $PM_{2.5}$ at its Robert Street station in Whangārei and PM_{10} at Bream Bay College station in Marsden Point. This report includes analysis of particulate matter and meteorological monitoring conducted by the council at its two permanent air quality monitoring sites between 2015 and 2021. Report assessed results against national standard (NESAQ), WHO guidelines and investigated the impact of COVID-19 lockdowns in PM_{10} and $PM_{2.5}$ concentrations.

Key findings

- PM_{10} concentrations at both sites were compliant with NESAQ.
- PM_{10} concentrations at both sites exceeded the WHO guidelines on one occasion.
- $PM_{2.5}$ concentrations at Whangārei confirmed compliance with the proposed NESAQ amendment but exceeded WHO guideline on several occasions during winter months.
- High concentrations of PM_{10} and $PM_{2.5}$ between December 2019 and January 2020 was a result of smoke originating from Australian bushfire.
- De-seasonalised trend analysis on PM_{10} and $PM_{2.5}$ concentrations confirmed significant reduction in particulate matter concentrations for Whangārei airshed.
- PM_{10} trend for Marsden Point was indeterminate.

Seasonal and diurnal patterns

- PM_{10} concentrations at Whangārei peaked in the afternoon and until late evening.
- PM_{10} concentrations at Marsden Point peaked around midday.
- $PM_{2.5}$ concentrations at Whangārei peaked just before midday and again in the evening.
- Both PM_{10} and $PM_{2.5}$ at both sites increased from Wednesday to Friday.
- Seasonal variation analysis showed distinct seasonal peak for $PM_{2.5}$ with the highest concentrations recorded in the months of June, July, and August.
- PM_{10} seasonal variation at Whangārei was similar to seasonal variation of $PM_{2.5}$. However, seasonal variation of $PM_{2.5}$ was higher than the seasonal variation of PM_{10}.
- PM_{10} concentrations at the Marsden Point were highest during summer.

Meteorological parameters

- There was no noticeable change in meteorological parameters at both monitoring sites except for the increase in minimum temperature. Minimum temperature increased by 0.99 ^{0}C at Whangārei and 1.1 ^{0}C at Marsden Point between 2015 and 2021.
- Seasonal trend was observed for humidity at Whangārei and Marsden Point e.g., high in winter and low in summer.
- Marsden Point was recorded as slightly cooler than Whangārei.

Covid-19 restrictions 2020 – 2021

- Covid-19 related lockdowns in 2020 showed reduction in particulate concentration at Whangārei, Marsden Point and Kaitāia airsheds, especially during level 4 restrictions.
- PM_{10} concentrations in Whangārei and Marsden Point increased during level 3 restriction.
- Kaitāia showed reduction in all Covid-19 related restriction levels.
- Effect of 2021 Covid-19 lockdown showed significant reduction in PM_{10} and $PM_{2.5}$ concentrations at Whangārei and Kaitāia airsheds.
- PM_{10} concentrations increased during 2021 lockdown in Marsden Point.
- PM_{10} concentration decreased by 50% at Kaitāia airshed during 2021 COVID-19 restrictions.

Recommendations

Northland Regional Council's air monitoring is limited. Council currently monitors at two airsheds Whangārei and Marsden Point out of five airsheds in Northland. Council only monitors PM_{10} whereas there are five air pollutants (PM_{10}, carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone) included in NESAQ. It would be ideal to monitor all air pollutants at all airsheds.

A reasonable recommendation is to have three permanent monitoring stations for PM_{10}, $PM_{2.5}$ and meteorology at Whangārei, Kaitāia and Dargaville and alternate monitoring between Kerikeri and Marsden Point using a mobile monitor. It is also recommended to have screen monitoring for NO_2 in Whangārei for at least one year. This will give confidence on state of NO_2 and will address current monitoring gaps. Council has monitored CO and SO_2 at Whangārei airshed in the past and discontinued as concentrations were well below the NESAQ. Ozone is not a primary air pollutant, and it is not believed that the atmospheric conditions are suitable to form ozone in Northland. However, NO_2 could be an issue in narrow busy streets like Bank Street in Whangārei.

References

Arriagada, N. B., Palmer, A. J., Bowman, D., MjS, Morgan, G. G., Jalaludin, B., B., Johnston, F. H. (2020). *Unprecedented smoke-related health burden associated with the 2019-20 bushfires in eastern Australia.* Medical Journal of Australia, 213(6), September 2020.

Barnett, A. G., Williams, G. M., Schwartz, J., Best, T. L., Neller, A. H., Petroeschevsky, A. L., & Simpson, R. W. (2006). The effects of air pollution on hospitalizations for cardiovascular disease in elderly people in Australian and New Zealand cities. *Environmental health perspectives*, *114*(7), 1018-1023.

Beer, T. (2010). *Air pollution and health risk*. Clean Air Society of Australia and New Zealand.

Bluett, J., Khanal, O., and Blender, C. (2022). *Identifying hotspots and targeting monitoring locations within Northland's priority airsheds*. CASANZ22: Conference Handbook. 26th International Clean Air and Environment Conference.

Boamponsem, L. (2022). *Auckland air quality – 2021 annual data report*. Auckland Council technical report, TR2022/5

Caldwell, J. (2019). *Ambient air quality monitoring report for the Waikato Region – 2017*. Waikato Regional Council Technical Report 2018/15. https://waikatoregion.govt.nz/services/publications/tr201815/

COVID19.govt.nz, (2021). *New Zealand COVID-19 alert levels summary.* https://covid19.govt.nz/assets/resources/tables/COVID-19-Alert-Levels-summary-table.pdf (accessed November 2022).

Davy, P. K., Ancelet, T. (2014). *Air particulate matter composition, sources and trends in the Whangārei airshed*. GNS Science Consultancy Report 2014/186.

Dillane, T., (2020). *Explained: why the North Island woke to an 'apocalyptic' orange haze from the Australian bushfires.* New Zealand Herald, 2 January 2020. https://www.nzherald.co.nz/nz/explained-why-the-north-island-woke-to-an-apocalyptic-orange-haze-from-the-australian-bushfires/G2D2I3LTRDKLGB7UPPZCWBLYQ4/?c_id=1&objectid=12297723

Habeebullah, T.M., Awad, A. H. A., Munir, S., Morsy, E., (2014). *The interaction between air quality and meteorological factors in a arid environment of Makkah, Saudi Arabia*. International Journal of Environmental Science and Development, Volume 6, No. 8, August 2015.

Health Effects Institute (2020). *State of global air 2020*. Special Report. Boston, MA: Health Effects Institute.

Khanal, O. R. (2003). *Organics in atmospheric particulates.* PhD Thesis, the University of Auckland, New Zealand.

Kuschel et al (2022). *Health and air pollution in New Zealand 2016 (HAPINZ 3.0): Volume 1 - Finding and implications.* Report prepared by G Kuschel, J Metcalfe, S Sridhar, P Davy, K Hastings, K

Mason, T Denne, J Berentson-Shaw, S Bell, S Hales, J Atkinson and A Woodward for Ministry for the Environment, Ministry of Health, Te Manatū Waka Ministry of Transport and Waka Kotahi NZ Transport Agency, March 2022.

LAWA (2021). Land Air Water Aotearoa. https://www.lawa.org.nz/learn/factsheets/air-quality-topic/why-is-air-quality-important/ (accessed on 26 July 2022).

Longley, I. (2020). *Steep improvements seen in Auckland air quality, says NIWA.* Air quality updates during Covid-19 level restrictions. https://niwa.co.nz/atmosphere/air-quality-updates-during-covid19-level-restrictions (accessed on 31 October 2022).

Metcalfe, J. & Wickham, L. (2019). *Health impacts of PM_{10} from unsealed roads in Northland*. Prepared for Ministry of Health, by Emission Impossible Ltd. www.emissionimpossible.co.nz

Ministry for the Environment & Statistics New Zealand (2015). *New Zealand's Environmental Reporting Series: Environment Aotearoa 2015*. Retrieved from www.environment.govt.nz and www.stats.govt.nz

Ministry for the Environment & Stats NZ (2021). *New Zealand's Environmental Reporting Series: Our air 2021*. Retrieved from environment.govt.nz

Ministry for the Environment & Stats NZ (2022). *New Zealand's environmental reporting series: Environment Aotearoa 2022*. Retrieved from environment.govt.nz

Ministry for the Environment (2002). Ambient air quality guidelines – 2002 update, Air quality report No. 32, Prepared by the Ministry for the Environment and the Ministry of Health.

Ministry for the Environment (2004). *Resource Management (National Environmental Standards for Air Quality) Regulations 2004*. https://www.legislation.govt.nz/regulation/public/2004/0309/latest/DLM286835.html?search=ta_regulation_R_rc%40rinf%40rnif_an%40bn%40rn_25_a&p=3

Ministry for the Environment (2009a). *GEMS/AIMS Air Quality Monitoring Programme Annual Report 2008*. Wellington: Ministry for the Environment. https://environment.govt.nz/assets/Publications/Files/gems-report-2008.pdf

Ministry for the Environment (2009b). *Good practice guide for air quality monitoring and data management 2009*. Wellington. www.mfe.govt.nz

Ministry for the Environment (2016). *Good practice guide for assessing and managing dust*. Wellington. www.mfe.govt.nz

Ministry for the Environment (2020). *Proposed amendments to the National Environmental Standard for air quality: particulate matter and mercury emissions – consultation document.* Wellington: Ministry for the Environment. www.mfe.govt.nz

Ministry of Health (2022). *Information about confirmed and probable cases of COVID-19 in New Zealand.* https://www.health.govt.nz/covid-19-novel-coronavirus/covid-19-data-and-statistics/covid-19-current-cases (accessed October 2022).

Mitchell, T.A. (2021). *An analysis of the impact of COVID-19 restrictions on air quality in the Wellington region.* Greater Wellington Regional Council, Publication No. GW/ESCI-T-21/37, Wellington.

Nature (2020). *Bush-fire smoke linked to hundreds of deaths*. https://www.nature.com/articles/d41586-020-00886-9

Nature News Feature (2020). *The race to decipher how climate change influenced Australia's record fires.* https://www.nature.com/articles/d41586-020-00173-7

NIWA (2020). *Recommendations for what areas to prioritise $PM_{2.5}$ monitoring in Northland airsheds*. NIWA client report No: 2020110AK, NIWA Project: ELF20103. A report prepared for Northland Regional Council, by NIWA, June 2020.

Northland Regional Council (2017). *State of the environment report 2015*. https://www.nrc.govt.nz/resource-library-summary/environmental-monitoring/state-of-the-environment-monitoring-12/

Northland Regional Council (2022). *Proposed Regional Plan for Northland August 2022* – Appeals Version.

NZTA (2020). *State Highway Traffic Volumes 1975-2020*. https://Www.Nzta.Govt.Nz/Resources/State-Highway-Traffic-Volumes/

Parliamentary Commissioner for the Environment (2015). *The state of air quality in New Zealand commentary by the Parliamentary Commissioner for Environment on the 2014 air domain report*. www.pce.parliament.nz

PDP, (2021). *Whangārei and Kaitāia air emission inventories for particulate matter – 2018.* Prepared for Northland Regional Council by Pattle Delamore Partners (PDP) Limited. https://www.nrc.govt.nz/resource-library-summary/research-and-reports/air-quality/

StatsNZ (2021). Retrieved from Census 2018. https://www.stats.govt.nz/topics/census?gclid=CjwKCAjwgviIBhBkEiwA10

Talbot, N and P Crimmins (2020). *Trends in Auckland's air quality 2006-2018*. Auckland Council technical report, TR2020/004.

Talbot, N., Takada, N., Bingham, A., Elder, AH., Yee, SL & Golubiewski, NE. (2021a). *Changes in Aotearoa New Zealand's air quality during 2020 social restriction response to the COVID-19 pandemic: Technical report.* Wellington: Ministry for the Environment.

Talbot, N., Takada, N., Bingham, A., Elder, AH., Yee, SL & Golubiewski, NE. (2021b). *An investigation of the impact of a successful COVID-19 response and meteorology on air quality in New Zealand.* Atmospheric Environment, https://doi.org/10.1016/j.atmosenv.2021.118322

Taranaki Regional Council, (2020). *Inhalable particulate ($PM_{2.5}$) regional monitoring program report 2016 – 2020.* Technical Report 2020 – 32.

Wilton E., Zawar-Reza P., Soltanzadeh I. (2012). *Airshed modelling for PM_{10} concentrations – Marsden Point*. Prepared for Northland Regional Council by Environet Ltd and Canterbury University.

Wilton, E (2007). *Air emission inventory Whangārei 2006*. Prepared for Northland Regional Council by Environet Ltd.

World Health Organization (2021). *WHO global air quality guidelines. Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide.* Geneva: World Health Organization, 2021. Licence: CCBY-NC-SA 3.0IGO.

Zoran, M. A., Savastru, R. S., Savastru, D. M., Tautan, M. N. (2020). *Assessing the relationship between levels of $PM_{2.5}$ and PM_{10} particulate matter impact on COVID-19 in Milan, Italy*. Science of the Total Environment, 738 (2020) 139825.

Appendices

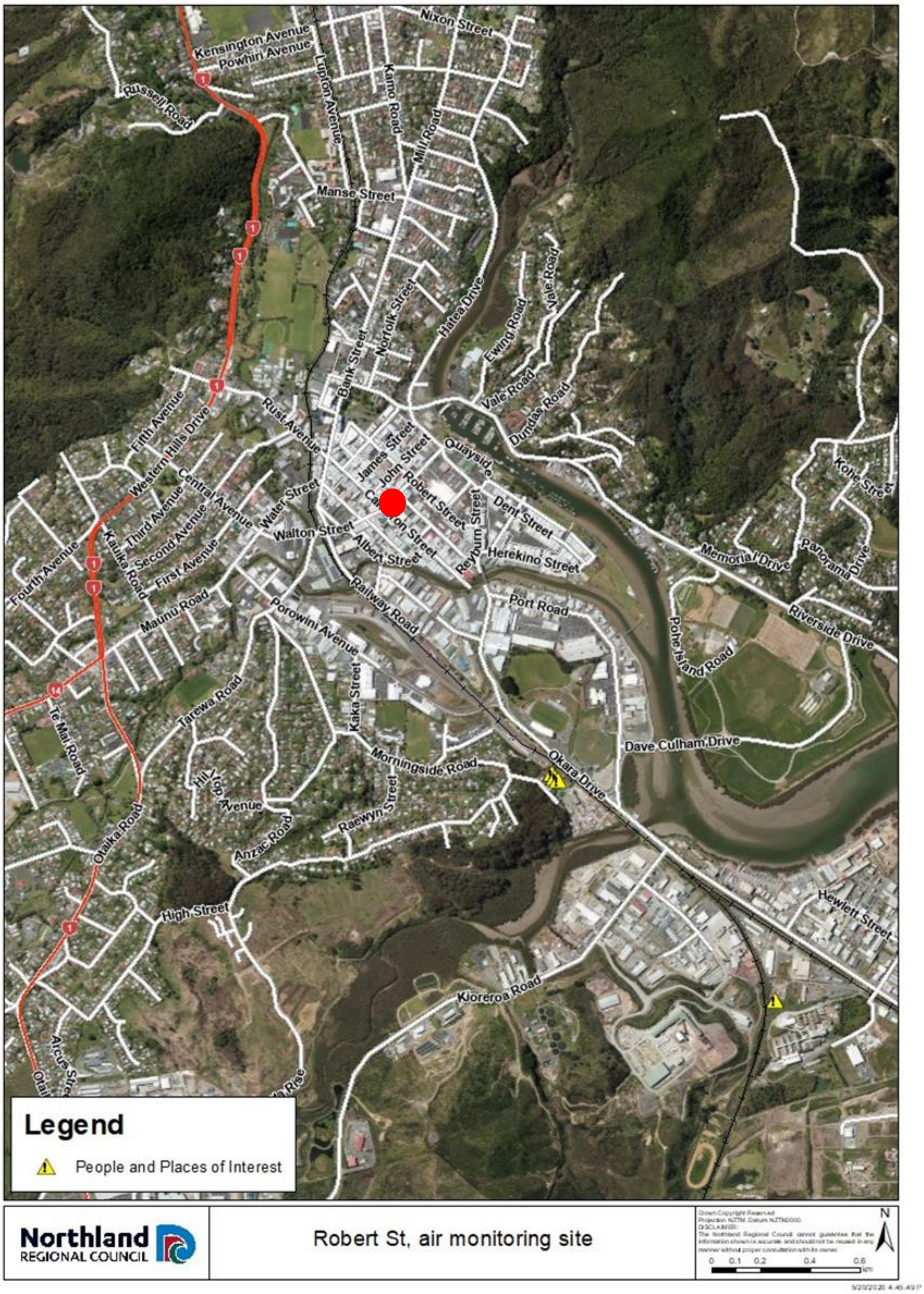
Appendix 1: Whangārei airshed ambient air monitoring.

A. Monitoring site metadata	
Indicators monitored	CO, SO_2, PM_{10} and $PM_{2.5}$. CO and SO_2 monitoring discontinued from 2016.
Site code	104977
Location ID	LOC.300837
IRIS ID	REG.802714
Site title	Whangārei
Address	88 Robert Street, Whangārei
Region	Northland
Map reference	Q07305-074
Site coordinates	E1719769 N6045549 (NZTM)
Latitude	-35.7267287
Longitude	174.3242521
Equipment owner	Northland Regional Council
Landowner's detail	Northland Regional Council 0800 002 004
Equipment housing	Shed
Housing environment	Air conditioned 25 °C
Monitoring objective	• Sustainably manage air quality in Whangārei airshed • Measure NES air quality compliance • Ensure public health protected and amenity values maintained • Assess airshed capacity • Measure effectiveness of air quality plan for Northland
Site category	Residential
Scale of representation	Neighbourhood
Air conditioner service provider contact details	Airzone Limited, Whangārei Phone: 09 438 9880
Photograph of the site	Street map and photo presented in following page.

B. Meteorological site metadata	
Meteorological variables measured	Wind speed, wind direction, ambient and room temperature, humidity, pressure, rainfall etc.
Meteorological data operator	Northland Regional Council
Location of meteorological site	Onsite at 4.5 meters above the ground level.
Meteorological data information	Northland Regional Council
Regional and local meteorological characteristics	Monitoring site is located in a flat terrain, close to town basin. Mild, humid and windy conditions are common in Whangārei. Winter is mild. Predominant wind direction for Whangārei is from southwest and northwest. Strong south-westerly wind dominates during spring and summer, whereas lighter winds from northwest predominates during autumn. Mostly calm conditions during autumn and winter. Average ambient temperature remains between 10- and 12-°C.

C. Contaminants metadata	
Contaminant	PM_{10} and $PM_{2.5}$, SO_2 and CO
Data owner	NRC
Instrument	Thermo BAMFH62 and Thermo BAM5014i
Period of operation	PM_{10} High volume sampler 1996 - 2003, PM_{10} BAM 2006 ongoing $PM_{2.5}$ August 2016 ongoing CO and SO_2 July 2010 – July 2016
Method	PM_{10} in accordance with AS 3580.9.11 – 2016: Determination of suspended particulate matter - PM_{10} beta attenuation monitors. $PM_{2.5}$ measurements are conducted in accordance with AS/NZS 3580.9.12 – 2013: Determination of suspended particulate matter – $PM_{2.5}$ beta attenuation monitors and AS/NZS 3580.9.11 – 2016.
Data logging	Watercare Services
Sampling height	Inlet height 3 meters
Calibration frequency	Every three months
Percent of valid data	Meeting the NES air quality standard since 2010

Air monitoring shed at Robert St, Whangārei


Legend
People and Places of Interest
Northland Regional Council
Robert St, air monitoring site
Kensington Avenue
Powhiri Avenue
Russell Road
Lupton Avenue
Kamo Road
Nixon Street
Mill Road
Manse Street
Norfolk Street
Bank Street
Hatea Drive
Ewing Road
Vale Road
Dundas Road
Rust Avenue
James Street
John Street
Robert Street
Quayside
Dent Street
Reyburn Street
Herekino Street
Walton Street
Water Street
Albert Street
Central Avenue
Western Hills Drive
Fifth Avenue
Third Avenue
Second Avenue
First Avenue
Fourth Avenue
Kauika Road
Maunu Road
Porowini Avenue
Railway Road
Port Road
Memorial Drive
Panorama Drive
Kohe Street
Riverside Drive
Pohe Island Road
Dave Culham Drive
Tarewa Road
Te Mai Road
Kaka Street
Morningside Road
Okara Drive
Hill Top Avenue
Raewyn Street
Anzac Road
Otaika Road
High Street
Kioreroa Road
Hewlett Street
Alcus Street

Appendix 2: Marsden Point airshed PM_{10} monitoring Ruakākā.

A. Monitoring site metadata	
Indicators monitored	PM_{10}
Location ID	LOC.300403
IRIS ID	REG.864726
Site title	Marsden Point airshed
Address	Peter Snell Road
Region	Northland
Site coordinates	E1731510 N6026793 (NZTM)
Latitude	-35.8761741
Longitude	174.4565981
Equipment owner	Northland Regional Council
Land owner's detail	Ministry of Education, Bream Bay College
Equipment housing	Shed
Housing environment	Air conditioned 25 °C
Monitoring objective	• Sustainably manage air quality in Marsden Point airshed • Measure NES air quality compliance • Ensure public health protected and amenity values maintained • Assess airshed capacity • Measure effectiveness of air quality plan for Northland
Site category	Residential
Scale of representation	Neighbourhood
Air conditioner service provider contact details	Airzone Limited, Whangārei Phone: 09 438 9880
Photograph of the site	Street map and photo presented in following page.

B. Meteorological site metadata	
Meteorological variables measured	Wind speed, wind direction, ambient and room temperature, humidity, pressure, rainfall etc.
Meteorological data operator	Northland Regional Council
Location of meteorological site	Onsite at 4.5 meters above the ground level.
Meteorological data information	Northland Regional Council
Regional and local meteorological characteristics	The monitoring site is located beside the front car park inside Bream Bay College school grounds. The site is about 80 m south of Peter Snell Road and 170 m east of Marsden Point Road on the western edge of the Ruakākā township. Marsden Point Road is the nearest main road with rural farmland to the west and residential areas to the east and south. An industrial area including the oil refinery at Marsden Point is located 3.5 km northeast of the site. The local topography of Ruakākā is a flat terrain with Bream Bay 1 km to the east. Dominant wind direction from west to south-west. Average temperature lies between 10 and 12 °C.

C. Contaminants metadata	
Contaminant	PM_{10}
Data owner	NRC
Instrument	Thermo BAMFH62
Period of operation	2012 ongoing
Method	PM_{10} in accordance with AS 3580.9.11 – 2016: Determination of suspended particulate matter - PM_{10} beta attenuation monitors.
Data logging	Watercare Services
Sampling height	Inlet height 3 meters
Calibration frequency	Every three months
Percent of valid data	Meeting the NES air quality standard since 2012

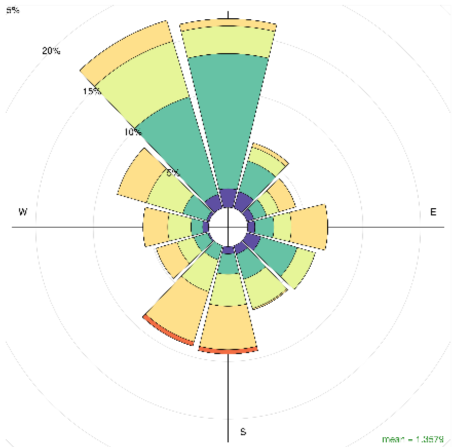
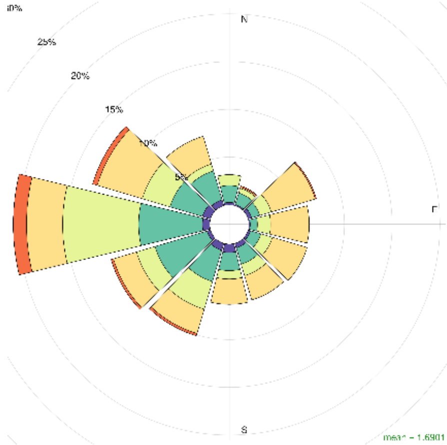
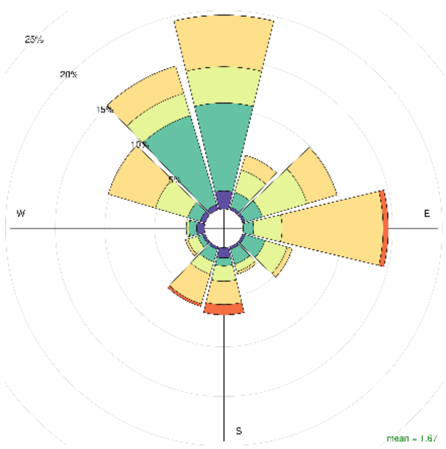
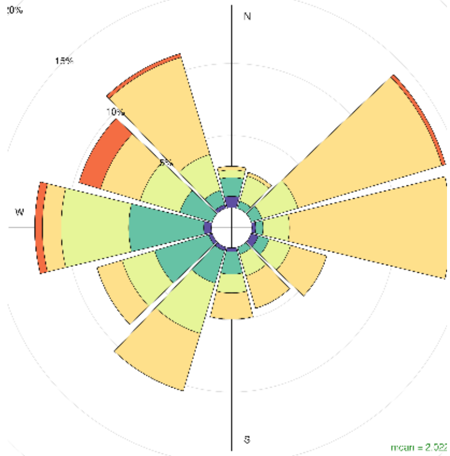
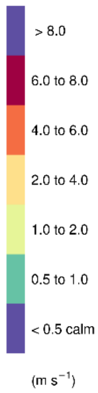
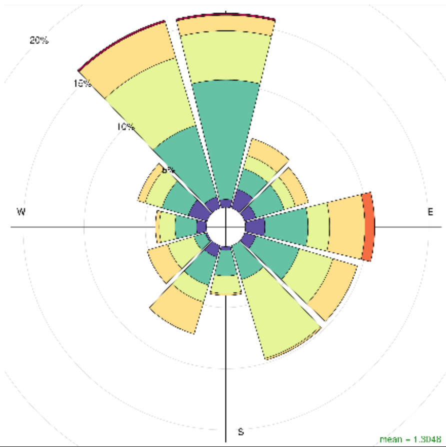
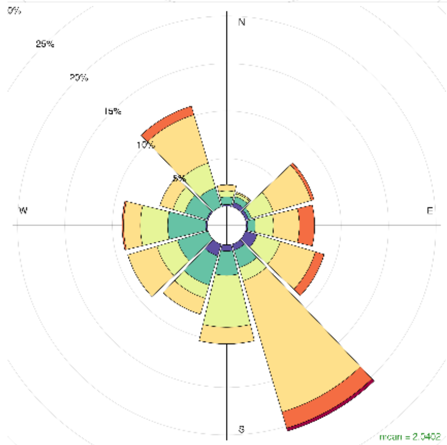
Ruakākā air monitoring site.

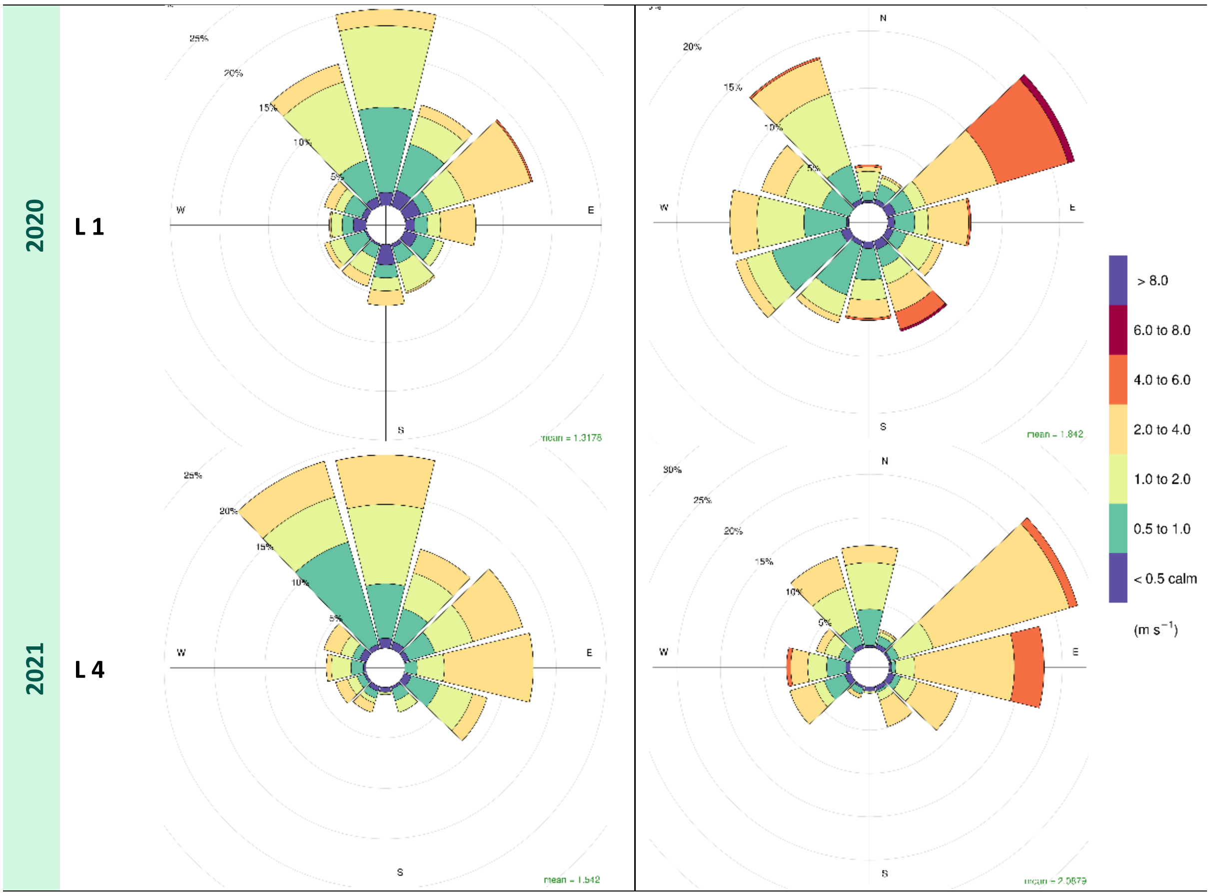

Casey Road
Roosevelt Road
Theodore Drive
Pokapu Road
Waiwarawara Drive
Port Marsden Highway
One Tree Point Road
15A
McCathie Road
Marsden Point Road
Allis Bloy Place
Innovate Road
Lakeside Park Road
Sime Road
Kepa Road
Peter Snell Road
Station Road
Taminga Street
Tamure Place
Karawai Street
Taranga Walk
Biller Road
Karo Street
Salle Road
1
Legend
People and Places of Interest
Northland
REGIONAL COUNCIL
Ruakaka air monitoring site
N

Appendix 3: COVID-19 lockdown restriction details (COVID19.govt.nz, 2021 & Talbot, et al, 2021).

Alert level	Restrictions imposed	Traffic volume change
Level 4 (26 Mar to 27 Apr 2020)	• People were instructed to stay at home • Send one person from household to the shop • No unnecessary travel permitted • All educational facilities closed • No public gathering • Stay two meters away from other people • Work from home	79 and 69% (light and heavy-duty vehicles respectively) traffic volume decreased
Level 3 (28 Apr to 13 May 2020)	• People were instructed to stay home other than to essential – permitted to go to work, school if they need to • Bubble expanded to family • Work from home • Gathering up to 10 people allowed • Reginal travel restricted • Stay two meters away from other people	79 and 69% (light and heavy-duty vehicles respectively) traffic volume decreased.
Level 2 (14 May to 8 Jun 2020)	• Meeting with friends and family permitted • Gathering limit increased up to 100 people • Domestic air travel permitted • Stay 2 meters away from people and 1 metre in workplace • Businesses are open, need to follow health guidelines • Use of masks on public transport and indoor environments	18 and 4 % (light and heavy-duty vehicles respectively) traffic volume decreased
Level 1 (9 Jun to	• All businesses, educational facilities, and workplaces open • Use of NZ COVID Tracer QR codes must be displayed in workplace and transport • Use of tracer app to keep track of people’s movement.	

Appendix 4: Wind roses during COVID-19 restriction levels in 2020 and 2021 for Whangārei and Marsden Point.

Level		Whangārei	Marsden Point
2020	L 4		
	L 3		 
	L 2		


2020
L 1
2021
L 4
> 8.0
6.0 to 8.0
4.0 to 6.0
2.0 to 4.0
1.0 to 2.0
0.5 to 1.0
< 0.5 calm
(m s^{-1})

Northland Regional Council

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